

**University of Bahrain**

**College of Engineering**



**Department of Mechanical  
Engineering**

# **Hoist Scheduling for an Anodizing Plant at an Extrusion Company**

**Thesis submitted in partial fulfillment of the requirements for the degree  
of**

**Master of Science in Engineering Management**

**Prepared by:**

**Alaa Jameel Isa Al-Saffar**

**ID: 2008-0113**

**Supervised by**

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**Professor**

**University of Bahrain**

**Kingdom of Bahrain**

**May 2018**

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**College: Engineering**

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University of Bahrain  
Deanship of Graduate Studies

### Thesis Discussion Committee Decision

|                                                                               |                       |
|-------------------------------------------------------------------------------|-----------------------|
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| Program: Master Science in Engineering Management                             |                       |
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|                                                                               |                       |
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The Discussion Committee met on \_\_\_\_ (day and date) \_\_\_\_\_ in Hall no. \_\_\_\_ (hall/room no.) \_\_\_\_\_. Upon discussing the student whose details are stated above in public, the discussion committee recommends the following:

The student awarded grade \_\_\_\_\_ In the thesis subject \_\_\_\_\_ IEN 598 \_\_\_\_\_

- ☐ Without making any changes to the thesis  
☐ After making the modifications attached with this decision
- 

Discussion Committee Members Approval:

| <u>Name</u>                  | <u>Signature</u> |
|------------------------------|------------------|
| 1. _____ (Advisor)           | _____            |
| 2. _____ (Internal Examiner) | _____            |
| 3. _____ (External Examiner) | _____            |

# Abstract

The field of scheduling metal surface treatment plants is extensively studied in the literature and it is referred to by the name of Hoist Scheduling Problem HSP. HSP is classified as flow-shop scheduling problem but differs because of the transportation constraints and the no-wait constraint. This research deals with a real anodizing plant in an extrusion company. In this plant a number of different profiles (jobs) are dipped in a series number of tanks which are filled with acids, water, dyes and other chemicals for varying lengths of time; the transportation of these jobs from one tank to another is done by five hoists (cranes). The plant is suffering from a main bottleneck in the hot sealing stage. The objective of this study to minimize the makespan of a demand of selected days and to overcome the main bottleneck problem. A heuristic algorithm was developed for scheduling the anodizing demand of the extrusion company. The algorithm was coded in Matlab (R2015b - editor) to simulate the production of certain days. The runs of the simulation were divided into three phases. In the first phase, the results were validated by comparing the anodizing times obtained by the algorithm with the actual times, the results showed a reduction in the makespan with an approximated average of 18%. In the second phase, different combinations were examined, where additional tanks were added and different job sequences were introduced to study the effect of these combinations on the makespan and on the main bottleneck problem. The results suggested that adding one additional hot sealing tank and sequence the jobs based on “Highest Recipe ID First” is the best combination. Additional jobs were added in the third phase to the actual number of jobs in each day using the actual configuration and two different sequences: one with the actual sequence and the other with the sequence that produced the minimum makespan. This is done in an attempt to utilize the remaining time that is left out after minimizing the makespans, the results revealed that the algorithm was able to utilize the time by an approximated average of 98% and to increase the number of jobs by an approximated average of 20%. What makes this study unique is it’s dealing with an anodizing plant that considers loading, unloading stages and input and output buffers, something rarely seen in the literature where most of the studies are dealing with electro-plating plants and do not consider the loading and unloading stages.

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# Table of Contents

| Subject                                  | Page number |
|------------------------------------------|-------------|
| Defense Committee's Approval             | A           |
| Abstract                                 | B           |
| Acknowledgements                         | C           |
| Table of Contents                        | D           |
| List of Tables                           | H           |
| List of Figures                          | L           |
| List of Appendices                       | N           |
| List of Notations                        | O           |
| List of Abbreviations                    | P           |
| Chapter One<br>Introduction to the Study |             |
| 1.1. Background                          | 2           |
| 1.2. The Research Problem                | 3           |
| 1.3. The Research Questions              | 4           |
| 1.4. Research Objectives                 | 5           |
| 1.5. The Significant of the Research     | 5           |
| 1.6. Limitation of the Research          | 5           |
| 1.7 Research Methodology                 | 5           |
| 1.8. Thesis Structure                    | 6           |
| 1.9. Terminologies and Definitions       | 6           |
| Chapter Two<br>Literature Review         |             |
| 2.1. Introduction                        | 13          |
| 2.1.1 Static Mode                        | 13          |

| <b>Subject</b>                                                               | <b>Page number</b> |
|------------------------------------------------------------------------------|--------------------|
| 2.1.2 Dynamic Mode                                                           | 14                 |
| 2.2. Previous Studies                                                        | 18                 |
| Chapter Three<br>Description of the Anodizing Plant and the Simulation Model |                    |
| 3.1. Introduction                                                            | 29                 |
| 3.2. Plant Physical Layout and the Simulation Model                          | 30                 |
| 3.2.1 Positions                                                              | 30                 |
| 3.2.2 Transferors                                                            | 35                 |
| 3.2.3 Hoists                                                                 | 35                 |
| 3.3. Stages of the Anodizing Plant                                           | 37                 |
| 3.4. Daily Flow of Jobs                                                      | 41                 |
| 3.5. Job Properties and Recipes                                              | 43                 |
| 3.6. Relaxations                                                             | 53                 |
| 3.8. Simulation Model                                                        | 58                 |
| 3.8.1 Collection of historical data                                          | 59                 |
| 3.8.2 Constructing the simulation runs                                       | 61                 |
| Chapter Four<br>Mathematical Model Formulation                               |                    |
| 4.1. Introduction                                                            | 69                 |
| 4.2. The Notations                                                           | 69                 |
| 4.3. The Mathematical Model                                                  | 71                 |
| 4.3.1 The objective function                                                 | 72                 |
| 4.3.2 Constraints of job routing                                             | 72                 |
| 4.3.3 Blocking constraints                                                   | 77                 |
| 4.3.4 Hoists ranges constraints                                              | 78                 |
| 4.3.5 Hoist collision constraints                                            | 78                 |

| <b>Subject</b>                                                     | <b>Page number</b> |
|--------------------------------------------------------------------|--------------------|
| Chapter Five<br>The Scheduling Algorithm                           |                    |
| 5.1. Introduction                                                  | 84                 |
| 5.2. Scheduling Approach of the Algorithm                          | 85                 |
| 5.3. Data Files of the Algorithm                                   | 87                 |
| 5.4. Structure of the Algorithm                                    | 98                 |
| 5.4.1 General structure                                            | 98                 |
| 5.4.2 Detailed Structure                                           | 103                |
| Chapter Six<br>Validation and Evaluation of the Algorithm          |                    |
| 6.1. Introduction                                                  | 113                |
| 6.2. Algorithm Validation                                          | 115                |
| 6.2.1 Comparing the results of the two sets of anodizing durations | 115                |
| 6.2.2 Gantt charts                                                 | 121                |
| 6.3. Results Evaluation                                            | 129                |
| 6.3.1 Evaluation of job flow times Job                             | 129                |
| 6.3.2 Evaluation of anodizing makespans and number of jobs         | 137                |
| 6.3.3 Waiting stages results                                       | 139                |
| 6.3.4 Utilization of the different positions                       | 142                |
| Chapter Seven<br>Extermination and Analysis of Results             |                    |
| 7.1. Introduction                                                  | 148                |
| 7.2. Effect of Sequences for Fixed Configuration on the Makespan   | 150                |

| <b>Subject</b>                                                                 | <b>Page number</b> |
|--------------------------------------------------------------------------------|--------------------|
| 7.3. Effect of Configurations for Fixed Sequence on the Makespan               | 154                |
| 7.4. Effect of Configuration and Sequence on Makespan                          | 157                |
| 7.5. Effect of Configuration and Sequence on Overcoming the Bottleneck Problem | 159                |
| 7.6. Further Experimentations                                                  | 160                |
| Chapter Eight<br>Conclusion, Recommendations and Further Studies               |                    |
| 8.1. Conclusion                                                                | 172                |
| 8.2. Recommendations                                                           | 174                |
| 8.3. Suggestions for Future Studies                                            | 175                |
| References                                                                     | 177                |
| Appendices                                                                     |                    |
| Abstract (Arabic)                                                              |                    |

## List of Tables

| No.  | Subject                                                                           | Page |
|------|-----------------------------------------------------------------------------------|------|
| 2.1  | The Difference between the Types of HSP                                           | 17   |
| 2.2  | Comparing the Characteristics of Previous Studies Plants in the Literature Review | 24   |
| 3.1  | Original Numbering of the Positions in the Actual Plant                           | 31   |
| 3.2  | Removed Positions from the Simulation Model and Justifications                    | 32   |
| 3.3  | Numbering of the Positions in the Simulation Model                                | 34   |
| 3.4  | Hoists Ranges in the Simulation Model                                             | 36   |
| 3.5  | The Stages of the Simulation Model                                                | 37   |
| 3.6  | Functions of the Stages in the Anodizing Plant                                    | 38   |
| 3.7  | Sections of the Plant in the Simulation Model                                     | 40   |
| 3.8  | Recipes Treatment Durations                                                       | 47   |
| 3.9  | Hot Sealing Durations Cases                                                       | 48   |
| 3.10 | Recipe Types and Their Differences                                                | 50   |
| 3.11 | Possible Positions                                                                | 51   |
| 3.12 | Numbers of Stage Positions and Their Function Type                                | 52   |
| 3.13 | Relaxations and Differences between the Actual Plant and the Simulation Plant     | 53   |
| 3.14 | Replaced Positions for Additional Anodizing and Hot Sealing Tanks                 | 64   |
| 3.15 | Tanks Configurations                                                              | 65   |
| 3.16 | Different Combinations of Sequences and Configurations                            | 66   |
| 3.17 | The Differences among the Nine Combinations                                       | 67   |

| <b>No.</b> | <b>Subject</b>                                                                                       | <b>Page</b> |
|------------|------------------------------------------------------------------------------------------------------|-------------|
| 5.1        | Example of the Actual Sequence                                                                       | 90          |
| 5.2        | Example of the LRIDF Sequence                                                                        | 91          |
| 5.3        | Example of the HRIDF Sequence                                                                        | 91          |
| 5.4        | Details of the Used Matrices in the Algorithm                                                        | 93          |
| 6.1        | The Fixed Input Data for all Combinations                                                            | 114         |
| 6.2        | The Results for Set 1 (the Actual Anodizing Durations)                                               | 116         |
| 6.3        | The Results of Set 2 (the Average Anodizing Durations)                                               | 117         |
| 6.4        | Differences of the Algorithm Makespans of the Two Sets                                               | 120         |
| 6.5        | Jobs no. 1, 26 and 50 Progress in Day no 2                                                           | 128         |
| 6.6        | Jobs no. 1, 26 and 50 Progress in Day no 8                                                           | 128         |
| 6.7        | Job Flow Differences between the Algorithm and the Actual Timings at the Anodizing Stage             | 135         |
| 6.8        | Averages, Largest, and Lowest Differences from Table 6.6 (Anodizing Stage)                           | 136         |
| 6.9        | Main Outcomes of the Differences between the Algorithm and the Actual Timings at the Anodizing Stage | 136         |
| 6.10       | Evaluation (makespans vs. number of jobs)                                                            | 138         |
| 6.11       | The Daily Total Durations of the Different Waiting Stages                                            | 140         |
| 6.12       | The Job Daily Averages of Durations at the Different Waiting Stage                                   | 141         |
| 6.13       | Results of Utilization of the Different Positions in Day no.2                                        | 143         |
| 6.14       | Results of Utilization of the Different Positions in Day no.8                                        | 144         |
| 7.1        | Main Results for Combination 2                                                                       | 149         |
| 7.2        | Main Results for Combination 5                                                                       | 149         |
| 7.3        | Main Results for Combination 9                                                                       | 150         |

| <b>No.</b> | <b>Subject</b>                                                                                      | <b>Page</b> |
|------------|-----------------------------------------------------------------------------------------------------|-------------|
| 7.4        | Sequences Effect with Configuration 1 on the Makespan                                               | 151         |
| 7.5        | Sequences Effect with Configuration 2 on the Makespan                                               | 152         |
| 7.6        | Sequences Effect with Configuration 3 on the Makespan                                               | 153         |
| 7.7        | Score of minimum makespan from Tables (7.4), (7.5) and (7.6)                                        | 154         |
| 7.8        | Tanks Configuration Effect with Sequence 1 on the Makespan                                          | 155         |
| 7.9        | Tanks Configuration Effect with Sequence 2 on the Makespan                                          | 155         |
| 7.10       | Tanks Configuration Effect with Sequence 3 on the Makespan                                          | 156         |
| 7.11       | Score of Minimum Makespans for Tables (7.8), (7.9) and (7.10)                                       | 157         |
| 7.12       | Makespans for the Different Combinations                                                            | 158         |
| 7.13       | Average Number of Jobs (round-up) in Anodizing and Hot Sealing Tanks for the Nine Combinations      | 160         |
| 7.14       | Further Experimentation Results (Configuration 1 with Sequence 1)                                   | 164         |
| 7.15       | Further Experimentation Results (Configuration 1 with the sequence of minimum makespan)             | 165         |
| 7.16       | Comparing the Algorithm Results of the Actual Combination (before and after adding the extra jobs)  | 167         |
| 7.17       | Comparing the Algorithm Results of the Minimum Combination (before and after adding the extra jobs) | 168         |

| No.  | Subject                                                                             | Page |
|------|-------------------------------------------------------------------------------------|------|
| 7.18 | Comparison of the Two Combinations Results (before and after adding the extra jobs) | 170  |

## List of Figures

| No.     | Subject                                                                                                      | Page |
|---------|--------------------------------------------------------------------------------------------------------------|------|
| 3.1 (a) | The Layout of the Anodizing Plant with the Original Positions and Hoists Numbering                           | 33   |
| 3.1 (b) | The layout of the Anodizing Plant with the Simulation Numbering (new position number inside the small boxes) | 33   |
| 3.2 (a) | Bar Type Carrier                                                                                             | 42   |
| 3.2 (b) | Angle Type Carrier                                                                                           | 42   |
| 4.1     | Safety Gap to Avoid Hoist Collision                                                                          | 79   |
| 4.2 (a) | Collision of Two Hoists at Neighbouring Positions                                                            | 81   |
| 4.2 (b) | Correction for Collision of Two Hoists at Neighbouring Positions                                             | 81   |
| 4.3 (a) | Collision of Two Hoists Crossing Each Other                                                                  | 82   |
| 4.3 (b) | Correction for Collision of Two Hoists Crossing Each Other                                                   | 82   |
| 5.1     | Simplified Example for the Algorithm in Case of Position                                                     | 86   |
| 5.2     | The General Structure of the Scheduling Algorithm                                                            | 102  |
| 5.3     | Detailed Structure for the Scheduling Algorithm                                                              | 111  |
| 6.1     | Day 02 (13-04-15) [Seq. 1 and Conf. 1 with 55 Jobs] - Full Gantt Chart                                       | 122  |
| 6.2     | Day 02 (13-04-15) [Seq. 1 and Conf. 1 with 505Jobs] - Gantt Chart (Period 00:00 to 4:00)                     | 123  |
| 6.3     | Day 02 (13-04-15) [Seq. 1 and Conf. 1 with 55 Jobs] - Gantt Chart (Period 12:00 to 16:00)                    | 124  |

| <b>No.</b> | <b>Subject</b>                                                                            | <b>Page</b> |
|------------|-------------------------------------------------------------------------------------------|-------------|
| 6.4        | Day 08 (17-06-17) [Seq. 1 and Conf. 1 with 50 Jobs] - Full Gantt Chart                    | 125         |
| 6.5        | Day 08 (17-06-17) [Seq. 1 and Conf. 1 with 50 Jobs] - Gantt Chart (Period 00:00 to 4:00)  | 126         |
| 6.6        | Day 08 (17-06-17) [Seq. 1 and Conf. 1 with 50 Jobs] - Gantt Chart (Period 12:00 to 16:00) | 127         |
| 6.7        | Day no. 2 Job Flow Time at the Anodizing Stage Evaluation Chart                           | 131         |
| 6.8        | Day no. 8 Job Flow Time at the Anodizing Stage Evaluation Chart                           | 132         |
| 6.9        | Evaluation (makespans vs. number of jobs)                                                 | 138         |
| 6.10       | Day 02 – Utilization (Occupancy) Percentage per Position                                  | 145         |
| 6.11       | Day 08 – Utilization (Occupancy) Percentage per Position                                  | 146         |
| 7.1        | Sequences Effect with Configuration 1 on the Makespan                                     | 151         |
| 7.2        | Sequences Effect with Configuration 2 on the Makespan                                     | 152         |
| 7.3        | Sequences Effect with Configuration 3 on the Makespan                                     | 153         |
| 7.4        | Effect of Sequence and Configuration on the Makespan                                      | 158         |
| 7.5        | Expected Makespans Before and After Adding Jobs                                           | 163         |
| 7.6        | Further Experimentation Results (Configuration 1 with Sequence 1)                         | 164         |
| 7.7        | Further Experimentation Results (Configuration 1 with the sequence of minimum makespan)   | 165         |

## List of Appendices

| No. | Appendix                                                                    |
|-----|-----------------------------------------------------------------------------|
| (1) | Hoist Collision Cases                                                       |
| (2) | The Notations Used in Matlab Coding                                         |
| (3) | The Matlab Coding For the Further Experimentations (Phase 3)                |
| (4) | Estimated Duration after Anodizing Stage to Unloading per Recipe ID         |
| (5) | Gantt Charts for the Twelve (Combination no. 1)                             |
| (6) | Job Flow Time at the Anodizing Stage for the Twelve Days by Combination 1   |
| (7) | Utilization of the Different Positions for the Twelve Days by Combination 1 |
| (8) | Results of Combinations 2 to 9                                              |
| (9) | Effect of Combinations on Overcoming the Bottleneck Problem                 |

## List of Notations

| Variable/<br>Symbol. | Explanation                                                                                                                  |
|----------------------|------------------------------------------------------------------------------------------------------------------------------|
| $T$ or $t$           | Time indicator for an operation event                                                                                        |
| $p$                  | The current job no.                                                                                                          |
| $i$                  | The current job ID                                                                                                           |
| $r$                  | The current job recipe no.                                                                                                   |
| $s$                  | The $s^{\text{th}}$ stage for the current job                                                                                |
| $ns$                 | The next stage after the $s^{\text{th}}$ stage for the current job                                                           |
| $k$                  | The position of the current stage, the initial position for a loaded hoist move or the final position of an empty hoist move |
| $v$                  | The next position for the next stage,<br>The final position for a loaded hoist move                                          |
| $c$                  | The initial position of an empty hoist move                                                                                  |
| $d$                  | Duration of an operation                                                                                                     |
| $P$                  | Process (treatment) operation                                                                                                |
| $h$                  | Hoist no.                                                                                                                    |
| $L$                  | Loaded hoist move operation                                                                                                  |
| $E$                  | Empty hoist move operation                                                                                                   |
| $W$                  | Waiting hoist operation                                                                                                      |
| $PS$                 | Process starting event                                                                                                       |
| $PF$                 | Process finishing event                                                                                                      |
| $LS$                 | Loaded hoist move starting event                                                                                             |
| $LF$                 | Loaded hoist move finishing event                                                                                            |
| $ES$                 | Empty hoist move starting event                                                                                              |
| $EF$                 | Empty hoist move finishing event                                                                                             |
| $WS$                 | Waiting hoist starting event                                                                                                 |
| $WF$                 | Waiting hoist finishing event                                                                                                |
| $/$                  | Or                                                                                                                           |
| $\rightarrow$        | To (from-to)                                                                                                                 |

## List of Abbreviations

| Abbreviation | Explanation                              |
|--------------|------------------------------------------|
| ANN          | Artificial Neural Network                |
| ARA          | Average Robot Assignment                 |
| ATW          | Adaptive Time Window                     |
| B            | Big section profiles                     |
| BSJL         | Boundary Shift by Job Location           |
| C            | Configuration for plant tank arrangement |
| CHSP         | Cyclic Hoist Scheduling Problem          |
| Col          | Type of Colored profiles                 |
| DHSP         | Dynamic Hoist Scheduling Problem         |
| DMD          | Different of makespan between two sets   |
| FBEST        | Forward-Backward Earliest Start Time     |
| HAS          | Hoist Assignment System                  |
| HRIDF        | Highest Recipe ID First                  |
| HSP          | Hoist Scheduling Problem                 |
| IDDS         | Input Data Decision System               |
| LRIDF        | Lowest Recipe ID First                   |
| MIDO         | Mixed Integer Dynamic Optimization       |
| MILP         | Mixed Integer Linear Programming         |
| M-OR         | Matt-ordinary section profiles           |
| M-SH         | Matt-small hollow section profiles       |
| NP           | Non-polynomial                           |
| NRF          | Nearest Robot First                      |
| PCB          | Printed Circuit Boards                   |
| PEB          | Permutation based scheduling heuristic   |
| PHSP         | Predictive Hoist Scheduling Problem      |
| R            | Rinsing Stage                            |
| RC           | Robotic Cell                             |
| RHSP         | Reactive Hoist Scheduling Problem        |

| Abbreviation | Explanation                       |
|--------------|-----------------------------------|
| TDKA         | Trace-Drive Knowledge Acquisition |
| S            | Sequence of jobs                  |
| SH           | Small Hollow section profiles     |
| STF          | Surface Treatment Facility        |

---

# **Chapter One**

## **Introduction to the Study**

---

**1.1. Background**

**1.2. The Research Problem**

**1.3. The Research Questions**

**1.4. Research Objectives**

**1.5. The Significant of the Research**

**1.6. Limitation of the Research**

**1.7. Research Methodology**

**1.8. Thesis Structure**

**1.9. Terminologies and Definitions**

# **Chapter One**

## **Introduction to the Study**

### **1.1 Background**

It is hardly to imagine any manufacturing facility without using some programs and tools to plan for production and preparing schedules for the activities and tasks, so that the production and quality are maintained and improved. Scheduling seeks to arrange the work in the manufacturing facility by timely allocation of the resources through optimization techniques. The aim for optimization can be to minimize the production time and the cost or maximize the profit, efficiency and quality.

Manufacturing scheduling is often referred to as Job Shop Scheduling or Flow Shop Scheduling in the literature. The study of the scheduling problems seems to be trivial but it is not. Scheduling problems are related to operation research, where some of them are hard to solve, and more complex algorithms are proposed to overcome the issue of long computation time that is taken to prepare schedules for these problems. The more complex the problem (number of machines and number of jobs, more constraints) the longer time it takes to solve and prepare a schedule. Job shop scheduling problems are well known for their hardness, in some cases they are impossible to solve (computation time may extend to weeks). Therefore simpler approaches are taken to solve them like heuristics and algorithms.

Scheduling of automated metal surface treatment plants like electroplating, printed circuit board and anodizing are referred in the literature by “Hoist Scheduling Problem” HSP. Where one hoist or more are assigned to transport

jobs from one stage to another stage while respecting the treatment durations in each stage. Even though hoist scheduling problems are extensively studied in the literature, they are still under development to meet other criteria and to find better and faster algorithms.

Hoist Scheduling Problem can be viewed as a job shop scheduling problem, where the stages (tanks) can be considered as the machines, the loads as jobs and the hoists as the transporters. But it is different from job shop scheduling problem because of two main special constraints: the first, it deals with transportation constraints; and the second, it is a no-wait problem, which means there is no intermediate buffers (no intermediate waiting positions).

In this thesis a Balexco anodizing plant is studied, with the purpose of minimizing the makespan, study how to overcome the main bottleneck problem, namely, the hot sealing stage and increase the production but without violating the quality constraints.

## **1.2 The Research Problem**

Balexco is a Bahraini company which manufactures aluminum profiles mostly the ones used as doors'/windows' frames through the process of extrusion, then these profiles are either undergo surface treatment or not. There are two types of surface treatment in Balexco Powder Coating and Anodizing.

According to Balexco future production plan, the daily target for the anodizing plant at Balexco should be 14 tons, where a typical working day consists of two shifts with a total of 16 hours. This target has not been achieved, because currently the maximum daily production can reach only about 8 tons. One of the main reasons for not meeting the targeted production is the presence of a bottleneck, where the hot sealing stage (last chemical

stage) is considered as the main bottleneck to the anodizing stage (an intermediate chemical stage). There are only four identical hot sealing tanks (each takes an average of 45 minutes per job), while there are four identical anodizing tanks (each takes an average of 30 minutes per job).

The only solution that is currently applied to cope up with this bottleneck and to avoid violating the “no-wait” constraint (i.e. once a load finishes one stage it must be moved to the next one, without waiting), is to increase the time interval taken between entering two consecutive jobs to the process which will result in a delay, thus increasing the production time and not fully utilizing the anodizing tanks.

Modeling Balexco anodizing plant in this thesis is considered unique, due to the plant complex layout, where loading, unloading, input/output buffers’ stages and five hoists with overlapping zones have to be into considered, in-addition to the consideration of 30 recipes, which make the problem multi-product problem, all of these things make it something rarely seen in the literature.

### **1.3 The Research Questions**

Q1) What is the best sequence of hoists’ movements?

Q2) How to minimize the production time?

Q3) How to overcome the main bottleneck problem?

## **1.4 Research Objectives**

The objectives of this research are to develop an algorithm that will minimize the makespan and to increase the production by using the obtained makespan to add more jobs in an attempt to increase the production. Another aim of this research is to identify and overcome the main bottleneck problem in the plant.

## **1.5 The Significance of the Research**

The importance of this study lies in coming up with an algorithm that can produce a schedule with minimum makespan for the production of one day of two shifts (16 hours), Furthermore, the study explores ways to overcome the main bottleneck of the plant in order to enhance its productivity.

## **1.6. Limitation of the Research**

The research is limited to minimization of the makespan for the daily production of two shifts (16 hours). The algorithm is limited with only 30 recipes out of the hundred recipes of the plant production because the original recipes are considered confidential. Also, breakdown times are not considered in the algorithm, due to lack of data.

## **1.7 Research Methodology**

In this study, a theoretical approach is adopted to obtain a better schedule for the anodizing plant at Balexco, where a suitable mathematical model is developed. Then the model is solved using a heuristic algorithm. A historical data of twelve days schedule is used to validate the algorithm. After that, experimentations with the algorithm are carried out to solve the main bottleneck problem and to increase productivity.

## **1.8. Thesis Structure**

This thesis is composed of eight chapters. In the first chapter the research problem, questions, and objectives are stated, as well as some definitions and terminologies that will be used throughout the thesis. In the second chapter, the hoist scheduling problem and similar previous studies are reviewed. Some of the characteristics of the studied plants in literature are compared with the Balexco anodizing plant. In the Third chapter, the anodizing plant in Balexco and the simulated version of the plant are described. A mathematical model is proposed in the fourth chapter that describes the time events and constraints. Some of these constraints are used in the algorithm, which will be explained in the fifth chapter. The results will undergo through three phase of validation and experimentations, these results are discussed in the sixth chapter and the seventh chapter. Finally, in the eighth chapter, the results are summarized in a conclusion, and few recommendations were given as well as topics that are left for further studies that will help in improving the algorithm even better.

## **1.9. Terminologies and Definitions**

- Carrier: is a holding device that holds a number of profiles with the same specifications (like the same section type and same finishing color).
- Job: is a group of profiles that have the same specifications (like the same section type and same finishing color) and attached to one carrier.
- Loaded carrier: is a carrier with attached profiles.
- Empty carrier: is a carrier without profiles, in this case the carrier can enter some treatments for cleaning purposes.
- Recipe: is the path (route) of the job, which is identified by the series of stages that a job must be treated at, and the duration in each stage.

- Stage: is one of the treatments of the overall anodizing process and it has one position or more, which do the same function (treatment).
- Time window: is a common term used in the HSP research, when some or all the stages have a minimum and maximum limit for the treatment duration.
- Position: is one unit of a stage.
- Parallel positions: is the term given to two or more positions for the same stage.
- Waiting stage: is a stage where the jobs are allowed to wait as long as necessary, these stages are only located before and after the main process line (the chemical positions) and not between line positions.
- Input buffer: is a type of waiting stage where the jobs stays at it as long as necessary, before entering the first chemical stage in the process line.
- Output buffer: is a type of a waiting stage where the jobs must wait at it for a certain duration before moving to the unloading stage.
- Transferor: is a stage which links two separated parts of a process line, it is composed of two positions and a cartage that moves the jobs between the two positions.
- Mono-product (mono-part) problem: is the case when the plant is producing one type of product.
- Multi-product (multi-part) problem: is the case when the plant is producing more than one type of product.
- Single-capacity tank: is the case when the plant has one position per stage.
- Multi-capacity tank: is the case when the plant has more than one position for each or some of the stages.

- Single-function position: is a type of position which does one kind of treatment and only treats a job once.
- Multi-function position: is a type of position which treats a job more than once (but the other times are considered as other stages), or it can be a type of position which does more than one kind of treatment.
- Hoist: is a crane or the carrying machine that moves the jobs from one position to another.
- Loaded hoist move: is the state when the hoist is moving and carrying a job from one position to another or sometimes for lifting and dipping it in the same position again.
- Empty hoist: is the state when the hoist is either moving from one position to another to pick-up another job, or it is in a stop condition (waiting) above certain position for the same job that has just loaded.
- Job rout: is a series of the treatment operations and loaded hoist move operations that a job has to go through from the beginning of the process line to the end of the process line. It does not include the empty hoist moves.
- Hoist range: is the limit of the hoist movements above certain positions.
- Single-hoist: is the case when the plant has one hoist to do all the moving operations.
- Multi-hoist: is the case when the plant has more than one hoist.
- Uni-directional: is the case when the stages and their positions are arranged in a row, thus the job route is only moving in one direction.
- Bi-directional: is the case when the job route can experience two directions.

- Order: is a set of profiles that a customer requires that may consist of several different types of profiles, each type has its own quantity and specifications (finishing color, type of alloy, shape, and size of the profiles).
- Sequence: is the order by which the jobs are prioritized to enter the first chemical stage in the process line, and it is defined by a number (refer to Sub-section 3.7.2).
- Configuration: is the arrangement of the stages and positions which is defined by a number that tells the number of positions in a certain stage (i.e. in this study the number of positions for the anodizing stage and hot sealing stage, refer to Sub-section 3.7.2).
- Combination: a setting for a structure of certain sequence and a certain configuration, also identified by a number (refer to Sub-section 3.7.2).
- Run: is the simulation for scheduling the production of a day with a certain combination.

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# **Chapter Two**

## **Literature Review**

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**2.1. Introduction**

**2.2. Previous Studies**

# **Chapter Two**

## **Literature Review**

### **2.1. Introduction**

One of the recent literature reviews on HSP is by Blouch et al. (2010), where they classified the problems of HSP into four types based on the context (nature) of the problem. These four contexts are also grouped under two modes: static mode and dynamic mode. The static mode includes Cyclic Hoist Scheduling Problem (CHSP) and Predictive Hoist Scheduling Problem (PHSP). The dynamic mode includes Dynamic Hoist Scheduling Problem (DHSP) and Reactive Hoist Scheduling Problem (RHSP), in some research RHSP is called Real-time Hoist Scheduling Problem.

#### **2.1.1 Static Mode**

The simplest form of CHSP can be defined as the problem with one hoist and all the jobs are identical, which means all of them have the same recipe (same route of process), such problem is called the “basic problem”. Philips and Unger (1976) established the first mathematical programming that describes this basic problem.

Kujawski and Świątek (2011) stated that the main objective in CHSP is to minimize the cyclic time by optimizing the hoist(s) repetitive move patterns and minimize the processing time, This is achieved by balancing the treatment durations for all stages by finding out the optimum time to pick-up a job at every tank without violating the processing durations (time window). The repeated moves in CHSP is a fixed, thus the time interval between the time entrances of two consecutive jobs is fixed.

Another type of static problem is when there are various jobs have to be processed, and there are quite stable production plans and sufficient information about delays of the arriving jobs. This type is the Predictive Hoist Scheduling Problem (PHSP) and it consists of two problems: one try to process a job in the system as soon as possible and the other problem is choosing the arrival dates. Thus, productivity is increased, also the number of resource conflicts between jobs is limited and the number of treatments whose duration exceeds the specified maximal processing time is reduced. (Bloch et al., 2010).

### **2.1.2 Dynamic Mode**

In the real context studies, jobs arrive randomly to the loading station or to the input buffers without any previous scheduling, thus these new jobs may change the original schedule for some of the previous jobs that are in the process line. In these problems, a decision has to be made, update the process line status, and give commands to the hoist(s) to do the actions according to the decision made. This means that the dynamic mode schedule is done while the production is going on production (Kujawski and Świątek, 2011)

In DHSP known also “local problem”, jobs come in different and arrive at the begging of the process line randomly, unlike PHSP where jobs arrival are known and/or can be forecasted with enough precision. The Local Problem is based on the process line status and the queue of jobs to be produced and their entering time to the process line. In-addition to respecting all the constraints and maximizing the performance of production (Fargier et al, 2001).

In local problem, the context has to do with scheduling the new jobs by delaying and re-scheduling the jobs that already in the process. This might

leads to violating some of the constraints. For example, picking up some jobs early thus violating their minimum treatment duration. This is done for the sake of increasing the productivity. Such violations can be overcome by delaying the new arrived jobs (Fargier et al, 2001; Kujawski and Świątek, 2011).

The mostly seen algorithms that are used to solve the local problem are heuristic algorithms. Some of these algorithms keep the job routing unchanged and just tries to compute a feasible solution rapidly by increasing the delay time of the new arrived jobs. Other algorithms such as greedy algorithm and a branch cutting heuristic in the branch-and-bound procedure is also used, and they showed an increase in the productivity. From another point of view, simulated annealing and genetic procedure are used to minimize the makespan (Fargier et al, 2001).

Heuristics solution is not guaranteed to be optimal, because they allow the creation of high-performance schedules while providing lower computational complexity than exact methods. DHSP is created during production, and jobs may vary type, thus the sequence of introduction times is also varying (Kujawski and Świątek, 2011).

The Real-time problem deals with the line status controlling, verifying the feasibility of updated schedules, implementing found schedules to automats and controlling the frequency of rescheduling and item introduction times. The real-time scheduling is solved by scheduling the new jobs as well as rescheduling the old jobs during the production with the consideration of the line state. The reason for this consideration is to see if there is a chance to allow for some constraints to be violated (like for instance the treatment

duration) for the sake to process another job and increase the production (Kujawski and Świątek, 2011).

In the Real-time Hoist Scheduling Problem (RHSP), carriers can have different routings but the maximal soaking time limit can be moderately exceeded. Thus, each carrier movement no longer needs to be forecasted because a carrier can remain within a tank as long as necessary. Re-phrasing what Fargier and Lamothe (2001) stated in their research, that in this context, there is a trade-off between the line throughput rate (production) and the quality of the product, which is mapped via rules of neural network problem.

In a dynamic problem there is a tradeoff between two main objectives, first is regarding quality, and the other is for productivity and flexibility. If quality is the main objective, then the forecasted schedule for new jobs must consider the jobs that are already in the system for the protection of minimum and maximum processing times for each job. The algorithms of this approach are very much descriptive in manufacturing but it is not robust enough, because the starting time for each job is strictly planned and this cannot be achieved in real life because of unavoidable production estimates of breakdowns as an example. Nevertheless, this solution remains the only one suitable for high added value production runs, which must be of very high quality, this type of problem is called “Dynamic Hoist Scheduling Problem” (DHSP) (Bloch et al., 2010).

On the other hand, if the priority is given to productivity and flexibility (in terms of diversity), then, in this case, the algorithm assigns which hoist to move which job. This decision is generally made in relation to the nature of the bath (the chemical in the tank and its concentration) where sometimes the time of treatment may be exceeded (violated) or changed, thus, violating

quality constraints for the sake of more production and flexibility. This approach is called “Reactive Hoist Scheduling Problem” (RHSP) (Bloch et al., 2010). To sum it up, the DHSP corresponds to “by job” management, whereas RHSP corresponds to “by task” management.

A general comparison between the types of HSP is given in Table (2.1), which summarizes the differences between the four types of HSP.

Table (2.1): The Difference between the Types of HSP.

| <b>Type</b> | <b>Context explained in brief</b>                                                                                                                                                          | <b>Introduction time between two Consecutive jobs</b>                          | <b>The Time of Making the Schedule</b> |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------|
| <b>CHSP</b> | Static schedule with repeated movements (patterns) of the hoists                                                                                                                           | Constant, due to the repetitive movements.                                     | Before production.                     |
| <b>PHSP</b> | Scheduling for various jobs (multi-products) with known arrival times to obtain a quite stable schedule.                                                                                   | Could Vary, due to the arriving of the new jobs of multi-types.                | Before production.                     |
| <b>DHSP</b> | Introduction time of a new job may be delayed by an estimated period to maintain the quality, thus it is “by job” management. New jobs can arrive randomly.                                | Could Vary, due to random arrival of new jobs.                                 | Done during the production.            |
| <b>RHSP</b> | Similar to DHSP, but it also considers the plant status and sees if there is a possibility to violate some of the constraints for the sake of other jobs, thus it is “by task” management. | Could Vary, due to random arrival of new jobs and changes in the plant status. | Done during the production             |

## 2.2. Previous Studies

The literature review given below is mostly related to heuristic algorithms because of the nature of the problem in this research. Table (2.2) gives some of the characteristics of each problem in the previous studies in this literature review. If the font of the words in the table are italic and in shaded cells, then characteristic is matching the problem in this research, and vice versa if the font of the words are normal and the cells are not shaded.

The objective of the work carried out by Thesen and Lei (1990) is to show that the manner in which decision of HSP can affect the productivity of the overall manufacturing system. A method called “Expert Scheduling System” is applied, and it can be implemented in systems where limited time and resources are available to solve complex sequencing problems. Another advantage is that it is relatively easy to add other decision rules such as those dealing with safety and recovery from unexpected error situations. The optimization is solved as soon as the new job arrives at the line.

Yih et al. (1993) used a hybrid approach to automatically schedule their problem, where they modeled the problem using semi-Markov decision process and an artificial neural network (ANN). The neural network modeling has lead to a trade-off between the line throughput rate and the violation of the limit soaking time. The two approaches are: Integer programming (semi-Markov model); and heuristic rule into the computer system to solve RHSP (Trace-Driven Knowledge Acquisition). The experimental study shows that the proposed method is able to effectively automate the decision-making process in real-time scheduling and yield better performance than human schedules.

A year later, Yih (1994) improved the algorithm for a DHSP. The proposed algorithm schedules jobs entering the system based on the specified range of processing durations. The simulation study shows that the algorithm schedules the jobs using the minimum processing times, with no defective products, better than the basic algorithm proposed in 1993.

Lamothe et al. (1994) formulated a heuristic algorithm based on a backtracking algorithm named “Nogoods” and Ginsberg dynamic (An algorithm similar to the Branch-and-Bound method). The algorithm results are simulated using the Philips and Unger (1979) benchmark problem, the results showed the algorithm ability to reach very good quality schedule in a short computation time. Later Lamothe et al. (1995) extended this research to resolve the real-time hoist schedule problem by considering a multiple hoists case rather than the limited case where each hoist has reserved zone in which no other hoist can enter just as in most of the industrial lines. Also, Lamothe et al. (1996) resolved the same problem with multi-hoists instead of a single hoist.

Chauvet et al. (1998) used an advanced type of a greedy heuristic rule that it can be applied for on-line scheduling. The rule is named ‘forward-backward earliest start time’ (FBEST) with the implementation of the ‘first-come-first-served’ principle. Each job entering the system is assigned to each tank as soon as possible, but when faced with a violation, the violating job is returned to a preceding stage where it is delayed, thus increasing the processing time of all jobs. This is why their rule is considered as a greedy algorithm. However, they provided an example of a plant that consists only of three stages, each stage has three tanks, each one with a different time window of treatment durations.

Fargier and Lamothe (2001) solved a bi-criteria decision problem that optimizes the quality and the line throughput rate via using fuzzy constraints. A trapezoidal shape is used as the model to develop the constraints of the treatment times (durations), in this shape four times are involved, namely: the two normal time window (the normal minimum duration and the normal maximum duration); the longest duration (when the chemical reaction is slow); and the shortest duration (when the chemical reaction is fast). Several levels of quality satisfaction are formulated via an equation that relates the constraints, thus several computations are done with minimum and maximum makespans. The last computation named “Quick bi-criteria decision” leaves a decision for a user, which results in a good trade-off in quick time.

Che et al. (2002) came up with an exact algorithm to solve a CHSP, in which they transformed the problem into multi-cyclic scheduling (an enumeration of intervals for expressions of decision variables), this enumeration is combined with a branch-and-bound algorithm. The results indicate that throughput of the multi-cyclic problem is more than that of the simple cyclic problem.

Jégou et al. (2006) proposed a multi-agent system for solving RHSP which is composed of two sub-systems. The first system is called Input Date Decision System (IDDS), it is used for making a decision regarding the time in which future events will occur within tanks. The second system is called Hoist Assigned System (HAS) which is used for making decisions regarding the hoists in association with the durations of the treatments in the tanks and preventing hoist collision as well. They did their experimentations for their system in a simulator consisting of eight hours, where they tuned the flexibility by changing the minimum time of each stage. Their results reveal that the flexibility is affecting the throughput, the best tune is by adding ten

(10) seconds to the minimum time in each stage. Also, they referred to three different heuristics named: the Nearest Robot First (NRF); the Average Robot Assignment (ARA); and Boundary Shift by Job Location (BSJL). All of these heuristics do not utilize the hoists as much as their system does, which reflected in obtaining higher throughput.

A research on a multi-items problem was done by Paul et al. (2007) using a heuristic algorithm named Adaptive Time Window (ATW), which is built on correcting the violations of the constraints by backtracking a job to preceding stages or back iteration for previous jobs. They modeled four different types of anodizing plants using a program called (eM-Plant) where they simulated the problem by changing three control parameters: the process flexibility; the processing time and the product mix. The results of their ATW algorithm show that it is competitive with another algorithm named Permutation-based scheduling heuristic (PEB), if the product mix is constant. Also, they claim that their ATW algorithm is expected to increase the production by 20%, if it is implemented in a real plant.

One research that studied anodizing plants similar to the one at Balexco is for a Danish company named (Bang and Olufsen) by Jakob Skov (2007). The main purpose of his research is to increase the production, where two approaches are taken, the first one simulates the scheduling scheme implemented by the company, while the second considers the No Wait constraints via applying meta-heuristics using the Alternative Graph Model. The first approach is a good step to develop the second one, the disadvantage of the simulation approach is that it can backtrack to one previous stage to correct the violation. The Alternative Graph Model also has some disadvantages, like not considering parallel tanks.

Zhang et al. (2012) performed many tests on the job shop problem like HSP and Robotic Cell (RC) using a local problem with genetic algorithm and shifting bottle-neck procedure to generate the final solutions. Their results show that their genetic algorithm is not better than the referred algorithm in RC industries, but better in the Surface Treatment Facility (STF).

Liu et al. (2012) worked on a real electroplating process, and they used a Mixed-Integer Dynamic Optimization (MIDO) model along with an algorithm to optimize between three objectives: minimizing the makespan, energy consumption and fresh/waste water of the rinsing tanks. Their obtained 3D Pareto frontier is claimed to provide important technical support for design and operation (scheduling) in the electroplating process.

Another research conducted on an anodizing plant is on a plant in Thailand by Pantusavase and Hassamontr (2015), they developed an algorithm to minimize the cycle time for a mixed loads sequence. In addition, they intended to minimize the cycle time by changing the ranges for hoists movements for a single product.

Feng et al. (2015) investigated a problem from a previous study but with a consideration of multi-capacity reentrant tanks, they applied Mixed-Integer Linear Programming (MILP) using CPLEX optimization software to do experimentations by changing the capacity of some stages. Their model shows more reduction in the makespan than the previous study as well as a reduction in the computational time.

Basán et al. (2017) developed a heuristic strategy for requesting the hoist based on the time window slots of the job recipe and the job priority, which is modeled using simulation user interface named (SIMIO). Experimentations

with the model are carried out by changing the jobs sequences based on four heuristics: the overall process duration; the weight of the jobs; the critical tanks (short timed visited tank) and the last visited tanks. Their proposed strategy is capable of generating near-optimal schedules to achieve their aim of reducing the makespan and cost for many scenarios in a short time period.

To sum up, the HSP is considered one of the hardest scheduling problems, especially when the processing times are short (short-limit) (Skov, 2007; Basán et al., 2015). Some HSPs can be so complex that they are classified as NP-hard problems (i.e. as the problem size increases, the computation time to solve it is exponentially increased) to the extent that some of them are impossible to solve (Skov, 2007).

However, there are several Heuristic algorithms that are capable of finding a reasonable solution, and when they are combined with other algorithms they might give a better solution. Another way to deal with such complex problems is to solve them by graphical simulation program rather than analytically (Basán et al., 2015).

Also, there is an increasing trend in the field of HSP to consider other criteria, like saving energy, reducing the cost and waste-water rather than just working with the minimization of makespan criterion.

In this study, a heuristic algorithm will be used to minimize the makespan, so more jobs can be treated. Also, a number of combinations (jobs sequences and tanks configurations) are examined for their effect on the makespan and on the bottleneck problem. Therefore, the design in term of the process configuration, and the scheduling aspect in term of job sequences will be considered.

Table (2.2): Comparing the Characteristics of Previous Studies Plants in the Literature Review.

| Author(s)/<br>(year)        | Industry                    | Context<br>XHSP | Number<br>of<br>Hoists | Product         | Processing<br>Times | Parallel<br>Tanks | Multi-<br>function<br>tanks | Buffers,<br>Loading/Unloading<br>Stages            | Direction<br>of Paths |
|-----------------------------|-----------------------------|-----------------|------------------------|-----------------|---------------------|-------------------|-----------------------------|----------------------------------------------------|-----------------------|
| Thesen and<br>Lei<br>(1990) | Electroplating              | RHSP            | <i>Multiple</i>        | <i>Multiple</i> | Time<br>Window      | -                 | -                           | -                                                  | -                     |
| Yih et al.<br>(1993)        | Circuit board<br>production | RHSP            | Single                 | <i>Multiple</i> | Time<br>Window      | All<br>Single     | -                           | -                                                  | -                     |
| Yih<br>(1994)               | PCB<br>Electroplating       | DHSP            | Single                 | <i>Multiple</i> | Time<br>Window      | -                 | -                           | Buffers: One for<br>inlet and one for an<br>outlet | One-<br>direction     |
| Lamothe et<br>al.<br>(1994) | Electroplating              | RHSP<br>CHSP    | Single                 | <i>Multiple</i> | Time<br>Window      | -                 | -                           | <i>Considered</i>                                  | -                     |
| Lamothe et<br>al.<br>(1995) | Electroplating              | RHSP            | Single                 | <i>Multiple</i> | Time<br>Window      | -                 | -                           | <i>Considered</i>                                  | -                     |

Continue Table (2.2): Comparing the Characteristics of the Previous Studies Plants in the Literature Review

| Author(s)/<br>(year)          | Industry                    | Context<br>XHSP | Number<br>of<br>Hoists | Product         | Processing<br>Times | Parallel<br>Tanks        | Multi-<br>function<br>tanks | Buffers,<br>Loading/Unloading<br>Stages | Direction<br>of Paths |
|-------------------------------|-----------------------------|-----------------|------------------------|-----------------|---------------------|--------------------------|-----------------------------|-----------------------------------------|-----------------------|
| Lamothe et al.<br>(1995)      | Electroplating              | RHSP            | <i>multiple</i>        | <i>Multiple</i> | Time Window         | -                        | -                           | <i>Considered</i>                       | -                     |
| Chauvet et al.<br>(1998)      | Surface treatment of Steel  | RHSP            | Single                 | <i>Multiple</i> | Time Window         | <i>multiple</i>          | -                           | -                                       | -                     |
| Fargier and Lamothe<br>(2001) | -                           | DHSP            | Single                 | -               | Time Window         | Single tank per stage    | -                           | <i>Considered</i>                       | -                     |
| Che et al.<br>(2002)          | Generally Material Handling | CHSP            | Single                 | Mono-part       | Fixed               | -                        | -                           | Consider loading and unloading stations | -                     |
| Jégou et al.<br>(2006)        | Electro-plating             | RHSP            | <i>Multiple</i>        | <i>Multiple</i> | Time Window         | <i>Some are multiple</i> | -                           | Not Considered                          | <i>Bi-directional</i> |

Continue Table (2.2): Comparing the Characteristics of the Previous Studies Plants in the Literature Review

| Author(s)/<br>(year)   | Industry                                | Context<br>XHSP | Number<br>of<br>Hoists | Product         | Processing<br>Times | Parallel<br>Tanks                                      | Multi-<br>function<br>tanks | Buffers,<br>Loading/Unloading<br>Stages           | Direction<br>of Paths      |
|------------------------|-----------------------------------------|-----------------|------------------------|-----------------|---------------------|--------------------------------------------------------|-----------------------------|---------------------------------------------------|----------------------------|
| Paul et al.<br>(2007)  | <i>Four<br/>Anodizing<br/>Processes</i> | DHSP            | Single                 | <i>Multiple</i> | Time<br>Window      | -                                                      | -                           | Input buffer and<br>output buffer                 | -                          |
| Skov<br>(2007)         | <i>Anodizing</i>                        | DHSP            | <i>Multiple</i>        | <i>Multiple</i> | Time<br>Window      | <i>Some<br/>stages<br/>have<br/>parallel<br/>tanks</i> | -                           | No consideration of<br>buffers                    | -                          |
| Zhang et al.<br>(2012) | Surface<br>Treatment<br>Facilities      | DHSP            | -                      | -               | Time<br>Window      | -                                                      | -                           | -                                                 | -                          |
| Liu et al<br>(2012)    | Electroplating                          | CHSP            | Single                 | Mono-<br>part   | Time<br>Window      | Single<br>capacity                                     | <i>Multi-<br/>function</i>  | Considers a stage<br>for loading and<br>unloading | <i>Bi-<br/>directional</i> |

Continue Table (2.2): Comparing the Characteristics of the Previous Studies Plants in the Literature Review

| Author(s)/<br>(year)                       | Industry                                      | Context<br>XHSP | Number<br>of<br>Hoists | Product         | Processing<br>Times | Parallel<br>Tanks                                      | Multi-<br>function<br>tanks | Buffers,<br>Loading/Unloading<br>Stages                                    | Direction<br>of Paths    |
|--------------------------------------------|-----------------------------------------------|-----------------|------------------------|-----------------|---------------------|--------------------------------------------------------|-----------------------------|----------------------------------------------------------------------------|--------------------------|
| Pantusavase<br>and<br>Hassamontr<br>(2015) | <i>Anodizing</i>                              | CHSP            | <i>Multiple</i>        | <i>Multiple</i> | Time<br>Window      | <i>Some<br/>stages<br/>have<br/>parallel<br/>tanks</i> | -                           | -                                                                          | -                        |
| Feng et al.<br>(2015)                      | Electroplating                                | DHSP            | Single                 | <i>Multiple</i> | Time<br>Window      | <i>Some<br/>are<br/>multiple</i>                       | <i>Multi-<br/>function</i>  | -                                                                          | -                        |
| Basán et al.<br>(2017)                     | <i>Aerospace<br/>industry<br/>(Anodizing)</i> | DHSP            | Single                 | <i>Multiple</i> | Time<br>Window      | Single<br>capacity                                     | <i>Multi-<br/>function</i>  | Considers loading,<br>unloading stages<br>and input and output<br>buffers. | <i>Bi-<br/>direction</i> |

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# **Chapter Three**

## **Description of the Anodizing Plant and the Simulation Model**

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**3.1. Introduction**

**3.2. Plant Physical Layout and the Simulation Model**

**3.3. Stages of the Anodizing Plant**

**3.4. Daily Flow of Jobs**

**3.5. Job Properties and Recipes**

**3.6. Relaxations**

**3.7. Simulation Model**

## **Chapter Three**

# **Description of the Anodizing plant and the Simulation Model**

### **3.1. Introduction**

Balexco products are mainly frames, which are used for doors and windows, these frames or aluminum profiles come in many different shapes, sizes, and colors.

The anodizing plant treats the aluminum profiles by adding a protective layer of aluminum oxide to protect it from corrosion, and to give it an attractive color that suits the customer requirements. This is accomplished by treating the aluminum profiles through a series of chemical processes.

The anodizing plant is a set of tanks that are filled with acids, water, and other chemicals, alongside loading stations, unloading stations and input and output buffers, these positions are located into two parallel sides which are linked by two transferors. Jobs start their paths either in the buffers, loading stations or outside the process line, and they have to go through stages according to their recipes. The transportation from one position to another is done by hoists. Each hoist has a limited range of movement which means each hoist moves above certain positions (zone). Overlaps between hoists ranges are necessary to transport the jobs from the beginning to the end of the anodizing line.

In this chapter, the actual anodizing plant and a simulation model of the actual plant are described in details. The simulated model is used for validation of the scheduling algorithm developed in Chapter 5, and to experiment different

combinations of the jobs sequences and additional tanks, which cannot be done in the actual plant. Furthermore, the problem context and the combinations that will be used to conduct different experiments (runs) using the simulation model are explained.

## **3.2. Plant Physical Layout and the Simulation Model**

Both plants (the actual and the simulation model) are composed of positions, transferors, and hoists. The following subsections describe these constituents.

### **3.2.1 Positions**

The actual anodizing plant at Balexco is composed of 74 positions (Figure 3.1 (a)). The plant is divided into two parallel sides linked by two transferors, the main types and number of positions of each type are as follows:

- 3 Loading stations.
- 2 Unloading stations.
- 3 Input Buffers (at side 1).
- 8 Input Buffers (at side 2).
- 19 Processing tanks (at side 1).
- 10 Processing tanks (at side 2).
- 2 safety positions (one at each side).
- 12 Output Buffers (Side 2 only).
- 13 Positions used to place the empty beams.

The positions in the actual plant are grouped into stages as shown in Table (3.1).

Table (3.1): Original Numbering of the Positions in the Actual Plant

| Side   | Actual Plant Position no.                 | Position Type                          | Stage                |
|--------|-------------------------------------------|----------------------------------------|----------------------|
| 1 & 2  | 1 & 76                                    | Transferor 1                           | Transferor 1         |
| Side 1 | 2 to 9                                    | Input Buffers (side 2)                 | Input Buffers Zone 2 |
|        | 10 & 12                                   | Chemical                               | Alkaline             |
|        | 11 & 13                                   |                                        | Rinsing              |
|        | 14 & 16                                   |                                        | Etching              |
|        | 15, 17 & 18                               |                                        | Rinsing              |
|        | 19                                        |                                        | Desmutting           |
|        | 20 & 21                                   |                                        | Rinsing              |
|        | 22, 23, 25 & 26                           |                                        | Anodizing            |
|        | 24, 27 & 28                               |                                        | Rinsing              |
|        | 30                                        | Safety position                        | -                    |
| 1&2    | 29 & 32                                   | Transferor 2                           | Transferor 2         |
| Side 2 | 31                                        | Safety position                        | -                    |
|        | 31 & 35                                   | Chemical                               | Electro-coloring     |
|        | 34, 36 & 37                               |                                        | Rinsing              |
|        | 37                                        |                                        | Demi-rinsing         |
|        | 39-42                                     |                                        | Hot Sealing          |
|        | 43 to 54                                  | Output Buffers                         | Output Buffers Zone  |
|        | 55 & 59                                   | Unloading Station                      | Unloading            |
|        | 63, 67 & 71                               | Loading station                        | Loading              |
|        | (56 to 58), (64 to 66), (68 to 60) & (72) | Empty positions to put the empty beams | -                    |
|        | 73 to 75                                  | Input Buffers (side 1)                 | Input Buffers Zone 1 |

For the sake of logical sequencing of the process route in the simulation model, the number of the positions are reduced and renumbered (refer to Table (3.3) and to the numbers in the small boxes beside each position in Figure (3.1 (b))), the hoists are renumbered as well. In the simulation model, the main starting position is an imaginary position which is located outside the process line, followed by the loading stations and so on until the unloading stage. Also, some of the positions were removed from the simulation plant for the reasons given in Table (3.2).

Table (3.2): Removed Positions from the Simulation Model and Justifications

| <b>Position removed</b>      | <b>Reason</b>                                                                                                    |
|------------------------------|------------------------------------------------------------------------------------------------------------------|
| Second Electro-coloring Tank | Out of service in the actual plant                                                                               |
| Safety Positions             | Hoist downtime is not considered in the problem formulation, due to lack of data of hoists' downtimes.           |
| Empty Beams Positions        | It is assumed that the number of beams is infinite, thus number of beams is not part of the problem formulation. |

In Figure (3.1 (b)) for the simulation model layout, the numbering of the two parallel sides is the reverse of the actual plant numbering in Figure (3.1 (a)), the reason for this new numbering is due to the starting points in the simulation model, which are the loading stations (positions no. 2, 3 and 4) and the position outside process line (position no.1). Another two starting positions are the input buffers zone 1 at side 1 and input buffers zone 2 at side 2. The reason given for reversing the numbering of the two sides is the same reason for re-numbering the positions and starting from a position outside the plant, followed by the loading stations and ending with unloading stations.

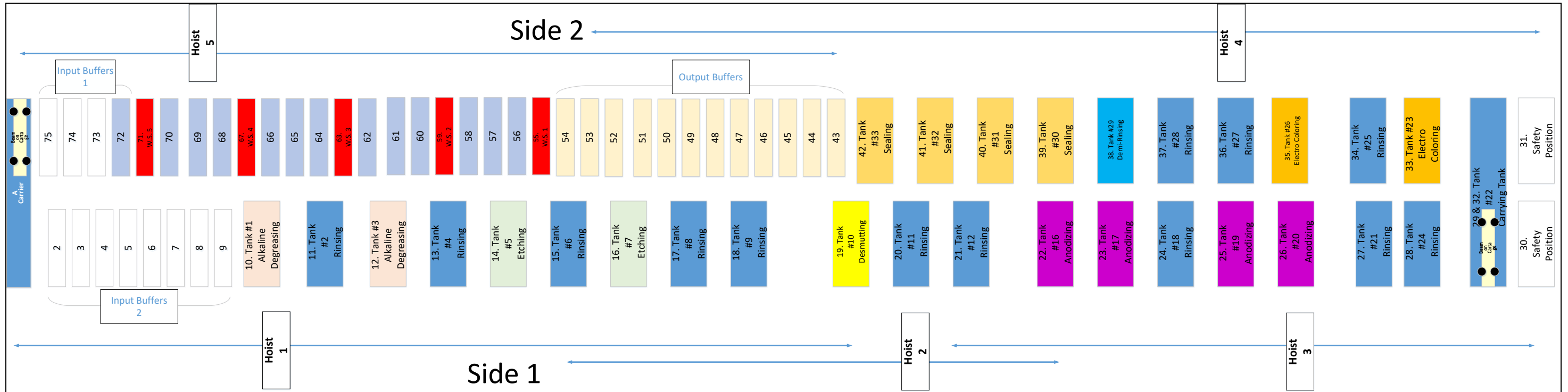


Figure (3.1 (a)): The Layout of the Anodizing Plant with the Original Positions and Hoists Numbering

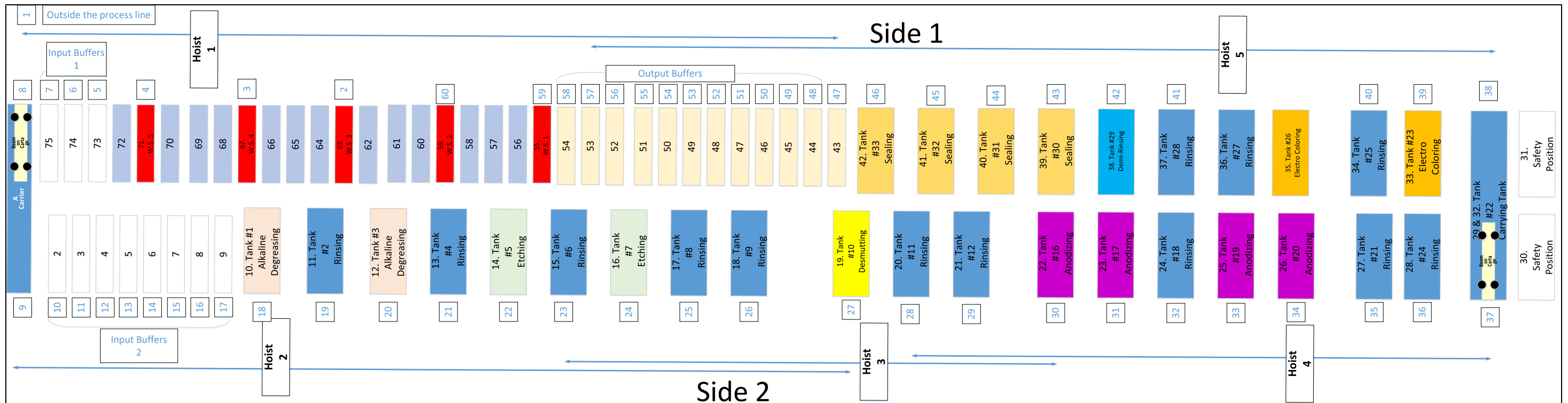


Figure (3.1 (b)): The layout of the Anodizing Plant with the Simulation Numbering (new position number inside the small boxes)

The positions numbering for the simulation model are given in Table (3.3).

Table (3.3): Numbering of the Positions in the Simulation Model

| Side   | Simulation Model<br>Position no. | Position Type          | Stage                |
|--------|----------------------------------|------------------------|----------------------|
| Side 1 | 1                                | Outside the plant      | Outside              |
|        | 2, 3, & 4                        | Loading stations       | Loading              |
|        | 5 to 7                           | Input Buffers (side 1) | Input Buffers Zone 1 |
| 1&2    | 8 & 9                            | Transferor 1           | Transferor 1         |
| Side 2 | 10 to 17                         | Input Buffer (side 2)  | Input Buffer Zone 2  |
|        | 18 & 20                          | Chemical               | Alkaline             |
|        | 19 & 21                          |                        | Rinsing              |
|        | 22 & 24                          |                        | Etching              |
|        | 23, 25 & 26                      |                        | Rinsing              |
|        | 27                               |                        | Desmutting           |
|        | 28 & 29                          |                        | Rinsing              |
|        | 30, 31, 33 & 34                  |                        | Anodizing            |
|        | 32, 35 & 36                      |                        | Rinsing              |
| 2&1    | 37 & 38                          | Transferor 2           | Transferor 2         |
| Side 1 | 39                               | Chemical               | Electro-coloring     |
|        | 40 & 41                          |                        | Rinsing              |
|        | 42                               |                        | Demi-rinsing         |
|        | 43 to 46                         |                        | Sealing              |
|        | 47 to 58                         | Output Buffers         | Output Buffers Zone  |
|        | 59 & 60                          | Unloading stations     | Unloading            |

### **3.2.2 Transferors**

There are two transferors, one carries the jobs from Side 1 to Side 2, while the other one carries the jobs from Side 2 to Side 1. Each transferor is considered one stage, but according to the positions numbering each transferor is composed of two positions, where one position is on one side of the plant and the second position is on the other side. Each transferor has one carrying cartage, this cartage moves one job from one end to the other end, and return to the original end empty, to receive a new job. The duration that it takes to move a job from one end to another is one minute, and the duration for the cartage to retune back to the original end is also one minute.

### **3.2.3 Hoists**

The plant has five hoists, two hoist travel at Side 1, and the remaining three travel at Side 2. In the actual plant layout hoist no. 1, 2 and 3 are at Side 1, and hoist no. 4 and 5 are at Side 2. In the simulation model hoists no. 1 and 5 are located at Side 1, while hoists no. 2, 3 and 4 are located at Side 2.

All the five hoists move above the positions in one line within their specified ranges. The process route can experience bi-directional hoist move, that means according to the position numbering, the next processing position (next tank) can be the position with the lower number than the current position number. Table (3.4) shows to the hoists ranges according to the simulation model numbering.

Table (3.4): Hoists Ranges in the Simulation Model

| Side   | Hoist no.        | Ranges by Positions                               |
|--------|------------------|---------------------------------------------------|
| Side 1 | 1                | 02 $\leftrightarrow$ 08 & 47 $\leftrightarrow$ 60 |
| Side 2 | 2                | 09 $\leftrightarrow$ 27                           |
|        | 3                | 23 $\leftrightarrow$ 30                           |
|        | 4                | 28 $\leftrightarrow$ 37                           |
| Side 1 | 5                | 38 $\leftrightarrow$ 57                           |
| Side 1 | 6<br>(imaginary) | 01 $\leftrightarrow$ 02, 03 or 04                 |

( $\leftrightarrow$ ): from-to and vice versa

The sixth hoist does not exist physically, the reason for adding this hoist in the simulation model is the need to consider a loaded move that represents the transportation of a job from the outside position to one of the loading stations since there is no hoist to do that.

As it can be seen from Figure (3.1 (b)), the hoists which are located on one side have some shared positions (exchanged position), in other words, the hoists ranges overlap. These overlapping zones are important, so that a job can be transported from the begging to the end of the process line. This also implies attention to avoid hoists collision during production.

### 3.3. Stages of the Anodizing Plant

Based on the new arrangement of positions for the simulation model, there are 27 stages, which are listed in Table (3.5), five of which are waiting stages (stage no. 1, 2, 3, 5 and 26, shaded in Table (3.5)). The function of each stage is explained in Table (3.6).

Table (3.5): The Stages of the Simulation Model.

| Stage no. | Stage Name           | Stage no. | Stage Name                 |
|-----------|----------------------|-----------|----------------------------|
| 1         | Outside              | 15        | Desmutting Rinsing 1       |
| 2         | Loading              | 16        | Desmutting Rinsing 2       |
| 3         | Input Buffers Zone 1 | 17        | Anodizing                  |
| 4         | Transferor 1         | 18        | Anodizing Rinsing 1        |
| 5         | Input Buffers Zone 2 | 19        | Anodizing Rinsing 2        |
| 6         | Alkaline             | 20        | Transferor 2               |
| 7         | Alkaline Rinsing     | 21        | Electro-Coloring           |
| 8         | Etching              | 22        | Electro-Coloring Rinsing 1 |
| 9         | Etching Rinsing 1    | 23        | Electro-Coloring Rinsing 2 |
| 10        | Etching Rinsing 2    | 24        | Demi-Rinsing               |
| 11        | Etching Rinsing 3    | 25        | Hot Sealing                |
| 12        | Etching Rinsing 4    | 26        | Output Buffers Zone        |
| 13        | Etching Rinsing 5    | 27        | Unloading                  |
| 14        | Desmutting           |           |                            |
|           | Waiting Stage        |           |                            |

Table (3.6): Functions of the Stages in the Anodizing Plant

| Stage Name          | Function                                                                                                                |
|---------------------|-------------------------------------------------------------------------------------------------------------------------|
| Outside             | The stage where the rest of the jobs (job no. 15 and above) wait to enter the loading stage.                            |
| Loading             | Jigging the profile to the carrier.                                                                                     |
| Input Buffer Zone 1 | The stage where the jobs wait for the transferor 1 to reach Input Buffer Zone 2                                         |
| Transferor 1        | Transfer the jobs from Input Buffer Zone 1 to Input Buffer Zone 2                                                       |
| Input Buffer Zone 2 | The stage where the job wait to enter the process to reach Output Buffer without violation.                             |
| Alkaline            | To clean the profiles from any dirt.                                                                                    |
| Alkaline Rinsing    | The rinsing stage that comes after Alkaline.                                                                            |
| Etching             | To smoothen the profile surface from any contaminants and hide surface imperfections such as scratches, die lines, etc. |
| Etching Rinsing     | The rinsing stage that comes after etching                                                                              |
| Desmutting          | To remove the “smut” of residual metallic alloying materials that are left on the profiles.                             |
| Desmutting Rinsing  | The rinsing stage that comes after Desmutting                                                                           |
| Anodizing           | Build the aluminum oxide layer on the outer surface of the profiles.                                                    |
| Anodizing Rinsing   | The rinsing stage that comes after anodizing                                                                            |
| Transferor 2        | Transfer the jobs from Side 2 to Side 1 back again                                                                      |

Continue Table (3.6): Functions of the Stage in the Anodizing Plant

| Stage Name               | Function                                                                                                                                           |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Electro-Coloring         | Fill the pours of the anodized aluminum with an acid chemical that acts as the paint, the longer the profile stays in this tank the darker it gets |
| Electro-Coloring Rinsing | The rinsing stage that comes after the electro-coloring stage                                                                                      |
| Dime-rinsing             | The last rinsing stage with more pure water.                                                                                                       |
| Hot Sealing              | It uses boiling water and some chemical to close the remaining pours in the surface.                                                               |
| Output Buffer Zone       | To cool-down the profiles and dry them out, and wait (if necessary) until an unloading station is available.                                       |
| Unloading                | To unload the profiles from the carrier.                                                                                                           |

The waiting stages are:

- 1) Outside: waiting starts from the begging of the day until there is available loading station.
- 2) Loading: waiting starts after jigging is done until there is available position at the Input Buffers Zone 1.
- 3) Input Buffers Zone 1: waiting starts from the time the job is placed in one of the buffers until there is available position at the Input Buffers Zone 2 in-addition to the readiness of Transferor 1.
- 4) Input Buffers Zone 2: waiting starts from the time the job is placed in one of the buffers until all the stages from Alkaline to the Output Buffers are ready to be used as the job proceeds starting from Alkaline to Output Buffers Zone.
- 5) Output Buffers Zone: waiting starts after 10 minutes from the time at which the job is placed in one of the buffers to the time at which there is an available unloading station.

Based on the waiting stages, the plant has been divided into five sections as shown in Table (3.7).

Table (3.7): Sections of the Plant in the Simulation Model

| <b>Section</b> | <b>From / To</b>                            | <b>Stage(s) involved</b> | <b>Number of stage(s)</b> |
|----------------|---------------------------------------------|--------------------------|---------------------------|
| 1              | from the Outside stage to the Loading stage | 1                        | 1                         |
| 2              | from the Loading stage to Input Buffers 1   | 2                        | 1                         |
| 3              | from Input Buffers 1 to Input Buffers 2     | 3 and 4                  | 2                         |
| 4              | from Input Buffers 2 to Output Buffers      | 5, 6,..., 25             | 21                        |
| 5              | from Output Buffers to Unloading            | 26 and 27                | 2                         |

The reason for dividing the plant in this way is to use them as checkpoints whenever there is a violation of the constraints of the model so that the violating job is returned to the last visited waiting stage instead of returning it to the begging of the line (outside). This reason will be more clarified in Chapter 5.

### **3.4. Daily Flow of Jobs**

Most of the working days consist of two shifts (16 hours), every day the plant should start-up at 6:00 am and shutdown at 10:00 pm. The simulation time starts at 0 seconds and ends after 56700 seconds (16 hours). However, there are some days consisting of three shifts (24 hours), but they are not considered in the simulation model, because days with three shifts in a row has to be considered as one long day or save the process line status at the end of each one day to be used for the beginning of the next day. Saving the line status for the beginning of the next day is needed, because, at the end of the previous day, there are usually jobs still under treatment in the chemical tanks. To overcome this difficulty only days of two shifts are selected for the simulation.

The production is a series of orders that need to be processed, each order is a set of aluminum profiles with different specifications, and some of these orders may share the same type of profiles. These profiles are waiting outside the anodizing line in large baskets after completing the preceding stages (extrusion and aging oven).

The required quantities of a customer's order or a type may exceed the daily capacity of the anodizing plant, thus the quantities are distributed among days. This means in a single day a mixture of orders and/or different types are

treated partially. Also, more than one carrier may be needed to process those partial orders and types.

There are two types of carriers, one used for the ordinary profiles and the other type used for small profiles. The carrier type which is used for the small section profiles is called the Angle type, the carrier used for the ordinary profiles uses bars and clips to hold the bigger profiles. Figures (3.2 (a)) and (3.2 (b)) show the difference between the two carriers in schematic drawings. Figure (3.2 (b)) shows the angle type carrier with only 4 racks, but in reality, the carrier has up to 21 racks, and the sizes of the small profiles are even much smaller and the number is greater than what the figure is showing.

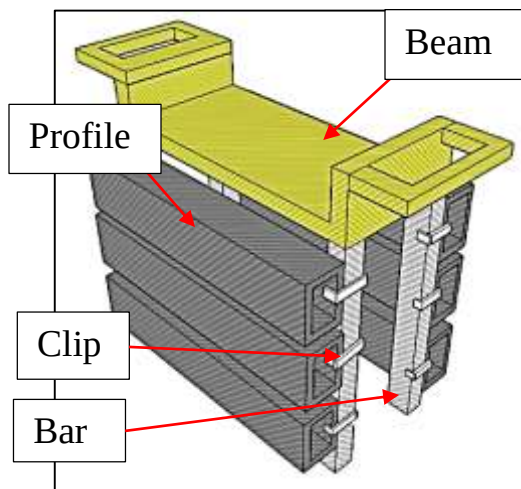


Figure (3.2 (a)): Bar Type Carrier.

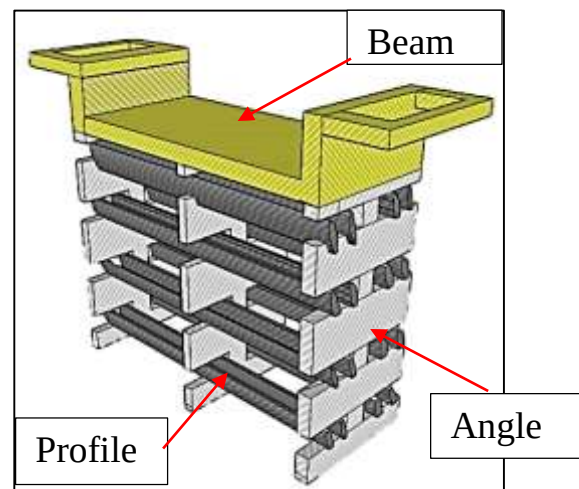


Figure (3.2 (b)): Angle Type Carrier.

In this report, the word “job” will be used to refer to the bulk of the aluminum profiles that are attached to one carrier and has the same profile specifications. In the actual plant, there is a limited number of carriers used, this means they are used more than once; however, in the simulated model the number of carriers are assumed infinite, thus each job has its own carrier.

In the real plant, the day starts with already placed jobs in the loading stations and in the input buffers stages (Input Buffers Zone 1 and Input Buffers Zone 2). These jobs were loaded (jigged) from the previous day waiting in the loading stations and in the buffers, for processing in the following day. The system can directly start treating these jobs in the following (chemical) stages, thus saving time that could have been lost in loading (jigging).

New jobs arrive and kept waiting at large baskets that are located outside the process line (position no.1). According to the latest updates, there is a daily plan that lists the types of profiles that should be processed with their quantities and their sequential order. It is left to the workers in the anodizing plant to plan how to distribute these profiles and how to jig them to the carriers.

As an old job finishes the treatment in a stage and moved to the next stage, the position of this stage will be used by a new job. This done until all the jobs finish the last stage (unloading) at the end of the day.

### **3.5. Job Properties and Recipes**

In the simulation model, a job is defined by four properties, these properties are:

- Job Priority
- Job ID
- Recipe ID
- Anodizing Treatment Duration

In-addition, there are two changing parameters that change as the job proceeds along the plant:

- Current Stage
- Current Position

Each job has its own process route which is specified by the starting stage, the sequence of the following stages and the duration of each stage. The starting stage and the starting position of a job depend on the job priority number.

The process route and the duration of each stage that a job has to go through is defined by its recipe number (Recipe ID).

For the simulation model, 30 recipes will be used out of more than hundred recipes processed by Ballexco anodizing plant. These general 30 recipes, shown in Table (3.8) come from classifying all recipes based on their:

a) **Color:**

- Matt Finish means no color, so this why it skips the Electro-coloring stage, as shown in Tables (3.8) and (3.10).
- 9 colors, ranging from light gray (Color 16) to Black (Black Finish).

b) **Section** (The Shape of the Profile)

- **SH:** very small hollow shaped profiles and they are loaded using the Angle type of carrier.
- **B:** bigger profiles with a section weight over 900 kg, loaded to the beam by using bars and clips.
- **Rest:** other ordinary profiles which range from small to big profiles with section weight less than 900 kg.

Whether the profiles are big or small, they can take the shape of open sections or hollow section. The length of the profiles should be 6 meters or less, so it will not exceed the length of the tanks.

The number of recipes that exists in the actual plant is more than 30 recipes because they come in many shapes and sizes which change the treatment durations in some stages (Etching, Anodizing, and Electro-Coloring). So for that reason not all of these recipes are considered, not to mention that the details of the original recipes are considered confidential.

Nevertheless, based on experience, the durations used in the simulation model are close to the actual durations. The duration for each stage for each recipe is around the average duration of the actual duration, except for the rinsing stages, Alkaline, Desmutting and the Hot Sealing stages which are almost exactly the same as in the actual production.

Looking at Table (3.8) it can be seen that all of the recipes have quite the same route, except that some of them skip some stages, others stay longer in the tanks as the shape and color changes. Table (3.8) does not show all the stages, the other stages not included in the table are listed below with their durations, which are for all the 30 recipes.

- 1) Outside: depends on the availability of the Loading stage
- 2) Loading:
  - Ten (10) minutes for the ordinary profiles, in-addition to waiting duration that depends on the availability on the following stages.
  - 30 minutes for the small profiles jigged to the angle type, in-addition to waiting duration that depends on the availability of the following stages.
- 3) Input Buffers Zone (1 and 2): depends on the availability of the following stages.
- 4) Transferors: one minute to move the job from one side to the other side, and one minute for the cartage to return to the original side.
- 5) Output buffers Zone: ten (10) minutes to let the processed profiles to dry and cool down, in-addition to waiting duration that depends on the availability of the unloading stage.
- 6) Unloading: three (3) minutes to unload the small profiles from the angle carrier, and ten (10) minutes to unload the other types of profile from the bar type carrier.

In Table (3.8) the symbol (➔) means that after each stage it must be followed by a number of rinsing treatments, designated by the letter (R), each rinsing treatment takes about one minute.

Table (3.8): Recipes Treatment Durations

| Recipe no. | Finish  | Section | Processing Time (minutes) |         |            |           |               |                  |              |              |
|------------|---------|---------|---------------------------|---------|------------|-----------|---------------|------------------|--------------|--------------|
|            |         |         | Alkane                    | Etching | Desmutting | Anodizing | Carrying Tank | Electro-Coloring | Demi-Rinsing | Sealing      |
| 1          | Matt    | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 2R   | 1             | -                | 1            | 45, 60 or 20 |
| 2          |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 2R   | 1             | -                | 1            | 45, 60 or 20 |
| 3          |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 2R   | 1             | -                | 1            | 45, 60 or 20 |
| 4          | Col 16* | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 1 → 2R           | 1            | 45, 60 or 20 |
| 5          |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 1 → 2R           | 1            | 45, 60 or 20 |
| 6          |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 1 → 2R           | 1            | 45, 60 or 20 |
| 7          | Col 15  | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 2 → 2R           | 1            | 45, 60 or 20 |
| 8          |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 2 → 2R           | 1            | 45, 60 or 20 |
| 9          |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 2 → 2R           | 1            | 45, 60 or 20 |
| 10         | Col 10  | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 3.5 → 2R         | 1            | 45, 60 or 20 |
| 11         |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 3.5 → 2R         | 1            | 45, 60 or 20 |
| 12         |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 3.5 → 2R         | 1            | 45, 60 or 20 |
| 13         | Col 11  | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 4.5 → 2R         | 1            | 45, 60 or 20 |
| 14         |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 4.5 → 2R         | 1            | 45, 60 or 20 |
| 15         |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 4.5 → 2R         | 1            | 45, 60 or 20 |
| 16         | Col 17  | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 6 → 2R           | 1            | 45, 60 or 20 |
| 17         |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 6 → 2R           | 1            | 45, 60 or 20 |
| 18         |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 6 → 2R           | 1            | 45, 60 or 20 |
| 19         | Col 21  | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 9 → 2R           | 1            | 45, 60 or 20 |
| 20         |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 9 → 2R           | 1            | 45, 60 or 20 |
| 21         |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 9 → 2R           | 1            | 45, 60 or 20 |
| 22         | Col 30  | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 11 → 2R          | 1            | 45, 60 or 20 |
| 23         |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 11 → 2R          | 1            | 45, 60 or 20 |
| 24         |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 11 → 2R          | 1            | 45, 60 or 20 |
| 25         | Col 40  | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 14.5 → 2R        | 1            | 45, 60 or 20 |
| 26         |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 14.5 → 2R        | 1            | 45, 60 or 20 |
| 27         |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 14.5 → 2R        | 1            | 45, 60 or 20 |
| 28         | Black   | SH      | 6 → 1R                    | 18 → 5R | -          | 40 → 1R   | 1             | 24 → 2R          | 1            | 45, 60 or 20 |
| 29         |         | B       | 6 → 1R                    | 18 → 3R | 1 → 2R     | 40 → 1R   | 1             | 24 → 2R          | 1            | 45, 60 or 20 |
| 30         |         | Rest    | 6 → 1R                    | 18 → 3R | 1 → 1R     | 40 → 1R   | 1             | 24 → 2R          | 1            | 45, 60 or 20 |

\* Col 16 means Color 16

As for the Hot Sealing stage, there are three durations (45, 60 or 20) minutes, the original duration is 45 minutes, and the other two values (60 and 20) are depending on what year the processing day is and the chosen tank where the job is placed for treatment. The hot sealing tanks are filled with boiling water and an added chemical, the water surface is covered by balls made of polymers to prevent evaporation of boiled water.

During the year 2015, the treatment duration in all the four positions of the hot sealing stage was 45 minutes, while during the year 2017 the duration increased to 60 minutes, except for one tank (position no. 43), which was filled with a new chemical that reduced the treatment duration to 20 minutes. Based on these durations, two cases (cases of Hot Sealing durations) were developed for the simulation model, as shown in Table (3.9). The duration was increased from 45 minutes to 60 minutes due to a change in the quality standards from the year 2015 to the year 2017.

Table (3.9): Hot Sealing Durations Cases

| <b>Case</b> | <b>Year</b> | <b>Number of sealing tanks with the original chemical (duration)</b> | <b>Number of sealing tanks with the new chemical (duration)</b> |
|-------------|-------------|----------------------------------------------------------------------|-----------------------------------------------------------------|
| 1           | 2015        | 4 tanks (45 minutes)                                                 | None                                                            |
| 2           | 2017        | 3 tanks (60 minutes)                                                 | 1 tank (20 minutes)                                             |

According to Table (3.10), the 30 recipes are classified further into six types, the classification is based on the skipped stages and the number of rinsing stages that comes after some of the stages. Table (3.10) illustrates the differences between the six types of the recipes and the recipes that follow them. Table (3.10) classifies the recipe types based on the required number of times for the stages by which they differ, for example, the Etching and Anodizing stages do not appear in Table (3.10), because they do not differ from one recipe type to another, both of them treat a job once. Also, it can be noticed in Table (3.10) that recipe types no. 1, 2 and 3 have Matt Finish recipes that is why they skip Electro-Coloring stage; while recipe types no. 4, 5 and 6 have Colored Finish recipes that is why they enter the Electro-Coloring stage followed by two rinsing stages.

Table (3.11) lists the possible positions that can be used for each stage depending on the recipe type, where the job must be treated in one position (if the required stage have more than one position) or in the only one available position (in case there is one position for the required stage). In Table (3.11), the rows represent the recipe type no. (refer to Table (3.10)) and the columns represent the stage number and name. If there is a skipped stage then the position in that stage is represented by the number zero.

Table (3.12) summaries the information in Table (3.11), where it states the number of possible positions for each stage regardless of the recipes. It also states whether the positions are used once (mono-function) or twice (multi-function) depending on the type of recipe and the stage.

Each position can treat one job at a time, similarly for the hoists when they move jobs (Constraints no. 4.14 and 4.15 in Chapter 4).

Table (3.10): Recipe Types and Their Differences

| <b>Recipe Type</b> | <b>Recipe ID</b>                      | <b>Number of Rinsing after Etching</b> | <b>Desmutting</b> | <b>Number of Rinsing stages after Desmutting</b> | <b>Number of Rinsing stages after Anodizing</b> | <b>Electro-Coloring</b> | <b>Number of Rinsing after Electro-Coloring</b> |
|--------------------|---------------------------------------|----------------------------------------|-------------------|--------------------------------------------------|-------------------------------------------------|-------------------------|-------------------------------------------------|
| <b>1</b>           | 1                                     | 5                                      | Skipped           | Skipped                                          | 2                                               | Skipped                 | Skipped                                         |
| <b>2</b>           | 2                                     | 3                                      | 1                 | 2                                                | 2                                               | Skipped                 | Skipped                                         |
| <b>3</b>           | 3                                     | 3                                      | 1                 | 1                                                | 2                                               | Skipped                 | Skipped                                         |
| <b>4</b>           | 4, 7, 10 13, 16, 19, 22, 25 & 28      | 5                                      | Skipped           | Skipped                                          | 1                                               | 1                       | 2                                               |
| <b>5</b>           | 5, 8, 11, 14, 17, 20, 23, 26, 29 & 30 | 3                                      | 1                 | 2                                                | 1                                               | 1                       | 2                                               |
| <b>6</b>           | 9, 12, 15, 18, 21, 24, 27 & 30        | 3                                      | 1                 | 1                                                | 1                                               | 1                       | 2                                               |

Table (3.11): Possible Positions

| Possible Positions<br>(PP Cell Array) |  | Stages (Name / no.) |         |                     |              |                     |                                   |                  |          |                   |                   |                   |                   |                   |            |                      |                      |           |                    |                    |              |                  |                            |                            |               |             |                    |                                                   |          |
|---------------------------------------|--|---------------------|---------|---------------------|--------------|---------------------|-----------------------------------|------------------|----------|-------------------|-------------------|-------------------|-------------------|-------------------|------------|----------------------|----------------------|-----------|--------------------|--------------------|--------------|------------------|----------------------------|----------------------------|---------------|-------------|--------------------|---------------------------------------------------|----------|
|                                       |  | Outside             | Loading | Input Buffer Zone 1 | Transferor 1 | Input Buffer Zone 2 | Alkaline                          | Alkaline Rinsing | Etching  | Etching Rinsing 1 | Etching Rinsing 2 | Etching Rinsing 3 | Etching Rinsing 4 | Etching Rinsing 5 | Desmutting | Desmutting Rinsing 1 | Desmutting Rinsing 2 | Anodizing | Anodizing Rising 1 | Anodizing Rising 2 | Transferor 2 | Electro-Coloring | Electro-Coloring Rinsing 1 | Electro-Coloring Rinsing 2 | Demi- rinsing | Hot Sealing | Output Buffer Zone | Un-Loading                                        |          |
|                                       |  | 1                   | 2       | 3                   | 4            | 5                   | 6                                 | 7                | 8        | 9                 | 10                | 11                | 12                | 13                | 14         | 15                   | 16                   | 17        | 18                 | 19                 | 20           | 21               | 22                         | 23                         | 24            | 25          | 26                 | 27                                                |          |
| Recipe Type                           |  | 1                   | 1       | 2, 3, or 4          | 5,6, or 7    | start at 8          | 10, 11, 12, 13, 14, 15, 16, or 17 | 18 or 20         | 19 or 21 | 22 or 24          | 23                | 23                | 25                | 25                | 26         | 0                    | 0                    | 0         | 30, 31, 33, or 34  | 32 or 35           | 35 or 36     | Start at 37      | 0                          | 0                          | 0             | 42          | 43, 44, 45, or 46  | [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57 or 58 | 59 or 60 |
|                                       |  | 2                   | 1       | 2, 3, or 4          | 5,6, or 7    | start at 8          | 10, 11, 12, 13, 14, 15, 16, or 17 | 18 or 20         | 19 or 21 | 22 or 24          | 23                | 25                | 26                | 0                 | 0          | 27                   | 28                   | 29        | [30 31 33 34]      | 32 or 35           | 35 or 36     | Start at 37      | 0                          | 0                          | 0             | 42          | 43, 44, 45, or 46  | [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57 or 58 | 59 or 60 |
|                                       |  | 3                   | 1       | 2, 3, or 4          | 5,6, or 7    | start at 8          | 10, 11, 12, 13, 14, 15, 16, or 17 | 18 or 20         | 19 or 21 | 22 or 24          | 23                | 25                | 26                | 0                 | 0          | 27                   | 28 or 29             | 0         | [30 31 33 34]      | 32 or 35           | 35 or 36     | Start at 37      | 0                          | 0                          | 0             | 42          | 43, 44, 45, or 46  | [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57 or 58 | 59 or 60 |
|                                       |  | 4                   | 1       | 2, 3, or 4          | 5,6, or 7    | start at 8          | 10, 11, 12, 13, 14, 15, 16, or 17 | 18 or 20         | 19 or 21 | 22 or 24          | 23                | 23                | 25                | 25                | 26         | 0                    | 0                    | 0         | [30 31 33 34]      | 32, 35, or 36      | 0            | Start at 37      | 39                         | 40                         | 41            | 42          | 43, 44, 45, or 46  | [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57 or 58 | 59 or 60 |
|                                       |  | 5                   | 1       | 2, 3, or 4          | 5,6, or 7    | start at 8          | 10, 11, 12, 13, 14, 15, 16, or 17 | 18 or 20         | 19 or 21 | 22 or 24          | 23                | 25                | 26                | 0                 | 0          | 27                   | 28                   | 29        | [30 31 33 34]      | 32, 35, or 36      | 0            | Start at 37      | 39                         | 40                         | 41            | 42          | 43, 44, 45, or 46  | [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57 or 58 | 59 or 60 |
|                                       |  | 6                   | 1       | 2, 3, or 4          | 5,6, or 7    | start at 8          | 10, 11, 12, 13, 14, 15, 16, or 17 | 18 or 20         | 19 or 21 | 22 or 24          | 23                | 25                | 26                | 0                 | 0          | 27                   | 28 or 29             | 0         | [30 31 33 34]      | 32, 35, or 36      | 0            | Start at 37      | 39                         | 40                         | 41            | 42          | 43, 44, 45, or 46  | [47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57 or 58 | 59 or 60 |

Table (3.12): Numbers of Stage Positions and Their Function Type

| Stage no.            | Name                         | Number of Positions      | Mono/Multi-function                                                               |
|----------------------|------------------------------|--------------------------|-----------------------------------------------------------------------------------|
| 1                    | Outside                      | 1 position               | Mono-function                                                                     |
| 2                    | Loading                      | 3 loading stations       | Mono-function                                                                     |
| 3                    | Input Buffer Zone 1          | 3 positions              | Mono-function                                                                     |
| 4                    | Transferor 1                 | 2 positions as one stage | Mono-function                                                                     |
| 5                    | Input Buffer Zone 2          | 8 positions              | Mono-function                                                                     |
| 6                    | Alkaline                     | 2 positions              | Mono-function                                                                     |
| 7                    | Alkaline Rinsing             | 2 positions              | Mono-function                                                                     |
| 8                    | Etching                      | 2 positions              | Mono-function                                                                     |
| 9, 10, 11, 12 and 13 | Etching Rinsing              | 5 positions              | In recipe type no. 1 & 4, positions no. 23 and 25 are multi-function (used twice) |
| 14                   | Desmutting                   | 1 position               | Mono-function                                                                     |
| 15 and 16            | Desmutting Rinsing           | 2 positions              | Mono-function                                                                     |
| 17                   | Anodizing                    | 4 positions              | Mono-function                                                                     |
| 18 and 19            | Anodizing Rinsing            | 2 positions              | Mono-function                                                                     |
| 20                   | Transferor 2 (Carrying tank) | 2 positions as one tank  | Mono-function                                                                     |
| 21                   | Electro-Coloring             | 1 position               | Mono-function                                                                     |
| 22 and 23            | Electro-Coloring Rinsing     | 2 positions              | Mono-function                                                                     |
| 24                   | Dime-rinsing                 | 1 position               | Mono-function                                                                     |
| 25                   | Hot Sealing                  | 4 positions              | Mono-function                                                                     |
| 26                   | Output Buffer Zone           | 12 positions             | Mono-function                                                                     |
| 27                   | Un-loading                   | 2 un-loading stations    | Mono-function                                                                     |

### 3.6. Relaxations

Table (3.13) shows the differences between the actual anodizing plant at Balexco and the simulated plant of this research along with the explanation of the considered relaxation(s) that made the difference. The reasons for these relaxations are to make the simulation simpler due to lack of time; However, some of these relaxations can be adjusted in future studies (refer to Section 7.3).

Table (3.13): Relaxations and Differences between the Actual Plant and the Simulation Plant.

|                                | Actual Plant                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Simulated Plant                                                                                                                                                                                                                                                                                       |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1) Number of Loading Positions | <p>Profiles loaded to bar type carriers undergo the loading stage through two loading stations, usually Stations of positions no. 2 and 3 with a duration of five (5) minutes on average for each station; while profiles of the angle type carrier are loaded at one station, usually station of position no. 4 with an average duration of 30 minutes.</p> <p>The reason for loading bar type carrier at two stations is to ease the loading by placing the cartage that holds the profiles between two stations, where one side of the carrier is loaded at one station, while the other side is loaded at the other station.</p> | <p>Any profile types (whether they are loaded to bar type carrier or angle type carrier) can be loaded in any loading station. The small profiles loaded to angle type will take 30 minutes of loading, while the ordinary profiles loaded to the bar type will take ten (10) minutes of loading.</p> |

Continue Table (3.13)

|                             | <b>Actual Plant</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | <b>Simulated Plant</b>                                                                                |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| 2) Time to Plan the Loading | There is some time spent to plan for loading the profiles like for example, the workers at the loading station have to calculate the number of profiles of a certain section that can be loaded to a bar type carrier.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | The time spent on planning how to load the profiles to the carriers was not considered.               |
| 3) Number of Recipes        | <p>There are hundreds of recipes each one has its own specific treatment durations that is different from the other.</p> <p>The reason for this is the presence of other factors than the finish type (color) and section type. Some of these other factors are related to the profiles, like the outer surface area of all profiles loaded to one carrier and the type of the type of alloy, which means it has its own duration in the Etching, Anodizing, and Electro-Coloring stages.</p> <p>Also, other factors related to the process, like the change in the chemical concentration, for example, if the caustic concentration in an etching tank is decreased, the duration of the treatment is extended accordingly.</p> | There are 30 recipes in general that groups the original recipes based on the color and section type. |

Continue Table (3.13)

|                           | Actual Plant                                                                                                                                       | Simulated Plant                                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4) Number of Shifts       | Some days consist of three shifts (24 hours), but most of the days are two shifts (16 hours).                                                      | Each day consists of only two shifts (16 hours).                                                                                                                                                                                                                                                                                                                                                                                    |
| 6) Skipping Buffer Zone 2 | Some jobs can skip some waiting stages, for example, a job from transferor 1 may skip the Input Buffers Zone 2 depending on how urgent is the job. | Each job has to stay for sometime in every waiting stage, regardless of its urgency                                                                                                                                                                                                                                                                                                                                                 |
| 7) Hoist Travel Durations | The hoist travel duration varies depending on how far the next position is, and the hoist acceleration.                                            | <p>Hoist travel duration between two positions is expressed in a form of the following linear equation:</p> $Duration = 3.1374 * (Number\ of\ positions\ in\ between + 1) - 0.2901$ <p>This equation is obtained from three durations taken from the real plant for three different positions' distances, which makes it less accurate. The reason for taking only three durations is not to intervene with ongoing production.</p> |
| 8) Assigning the Hoists   | Hoist is assigned based on the nearest available hoist and collision avoidance.                                                                    | Hoist is assigned based on the hoists ranges in which the position of finished job lies under, the availability of the hoist and collision avoidance.                                                                                                                                                                                                                                                                               |

Continue Table (3.13)

|                                              | <b>Actual Plant</b>                                                                                                                                                              | <b>Simulated Plant</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9) The Accuracy of Empty Hoist Move Duration | <p>All hoist movement durations are accurate, whether they are loaded hoist move, empty hoist move, or hoist waiting time above a position where the job is about to finish.</p> | <p>Empty hoist move and hoist waiting time are estimated to be always 20 seconds for each, which is not accurate.</p> <p>The reason why this method is not accurate is that the hoists traveling durations and how they are assigned are relaxed in this study.</p> <p>A disadvantage of this, it simulates an empty hoist between positions with more than 20 seconds to be done in 20 seconds (fast move), and vice versa.</p> <p>However, this relaxation is expected not to be that significant, because, in Anodizing plant, the hoist travel durations are smaller compared to the treatment durations. Unlike Printed Circuit Boards (PCB) plants where treatment durations and hoists traveling durations are short and close to each other, thus the accuracy of the hoists traveling durations in PCB plants and the way they are assigned are critical and cannot be relaxed.</p> |

Continue Table (3.13)

|                               | <b>Actual Plant</b>                                                                                                                                                                                                                                                                                                                     | <b>Simulated Plant</b>                                                                                                                                                                                                                                    |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10) Treatment Durations       | Recipes durations are fixed (not varying between minimum and maximum durations) and specific for each recipe type (specific profiles). The reason for this is the criticality of the treatment duration, to obtain the same quality for all profiles of one order, especially for the Electro-Coloring stage where every second matter. | Recipe durations are fixed (not varying between minimum and maximum durations), but they are around an average duration based on the 30 general recipes, except for the anodizing stage. The reason for this is the absence of data for the other stages. |
| 11) Cleaning Stages           | The cleaning stage for bar type carrier is done after unloading at the unloading station, while the angel type carrier has to go through etching stage empty (without profiles) for one minute followed by three rinsing stages.                                                                                                        | The cleaning stage is not considered for either type of carriers (not the bars type nor the angel type).                                                                                                                                                  |
| 12) Breakdown and Maintenance | Some of the positions might not be in operation, due to maintenance, breakdowns or similar reasons.<br><br>Also hoists jams frequently for few seconds                                                                                                                                                                                  | All positions are in operation for the entire two shifts (16 hours) and for each day.<br><br>Hoists do their operations without any jams.                                                                                                                 |

### 3.7. Simulation Model

The context of the problem in this research is considered to be a Predictive Hoist Scheduling Problem (PHSP), because the list of the jobs that to be scheduled are already given along with their recipes and do not receive any randomly arriving new jobs.

Although, the used algorithms seen in the literature are quite complex, a simple heuristic algorithm was used to solve the problem of this research, because the list of jobs with their recipes are given, the hoists empty movements and waiting times are relaxed in the simulation model, and the jobs are classified based on the 30 recipes mentioned in Section 3.5 for the simulation model.

The basic idea of the used heuristic algorithm is dealing with one job at a time (each job individually) from the beginning to the end of the process by blocking the durations needed by the job for the assigned positions and hoists. After finishing with one job, the time is reset to deal with the next job, and so on until all jobs are completed, where the algorithm will try to enter each new (next) job to the process line as soon as possible. Also, the algorithm has to decide whether it will re-use the same position and the same hoists that have been used by the previous jobs or not.

A Branch-and-bound algorithm or Genetic Algorithm could have been combined with the heuristic algorithm to create different scenarios for selecting another hoist (the closest hoist), however, it was not considered in this study, because in this anodizing plant, the hoist durations are short compared with the chemical treatment durations, thus the hoist selection is expected not to be that much critical. This does not mean that the hoist travel

duration will not affect the final makespan, but for the sake of simplicity and lack of time to be included in this thesis, creating different scenarios of hoists selection was not considered.

### **3.7.1 Collection of historical data**

Historical data of twelve (12) days are chosen to run and test the algorithm, three days are from April 2015 and the other nine are from June 2017.

The selection of data is based on the following:

#### **1) Fewer Breakdowns**

Although the gathered data does not show the times of the breakdowns that the system had, but it can be noticed after sorting the times of jobs entering the anodizing stage by observing the time interval between two consecutive jobs. If the time interval is more than one hour, there is a high probability that a breakdown had occurred. This observation lead to turn away days where there are several large time intervals.

Another way is to anticipate less breakdown by observing if there are a high number of jobs being produced, in this study every selected day had more than 44 jobs.

#### **2) Different Periods**

The reason for choosing days from two different months is originally to consider the effect of breakdown in scheduling, where it is expected that breakdowns have more significant effect in the summer days than in the winter.

But since breakdowns are not considered and the number of good days from April 2015 are only three, more days had to be selected which had less anticipated breakdowns, those days were nine days from June

2017; Although, they are summer days, but it is anticipated that they had fewer breakdowns.

### **3) Variety of Production**

The selected days has a quite noticeable amount of variety of products that ranged from the matt finish of small hollow shaped profiles to the colored profiles.

The data used in this study is extracted from the anodizing daily reports which are log sheets, where the number, the properties of the jobs and the starting time and finishing time at the anodizing stage are only available. Each sheet is for one anodizing tank in one shift, this means for each working day there should be eight log sheets (four anodizing tanks per shift). In some days it could be less, because only two or three anodizing tanks are in operation while the others are not. Despite the reason of why some of the tanks are used or not, this does not prevent to use the data for the simulation model, because the algorithm will assume that all the tanks are ready to be used, of course, this will produce different schedule from the actual schedule as the algorithm may use a tank which was not in operation in the actual plant.

Since the data is distributed into several sheets, it had to be compiled into one single sheet and then the jobs are sorted based on the time at which they enter the anodizing stage. This sorting will be used as an indication of the sequence of the jobs (job priorities), i.e. the first job that enters the anodizing stage in the actual production will be considered a job with priority no.1, and so on for the rest of the jobs.

### **3.7.2 Constructing the simulation runs**

The purpose of this sub-section is to define and construct the combination that will be used of the simulation model for each day, where each day will be simulated with these different combinations. Some of the terms will be clarified later in Chapter 5 where the algorithm is explained in more details.

The simulation runs are divided into three phases:

Phase 1: Validation Runs

Phase 2: Experimentation Runs

Phase 3: Further Experimentation Runs

#### **a) Objectives of the phases**

The objective of phase 1 is validating the obtained results of the simulation algorithm for the starting and finishing times at the anodizing stage with the actual ones by comparing the difference between the two times for all the jobs. The comparison will be limited on the anodizing stage only because it is the only stage with available data.

After, validating the results, the objective of the second phase is to study the effect of changing the sequence (jobs sequence) and the configuration (adding more tanks) on the makespan, also to determine the required number of anodizing tanks and hot sealing tanks to overcome the problem of hot sealing bottleneck.

The objective of phase 3 is to test the ability of the algorithm to treat more jobs in the reaming time left after minimizing the makespan, till the end of the two shifts (16 hours).

Each run is defined by the selected day number, the sequence of the jobs (sequence number) and the number of the additional anodizing tanks and the additional hot sealing tanks (configuration number). The sequence and the configuration in phase 1 are the actual ones, while in the other phases they are changed.

## **b) Sequences**

The sequence of the jobs is the order in which the jobs enter the first chemical treatment (Alkaline). In this study, three types of job sequencing methods are used in the simulation model.

### **Sequence 1: The Actual Sequence**

This is taken from the order in which the jobs enter the anodizing stage, assuming it is the same order in which the jobs enter the first chemical treatment. The reason for this assumption is that the stages that could have been skipped are only the desmutting stage and the following rinsing stages which are short treatment durations.

### **Sequence 2: Lowest Recipe ID First (LRIDF).**

The second sequencing method is ordering the jobs' entry to the first chemical treatment in ascending order of their recipe ID. This sequence serves the job with the lowest recipe ID first, as the recipes with lowest recipe ID are considered for short processing time recipes.

### **Sequence 3: Highest Recipe ID First (HRIDF).**

The third sequencing method is ordering the jobs' entry to the first chemical treatment in descending order of their recipe ID. This sequence serves the job

with the highest recipe ID first, as the recipes with highest recipe ID are considered for long processing time recipes.

These sequences will be explained and illustrated in Chapter 5 in details.

### **c) Configurations**

As for the number of tanks for the anodizing and hot sealing stages, three configurations are considered in the simulation model. The first configuration is the actual number of tanks (the real plant configuration), the other two configurations have more anodizing and hot sealing tanks. The added new tanks replace some of the positions in the simulated plant because they are not used in the actual configuration. Table (3.14) shows the actual anodizing and hot sealing tanks and the positions which are used to add new anodizing and hot sealing positions, along with the reason of why these positions were used to add the new tanks. The main reason for replacing some positions with new tanks is to avoid changes in the numbering of the positions for the different configurations in the simulation model, because if the new tanks were added in-between the actual positions, then the following position have to be re-numbered, which would complicate the algorithm flow.

In Table (3.14), the hot sealing duration can be one of three durations (60, 45 or 20 minutes), however, the reason for choosing 20 minutes for the additional hot sealing tanks because it is common duration for the simulated days in years 2015 and 2017.

Table (3.14): Replaced Positions for Additional Anodizing and Hot Sealing Tanks

| Position | Stage of the Position<br>(minutes of treatment) |                             | Reason for Replacing the Actual Position                                                                                                                                      |
|----------|-------------------------------------------------|-----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|          | Actual Position                                 | Replaced with               |                                                                                                                                                                               |
| 30       | Anodizing *                                     | Unchanged *                 | -                                                                                                                                                                             |
| 31       | Anodizing *                                     | Unchanged *                 | -                                                                                                                                                                             |
| 33       | Anodizing *                                     | Unchanged *                 | -                                                                                                                                                                             |
| 34       | Anodizing *                                     | Unchanged *                 | -                                                                                                                                                                             |
| 36       | Anodizing<br>Rinsing (1)                        | Anodizing *                 | Not used much.                                                                                                                                                                |
| 43       | Hot Sealing<br>(20, 45 or 60)                   | Unchanged<br>(20, 45 or 60) | -                                                                                                                                                                             |
| 44       | Hot Sealing<br>(20, 45 or 60)                   | Unchanged<br>(20, 45 or 60) | -                                                                                                                                                                             |
| 45       | Hot Sealing<br>(20, 45 or 60)                   | Unchanged<br>(20, 45 or 60) | -                                                                                                                                                                             |
| 46       | Hot Sealing<br>(20, 45 or 60)                   | Unchanged<br>(20, 45 or 60) | -                                                                                                                                                                             |
| 47       | Output Buffers<br>(+10)                         | Hot Sealing<br>(20)         | According to the results of phase 1, 3 out of the 12 buffers are used, the rest are not, thus replacing two buffers with two hot sealing will not affect the production flow. |
| 48       | Output Buffers<br>(+10)                         | Hot Sealing<br>(20)         |                                                                                                                                                                               |

\* depends on the type of the job

Table (3.15) illustrates the three configurations that will be used in the simulation model, by comparing the total number of anodizing tanks and hot sealing with their associated position number.

Table (3.15): Tanks Configurations

| <b>Configuration</b> | <b>Num. of Anodizing Positions</b> | <b>Anodizing Positions</b> | <b>Num. of Hot Sealing Positions</b> | <b>Hot Sealing Positions</b> |
|----------------------|------------------------------------|----------------------------|--------------------------------------|------------------------------|
| <b>1</b>             | 4                                  | 30, 31, 33, and 34         | 4                                    | 43, 44, 45, and 46           |
| <b>2</b>             | 5                                  | 30, 31, 33, 34, and 36     | 5                                    | 43, 44, 45, 46, and 47       |
| <b>3</b>             | 5                                  | 30, 31, 33, 34, and 36     | 6                                    | 43, 44, 45, 46, 47, and 48   |

#### **d) Combinations**

As mentioned earlier each run is defined by the day number, the sequence number, and the configuration number. The combination of sequence and configuration is referred to as “combination” in this thesis.

In the validation phase, the actual set-up (current) is used, where each run is represented by the day number, sequence 1 and configuration 1. In the experimentation phase, eight combinations are tested by changing the sequence and the configuration. Table (3.16) shows the nine possible combinations that are simulated for each day, this means there are 108 runs (12 days  $\times$  9 combinations) for both phases 1 and 2.

Table (3.16): Different Combinations of Sequences and Configurations

| Combination No. | Sequence No. | Configuration No. | Phase in which it is applied | Number of runs per combination | Number of runs per phase |
|-----------------|--------------|-------------------|------------------------------|--------------------------------|--------------------------|
| 1               | 1            | 1                 | 1                            | 12                             | 12                       |
| 2               | 1            | 2                 | 2                            | 12                             | 96                       |
| 3               | 1            | 3                 | 2                            | 12                             |                          |
| 4               | 2            | 1                 | 2                            | 12                             |                          |
| 5               | 2            | 2                 | 2                            | 12                             |                          |
| 6               | 2            | 3                 | 2                            | 12                             |                          |
| 7               | 3            | 1                 | 2                            | 12                             |                          |
| 8               | 3            | 2                 | 2                            | 12                             |                          |
| 9               | 3            | 3                 | 2                            | 12                             |                          |
|                 |              |                   | <b>Total</b>                 | <b>108</b>                     | <b>108</b>               |

Table (3.17) shows the differences among the nine combinations by stating the differences in sequences and configurations

In the third phase, extra experimentations are carried out, for a maximum number 24 runs (12 days  $\times$  2 combinations), where two combinations are selected, these two combinations are:

- Configuration 1 and Sequence 1.
- Configuration 1 and the sequence with minimum makespan

In case the sequence with minimum makespan happens to be sequence 1, then that day will have one run in phase 3.

Table (3.17): The Differences among the Nine Combinations

| Comb. | Sequence                                                   | Configuration                                 |
|-------|------------------------------------------------------------|-----------------------------------------------|
| 1     | Actual Sequence<br>(Recipe ID not related)                 | +0 Anodizing &<br>+0 Hot Sealing (20 minutes) |
| 2     | Actual Sequence<br>(Recipe ID not related)                 | +1 Anodizing &<br>+1 Hot Sealing (20 minutes) |
| 3     | Actual Sequence<br>(Recipe ID not related)                 | +1 Anodizing &<br>+2 Hot Sealing (20 minutes) |
| 4     | Lowest Recipe ID First<br>(Ascending Order of Recipe ID)   | +0 Anodizing<br>+0 Hot Sealing                |
| 5     | Lowest Recipe ID First<br>(Ascending Order of Recipe ID)   | +1 Anodizing &<br>+1 Hot Sealing (20 minutes) |
| 6     | Lowest Recipe ID First<br>(Ascending Order of Recipe ID)   | +1 Anodizing &<br>+2 Hot Sealing (20 minutes) |
| 7     | Highest Recipe ID First<br>(Descending Order of Recipe ID) | +0 Anodizing<br>+0 Hot Sealing                |
| 8     | Highest Recipe ID First<br>(Descending Order of Recipe ID) | +1 Anodizing &<br>+1 Hot Sealing (20 minutes) |
| 9     | Highest Recipe ID First<br>(Descending Order of Recipe ID) | +1 Anodizing &<br>+2 Hot Sealing (20 minutes) |

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# **Chapter Four**

## **Mathematical Model Formulation**

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**4.1. Introduction**

**4.2. The Notations**

**4.3. The Mathematical Model**

# **Chapter Four**

## **Mathematical Model Formulation**

### **4.1. Introduction**

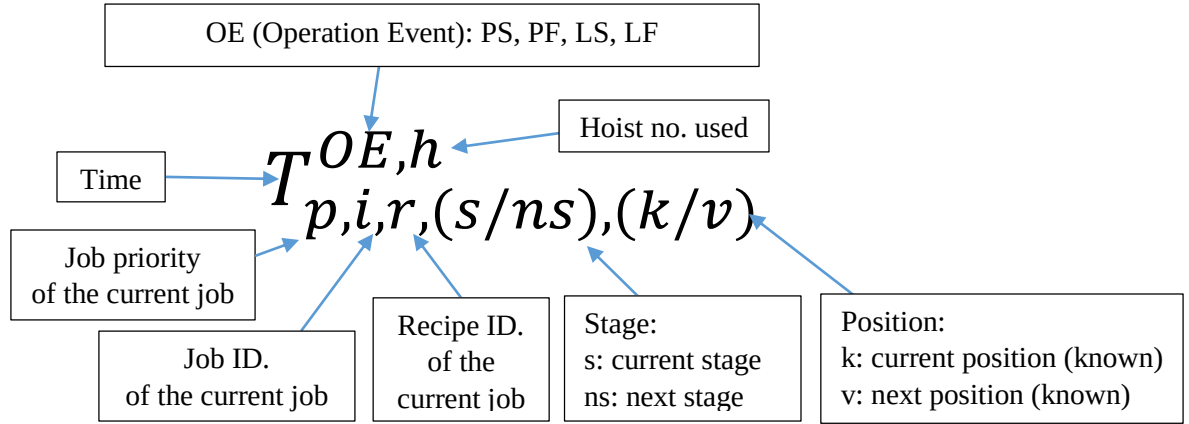
The mathematical model is composed of an objective function and a set of constraints that express the time events and their constraints, the constraints will form the basic equations needed for the algorithm to run the simulation model. However, the used notations in this chapter are quite different from the notations used for the algorithm. The reason for this is because the notations in this chapter are more general to describe the system constraints, while the notations used for the algorithm in Chapter 5 are simplified to understand the flow of the algorithm.

Before developing the equations of the model, the notations which are used to formulate the model are presented.

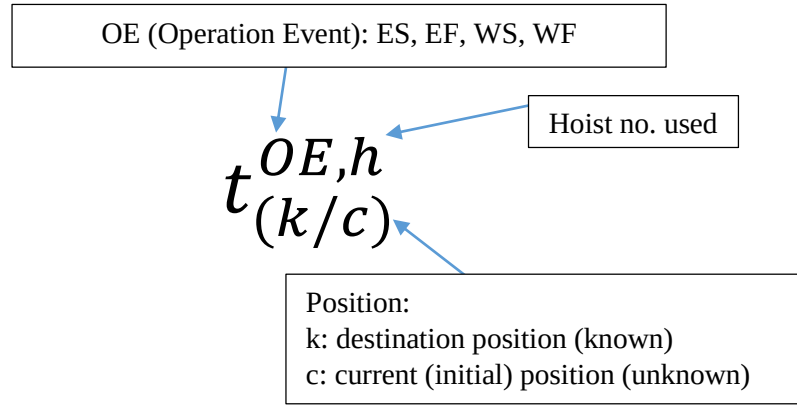
### **4.2. The Notations**

Two main notations are used, one is the time indicator of an operation event where the operation is either a treatment or a loaded hoist movement. The other notation is time indicator of an operation event of an empty hoist move or a waiting hoist. The reason for making these two types of notations is because in some cases the empty hoist move has to come from an unknown position. The position from which an empty hoist comes from is said to be unknown, because the algorithm takes the duration of any empty hoist move or any waiting hoist to take 20 seconds, regardless of its initial position; however, in the mathematical model, it should be determined

The Notation used for the time indicator of treatment or loaded hoist move is:



The Notation used for the time indicator of an empty hoist move or a waiting hoist is:



Where:

- **Jobs:**  $i = (1, 2, 3, \dots, n)$ , where  $n$  is the last priority job.
- **Recipes:**  $r = \{1, 2, 3, \dots, 30\}$ , there are 30 recipes.
- **Stage:**  $s/ns = (1/ 2/ 3/ \dots/ 27)$ , where 27 is the last stage (unloading) for all the recipes, yet some of the stages are skipped for some recipes.
- **Position:**  $k/v = \{1, 2, 3, \dots, 60\}$ , there are 60 positions.  
 $v = f(r\_type, ns)$ .

The next position is ( $v$ ) a depending on two variables: the recipe type and the next stage.

- **Event:**  $OE = \{PS/PF/LS/LF/ES/EF\}$

There are four types of operations, both have a starting event and finishing event:

$PS$  : Process (Treatment) Start

$PF$  : Process (Treatment) Finish

$LS$  : Loaded hoist move Start

$LF$  : Loaded hoist move Finish

$ES$  : Empty hoist move Start

$EF$  : Empty hoist move Finish

$WS$  : Waiting hoist Start

$WF$  : Waiting hoist Finish

The waiting hoist is an empty hoist but in a stop condition.

- **Hoist:**  $h = \{1/2/3/4/5/6\}$ , if the operation is a hoist operation, there are 5 possible hoists, the sixth hoist is an imaginary hoist that carries the jobs from Outside stage to the Loading stage.

### 4.3. The Mathematical Model

The mathematical model is composed of an objective function and list of constraints, due to the complexity of some of the constraints, alternative constraints replaced them.

### 4.3.1 The objective function

The objective function is to minimize the make-span (the finishing time of the last job at the last stage), the last stage is the Unloading (stage no. 27).

$$C_{max} = \min_{\forall \text{ Possible Sequences}} (\max_{\forall i} (T_{n,i,r,27,k}^{PF,h})) \quad (4.1)$$

Where:  $C_{max}$  is the makespan, the job with the maximum finishing time at the last stage (stage no. 27).

The possible job sequences is set to be the tuning parameter (changing the jobs priorities) to obtain the minimum makespan. Another tuning parameter could be testing all the alternative hoists movements, but it was not considered due to its complexity.

### 4.3.2 Constraints of job routing

- The fishing time of a treatment in a position is expressed by constraints (4.2)

$$T_{p,i,r,s,k}^{PF} = T_{p,i,r,s,k}^{PS} + d_{r,s}^P \quad (4.2)$$

Where:

$T_{p,i,r,s,k}^{PF}$ : is the finishing time of the current job at the current stage (s) at position (k)

$T_{p,i,r,s,k}^{PS}$ : is the starting time of the current jobs at the current stage (s) at position (k), the starting time of the current stage is the time in which the loaded hoist arrives at this stage from a previous stage, while the starting time of any starting stage is equals 20 seconds.

Also, the finishing time ( $T_{p,i,r,s,k}^{PF}$ ) is the same time for an empty hoist move when it arrive at this position (k), as descried in constraint (4.3).

$d_{r,s}^P$ : is the duration for the current process with recipe no. (r) at the  $s^{th}$  stage.

- An Empty hoist should be available at the position ( $k$ ), where the current job is about to finish. This means that the empty hoist should be present at the same or before the finishing time of the treatment that about to finish as expressed by constraint (4.3).

$$t_k^{(E/W)F,h} \leq T_{p,i,r,s,k}^{PF} \quad (4.3)$$

Where:

$t_k^{(E/W)F,h}$ : is the time when the empty hoist is stopped to pick-up the current job from position ( $k$ ).

$T_{p,i,r,s,k}^{PF}$ : is the time when the current job is finished in position ( $k$ ).

There are two possible scenarios for the arrived empty hoist, either it was waiting at position ( $k$ ) for some amount of time, or it came from another position say position ( $c$ ) (empty hoist move), constraint (4.4) shows these two possibilities.

$$t_k^{(E/W)F,h} = \begin{cases} t_k^{WF,h} \\ t_k^{EF,h} \end{cases} \quad (4.4)$$

Where:

$$t_k^{WF,h} = t_k^{WS,h} + d_k^{W,h} \quad (4.5)$$

$$t_k^{EF,h} = t_c^{ES,h} + d_{c \rightarrow k}^{E,h} \quad (4.6)$$

$d_k^{W,h}$ : is the waiting duration in which hoist ( $h$ ) has to wait at position ( $k$ ) to pick-up the current job.

$d_{c \rightarrow k}^{E,h}$ : is the duration for the empty hoist move from position ( $c$ ) to position ( $k$ ).

For Constraint (4.5), there are two possibilities for the starting time for the waiting hoist, these two possibilities are given in constraint (4.7).

$$t_k^{WS,h} = \begin{cases} T_{p,i,r,s,k}^{LF,h} \\ t_k^{EF,(h/h')} \end{cases} \quad (4.7)$$

Where:

$T_{p,i,r,s,k}^{LF,h}$ : is the time when the hoist has loaded (dipped) the current job in position ( $k$ ). If ( $t_k^{WS,h} = T_{p,i,r,s,k}^{LF,h}$ ), it means the hoist was waiting at position ( $k$ ) for the entire treatment duration of the current job.

$$t_k^{EF,(h/h')} = \min_{\forall h} (t_c^{ES,h} + d_{c \rightarrow k}^{E,h}, t_{c'}^{ES,h'} + d_{c' \rightarrow k}^{E,h'}) \quad (4.8)$$

Constraint (4.8) implies that the hoist that will be assigned for the empty move and pick-up the current job from position ( $k$ ), is the hoist closest to position ( $k$ ), i.e. the minimum empty hoist duration.

On the other hand, for Constraint (4.6), there are two possibilities for the starting time of an empty hoist move. Constraint (4.9) these two possibilities, either it was waiting at position ( $c$ ), or it loaded another job in position ( $c$ ) for another job ( $i'$ ).

$$t_c^{ES,h} = \begin{cases} t_c^{WF,h} \\ T_{p',i',r',s',c}^{LF,h} \end{cases} \quad (4.9)$$

Where:

$t_c^{WF,h}$ : is the time when the hoist start waiting at position ( $c$ ), which has the same equation in constraint (4.5), but it is for position ( $c$ ) instead of ( $k$ ).

$T_{p',i',r',s',c}^{LF,h}$ : is the time when a hoist has just dipped a job in position ( $c$ ).

To sum-up what can be drawn from constraints (4.3) to (4.9) is that a hoist path is a combination of partial jobs routs, empty moves, and waiting durations. The constraints also tell that the empty move involves two positions with two different jobs, and since the algorithm is dealing with one job at a time (as explained in Chapter 5), applying the constraints (4.3) to (4.9) is difficult. Even if the hoists status are saved every time (i.e. their location and whether they are busy or idle), so the last position at which each hoist stopped at can be referred to, there still difficulty in how to link the partial routs of different jobs to draw the hoist path with respecting all the constraints.

- Because of such difficulty, the constraints (4.3) to (4.9) are replaced with an alternative constraint. Constraint (4.10) says for every treatment operation 20 seconds are reserved before the treatment finishes.

$$t_c^{(E/W),h} = T_{p,i,r,s,k}^{PF} - d_{c \rightarrow k}^{(E/W),h} \quad (4.10)$$

Where:

$$d_{c \rightarrow k}^{(E/W),h} = 20 \text{ seconds}$$

This 20 seconds duration is reserved for any empty hoist is moving to position ( $k$ ), regardless of the initial position and/or for any waiting hoist at position ( $k$ ). The duration was estimated to be 20 seconds as a rough average of all the possible empty hoist durations.

Once the job is finished in a position, the hoist starts unloading (picking up) the job out from the position, constraint (4.11):

$$T_{p,i,r,s,k}^{LS,h} = T_{p,i,r,s,k}^{PF} \quad (4.11)$$

The time when a load job arrives at the next position is given in (4.12).

$$T_{p,i,r,s,v}^{LF,h} = T_{p,i,r,s,k}^{LS,h} + \text{pickup time} + d_{k \rightarrow v}^{L,h} + \text{dipping time} \quad (4.12)$$

Where:

$T_{p,i,r,s,v}^{LF,h}$ : is the loaded job finishing time to pick up the job from position ( $k$ ), move and drop the job at position ( $v$ ).

$$\text{pickup time} = \begin{cases} 15 \text{ seconds, if the position is not a tank} \\ 20 \text{ seconds, if the position is a tank} \end{cases}$$

$$\text{dipping time} = 15 \text{ seconds, for any position}$$

$d_{k \rightarrow v}^{L,h}$ : is the duration for the loaded hoist to move from position ( $k$ ) to position ( $v$ )

The next treatment starts once the dipping is done:

$$T_{p,i,r,ns,v}^{PS} = T_{p,i,r,s,v}^{LF,h} \quad (4.13)$$

Where:

$T_{p,i,r,ns,v}^{PS}$ : is the starting time of the current job at the next stage ( $ns$ ) at position ( $v$ ).

Then Equation given in (4.2) is applied for the next stage

The aim of the constraints (4.2) to (4.13) is to make sure that every job route does not include any waiting duration, thus not violating one of the main constraint of HSP, which is the jobs should not wait between the stages. This is excluding the waiting stages where the waiting durations keep increasing as long as increasing delays are necessary, as explained in Chapter 5.

### 4.3.3 Blocking constraints

Blocking constraints are about avoiding two jobs to be served by the same facility at the same time. Let's assume there are two jobs ( $i$  and  $i'$ ), where each job has the following recipe, stage, and position:

| Job Priority  | Job ID | Recipe | Stage | Position |
|---------------|--------|--------|-------|----------|
| $p$ (current) | $i$    | $r$    | $s$   | $k$      |
| $p'$ (old)    | $i'$   | $r'$   | $s'$  | $k'$     |

There are two types of facilities:

#### Positions:

The only thing to do to avoid having two jobs being treated in the same position and at the same time is to finish treating the first job and then to start treating the second job. This can be achieved by the inequalities in constraints (4.14).

$$T_{p,i,r,s,k}^{PS} > T_{p',i',r',s',k'}^{PF}, \quad \text{For all } i \quad (4.14)$$

Where  $k' = k$ , position ( $k'$ ) is position ( $k$ ), i.e. same position.

#### Hoists:

Blocking the hoist for one job is achieved by loading (dipping) the first job in position  $k$ , and then unloading (picking-up) the second job from position  $k'$ . This can be achieved by the inequalities in constraints (4.15)

$$T_{p,i,r,s,k}^{LS,h'} > T_{p',i',r',s',k'}^{LF,h} + d_{k' \rightarrow k}^{E,h} \quad (4.15)$$

Where  $h = h'$ , hoist ( $h'$ ) is hoist ( $h$ ), i.e. same hoist.

#### 4.3.4 Hoists ranges constraints

Each hoist has a limited range to move above certain positions, so if:

$$h = 1: (2 \leq k \leq 8) \text{ and } (47 \leq k \leq 60) \quad (4.16)$$

$$h = 2: (9 \leq k \leq 27) \quad (4.17)$$

$$h = 3: (23 \leq k \leq 30) \quad (4.18)$$

$$h = 4: (28 \leq k \leq 37) \quad (4.19)$$

$$h = 5: (38 \leq k \leq 57) \quad (4.20)$$

The sixth hoist does not need a constraint, because it is vicious hoist used for movements from outside position to the loading stage, because none of the ranges above falls under  $(1 \leq k \leq 4)$ .

#### 4.3.5 Hoist collision constraints

Hoist collision could occur when two hoists happen to be near to each other (space between the two is less than two positions) and at the same time. Hoist collisions are only possible in the overlap zones, and it cannot happen in anywhere else out of the overlap zones.

To avoid hoist collision, the hoist should be away from each other by a safety gap, this safety gap is the distance of more than the width of one position, this means a gap of one position or less means a collision will happen (see Figure (4.1)).

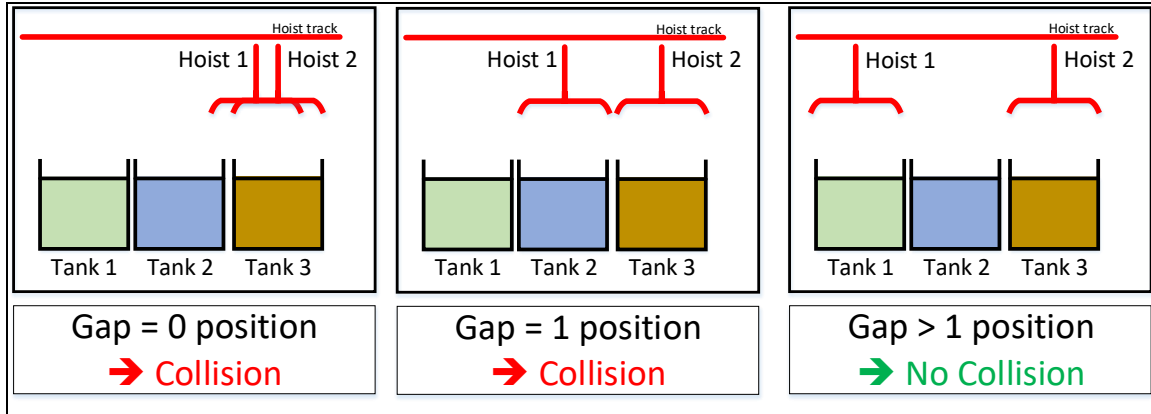


Figure (4.1): Safety Gap to Avoid Hoist Collision

Assume there are two hoists ( $h$  and  $h'$ ), hoist ( $h'$ ) was assigned for a previous move (loaded/empty) in the past, while hoist ( $h$ ) is assigned to do a current move (loaded/empty). Since hoist ( $h'$ ) did its move in the past, this means this move is already done and cannot be changed (delayed) in time, while that of hoist ( $h$ ) can be delayed because it is not checked yet. While the current hoist ( $h$ ) is moving from position ( $k$ ) to position ( $v$ ) it must be far from hoist ( $h'$ ) by at least one position. Figures (4.2 (a and b)) and (4.3 (a and b)) illustrate two cases of hoists collisions and the corrections needed (i.e. delay starting time of hoist ( $h$ )) to prevent collision. Appendix (1) illustrates another eight cases.

For the sake of simplicity, the safety duration in the second case is not considered, because any previous hoist move will already be blocked by the algorithm (as explained in Chapter 5). Thus, the constraints (4.21) and (4.22) are enough to prevent hoist collision by the current hoist ( $h$ ), where constraint (4.21) is for the starting position (position  $k$ ) for the current hoist ( $h$ ) and constraint (4.22) is for the finishing position (position  $v$ ) for the current hoist ( $h$ ).

The meaning of constraint (4.21) is that starting time of the current hoist ( $h$ ) move (whether it was loaded or empty) should not be from position ( $k$ ) during the period when hoist  $h'$  is blocked at positions ( $k - 1, k$  or  $k + 1$ ).

Similarly, for constraint (4.22) for the finishing time of the current hoist ( $h$ ), the hoist should not finish at position ( $v$ ) during the period when hoist ( $h'$ ) is blocked at positions ( $v - 1, v$ , or  $v + 1$ ).

$$t_k^{(LS/ES),h} > t_{k'}^{(LS/LF/ES/EF),h'}, \text{ where } k' \neq k - 1/k/k + 1 \quad (4.21)$$

$$t_v^{(LF/EF),h} > t_{v'}^{(LS/LF/ES/EF),h'}, \text{ where } v' \neq v - 1/v/v + 1 \quad (4.22)$$

However, in the actual plant, it is not necessary that:

$$t_k^{(LS/ES),h} > t_{k'}^{(LS/LF/ES/EF),h'}$$

Or

$$t_v^{(LF/EF),h} > t_{v'}^{(LS|LF|ES|EF),h'} .$$

|        | Collision/No Collision                                                                                                                                                                                      | Correction                                                                                                                  |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| Case 1 | <p><b>No Safety Gap</b></p>                                                                                                                                                                                 | <p><b>Safety Gap</b></p>                                                                                                    |
|        | <p><b>Collision:</b></p> <p>Hoist (<math>h'</math>) ends at <math>k - 1</math> and hoist (<math>h</math>) starts at <math>k</math> at the same time.</p> <p>The gap between the two hoists is not safe.</p> | <p><b>Correction:</b></p> <p>Delay starting of hoist (<math>h</math>) by 5 seconds (<math>2 \times 2.5</math> seconds).</p> |
|        | Figure (4.2 (a)) Collision of Two Hoists at Neighbouring Positions                                                                                                                                          | Figure (4.2 (b)) Correction for Collision of Two Hoists at Neighbouring Positions                                           |

|        | Collision/No Collision                                                                                                                                                                                                                                               | Correction                                                                                                                                                             |
|--------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case 2 | <p><b>Collision:</b></p> <p>Hoist (<math>h'</math>) ends at <math>k + 1</math> and hoist (<math>h</math>) starts at <math>k</math>, but hoist (<math>h'</math>) did not have enough time to move away. The safety duration between the two hoists is not enough.</p> | <p><b>Correction:</b></p> <p>Delay starting of hoist (<math>h</math>) by 15 seconds (<math>6 \times 2.5</math> seconds), until hoist (<math>h'</math>) moves away.</p> |
|        | Figure (4.3 (a)): Collision of Two Hoists Crossing Each Other                                                                                                                                                                                                        | Figure (4.3 (b)): Correction for Collision of Two Hoists Crossing Each Other                                                                                           |

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# **Chapter Five**

## **The Scheduling Algorithm**

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**5.1. Introduction**

**5.2. Scheduling Approach of the Algorithm**

**5.3. Data Files of the Algorithm**

**5.4. Structure of the Algorithm**

# **Chapter Five**

## **The Scheduling Algorithm**

### **5.1. Introduction**

As it was explained in Chapter 3, the scheduling type for the problem in this study is PHSP, because the jobs list with their recipes are given. A simple heuristic algorithm is chosen to schedule the jobs of a specific period for minimum makespan without consideration of breakdowns.

The algorithm idea is based on dealing with each job individually, and whenever a stage is done successfully (without the violation of the constraints), that stage is blocked during the time period when the current job is being treated. On the other hand, if there is a violation, then this current job is returned to the latest waiting stage, where it is delayed for 20 seconds and the procedure repeated again until it successfully finishes the last stage (unloading stage).

The Algorithm is coded using Matlab R2015b editor and run using an Intel (R) Core (TM) processor with a speed of (2.00 GHz to 2.60 GHz) and with a RAM memory size of 8.00 GB. The reason the coding is done with Matlab editor is for the easiness to deal with matrices, which are the basic tools of the algorithm. Two-Dimensional matrices, namely (positions no  $\times$  units of time), (hoist no.  $\times$  units of time) and others used as schedule baseline to track the movement of the jobs in the plant as they proceed with their treatments.

## 5.2. Scheduling Approach of the Algorithm

The algorithm works by blocking the positions and the hoists whenever they are used to deal with a current job successfully (without violating the constraints), it starts scheduling the first priority job alone from the “Input Buffers Zone 2” stage until the Unloading stage. As it does so the starting time and the finishing time for each stage are calculated.

When it comes to the second job and the rest of the jobs, the starting times indicators of the previous job are reset to zero, so these time indicators are used for the new job, also the algorithm must obey the blocking constraints and the hoist constraints once it is done from the first job. It must check the availability of a next position for the current job and the availability of a hoist to move the job, only then the algorithm can block the current stage.

In case one of the constraints is violated, then the current job is returned to the latest visited waiting stage where it will be delayed for 20 seconds. This also means that the algorithm will un-block all the schedule done for the current job from the time the empty hoist move is started to pick-up the current job from the latest waiting stage to the time when the violation occurred. After the 20 seconds delay, the procedure is resumed until the job completes all the stages without violations.

Figure (5.1) illustrates the basic idea of how the algorithm is going to work in case of violation of constraint (4.14) (the position blocking constraint in sub-section 4.3.3) between two jobs only. In the figure, there is only one waiting stage (Buffer Zone), one tank per stag, one hoist and three jobs. This example shows the actions taken in case of violating the position blockage constraint, other constraints such as loaded hoist constraints are not illustrated here.

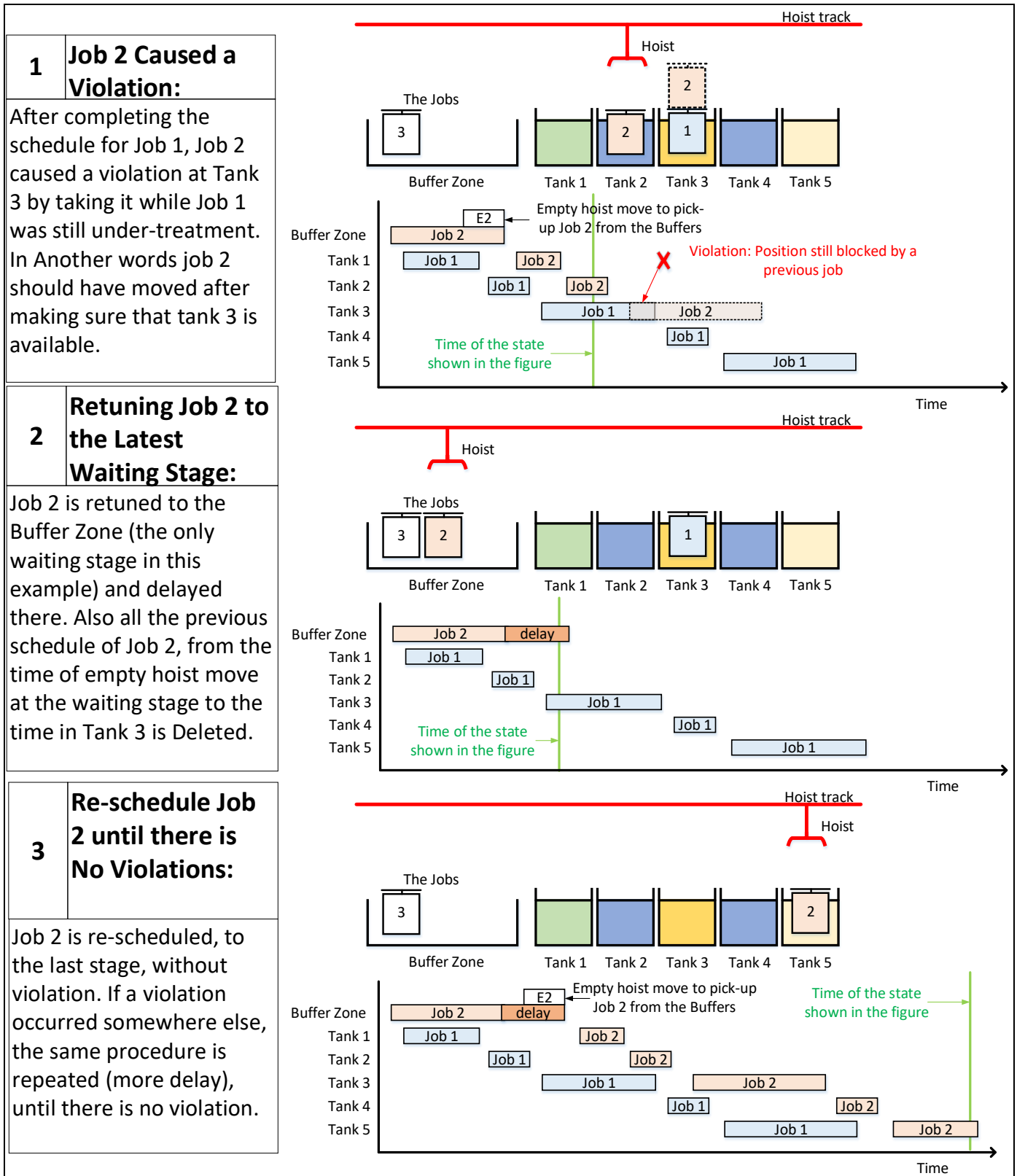


Figure (5.1): Simplified Example for the Algorithm in Case of Position Blockage Violation

The current job in the figure is job 2, while job 1 is considered as a previous job which is already been scheduled successfully without violations. Job 2 is let to stay in the buffer zone for some time before it moves to the first tank, at the time it is placed in Tank 3 it overlaps with job 1, in other words, job 2 is placed in Tank 3 while job 1 is still under-treatment. To overcome this violation, job 2 has to be returned to the latest waiting stage (Buffer Zone) and all the previous schedule of job 2 (history) is deleted from the time the empty hoist pick job 2 from the buffer to the time of the violation.

This violation could have been avoided if there is a parallel tank (double tank) as Tank 3. As for the waiting stage, if there is another waiting stage which job 2 visited after the one which shown in the figure, then the deletion would happen at the latest waiting stage that job 2 visited, while all the previous schedule is saved and not deleted.

### **5.3. Data Files of the Algorithm**

The required main data files are for the algorithm can be categorized into three categories:

- a) Main Inputs Data File.
- b) Daily Inputs Data File for each sequence.
- c) Outputs File per Run.

### **a) Main Inputs Data File:**

Main input data file is an excel file where the orders are listed along with their specifications:

- Day number
- Sequence of the jobs (identified by a number)
- Configuration of the tanks (identified by a number)
- Total number of jobs
- The real makespan at the anodizing stage (in seconds)
- Name of the input file
- Name of the results file

### **b) Daily Inputs Data File for each sequence**

For each day and for each sequence of jobs, there is an excel file that details the following information for each job based on the job priority. The job priority is sorted based on the order in which the jobs enter the system (the first chemical treatment), assuming it is the same order in which the jobs enter the anodizing stage.

- Priority
- Starting Location (Starting Position)
- Starting Stage
- Job ID
- Recipe ID
- Anodizing Treatment Duration (Real)
- Real\_TPS: the real starting time at the anodizing stage.
- Real\_TPF: the real finishing time at the anodizing stage.

As discussed earlier in sub-section 3.7.2, there are three sequencing rules to be tested in this study, these rules are used to order the job entry to the first chemical treatment, in another word prioritizing the jobs. The sequencing rules are the Actual Sequence, the Lowest Recipe ID First (LRIDF) and the Highest Recipe ID First (HRIDF).

The actual sequence is based on the real order by which the jobs enter the anodizing stage, assuming it is the same order in which the jobs entered the first chemical treatment. On the other hand, the other two rules are based on the ascending and the descending order of the jobs' recipes ID. In the LRIDF and the HRIDF sequences, the corresponding Job ID and the corresponding real anodizing duration changes along with the recipe ID (this does not mean that the anodizing durations are sorted in ascending order or in the descending order), as they are part of the job inherited properties. The other properties of the job which are the starting position and the starting stage are fixed and do not change as the order of the recipe ID changes.

Tables (5.1), (5.2) and (5.3) represent examples for these three sequences by showing part of a full table that lists the jobs for a given day (in this example there are 53 jobs).

In all of the three sequences, the starting positions are the initial positions where the jobs are placed when the simulation time = 0 seconds (00:00:00 hr). The first eight (8) priority jobs are placed in Input Buffer Zone 2 stage (stage no. 5), the following three (3) priority jobs are placed in Input Buffer Zone 1 stage (stage no 3), the three priority jobs that comes after are placed in the loading stations (stage no. 2), and the remaining priority jobs are placed outside the process line (stage no.1).

The reason for placing jobs at the input buffer zones and the loading stations at the beginning of the simulation is to save time needed for loading all the jobs.

Also, most of the working days in the real plant usually start with already loaded jobs waiting at the buffers from the previous day.

Table (5.1): Example of the Actual Sequence

| Priority | Starting Position. | Starting Stage | Job ID | Recipe ID | Anodizing (seconds) | Anodizing Real TPS | Anodizing Real TPF |
|----------|--------------------|----------------|--------|-----------|---------------------|--------------------|--------------------|
| 1        | 10                 | 5              | 1      | 3         | 2760                | 6:41:00            | 7:27:00            |
| 2        | 11                 | 5              | 2      | 3         | 2100                | 6:51:00            | 7:26:00            |
| 3        | 12                 | 5              | 3      | 6         | 1620                | 7:18:00            | 7:45:00            |
| 4        | 13                 | 5              | 4      | 3         | 1680                | 7:20:00            | 7:48:00            |
| 5        | 14                 | 5              | 5      | 1         | 1980                | 7:40:00            | 8:13:00            |
| 6        | 15                 | 5              | 6      | 1         | 2220                | 7:46:00            | 8:23:00            |
| 7        | 16                 | 5              | 7      | 3         | 1680                | 8:00:00            | 8:28:00            |
| 8        | 17                 | 5              | 8      | 3         | 1620                | 8:00:00            | 8:27:00            |
| 9        | 5                  | 3              | 9      | 1         | 1980                | 8:30:00            | 9:03:00            |
| 10       | 6                  | 3              | 10     | 3         | 1680                | 8:48:00            | 9:16:00            |
| 11       | 7                  | 3              | 11     | 3         | 1620                | 9:00:00            | 9:27:00            |
| 12       | 2                  | 2              | 12     | 1         | 1980                | 9:09:00            | 9:38:00            |
| 13       | 3                  | 2              | 13     | 1         | 1680                | 9:27:00            | 9:55:00            |
| 14       | 4                  | 2              | 14     | 3         | 2220                | 9:39:00            | 10:12:00           |
| 15       | 1                  | 1              | 15     | 1         | 1860                | 9:47:00            | 10:18:00           |
| 16       | 1                  | 1              | 16     | 3         | 1620                | 10:28:00           | 10:55:00           |
|          |                    |                |        |           |                     |                    |                    |
| 53       | 1                  | 1              | 50     | 3         | 2100                | 20:32:00           | 21:07:00           |

Table (5.2): Example of the LRIDF Sequence

| Priority | Starting Position. | Starting Stage | Job ID | Recipe ID | Anodizing (seconds) |
|----------|--------------------|----------------|--------|-----------|---------------------|
| 1        | 10                 | 5              | 5      | 1         | 1980                |
| 2        | 11                 | 5              | 6      | 1         | 2220                |
| 3        | 12                 | 5              | 9      | 1         | 1980                |
| 4        | 13                 | 5              | 12     | 1         | 1980                |
| 5        | 14                 | 5              | 13     | 1         | 1680                |
| 6        | 15                 | 5              | 15     | 1         | 1860                |
| 7        | 16                 | 5              | 17     | 1         | 1920                |
| 8        | 17                 | 5              | 18     | 1         | 2100                |
| 9        | 5                  | 3              | 19     | 1         | 1920                |
| 10       | 6                  | 3              | 20     | 1         | 1620                |
| 11       | 7                  | 3              | 21     | 1         | 2100                |
| 12       | 2                  | 2              | 22     | 1         | 2100                |
| 13       | 3                  | 2              | 23     | 1         | 1680                |
| 14       | 4                  | 2              | 25     | 1         | 1920                |
| 15       | 1                  | 1              | 26     | 1         | 1680                |
| 16       | 1                  | 1              | 28     | 1         | 1920                |
| .....    |                    |                |        |           |                     |
| 53       | 1                  | 1              | 3      | 6         | 1620                |
| .....    |                    |                |        |           |                     |

Table (5.3): Example of the HRIDF Sequence

| Priority | Starting Position. | Starting Stage | Job ID | Recipe ID | Anodizing (seconds) |
|----------|--------------------|----------------|--------|-----------|---------------------|
| 1        | 10                 | 5              | 3      | 6         | 1620                |
| 2        | 11                 | 5              | 1      | 3         | 2760                |
| 3        | 12                 | 5              | 2      | 3         | 2100                |
| 4        | 13                 | 5              | 4      | 3         | 1680                |
| 5        | 14                 | 5              | 7      | 3         | 1680                |
| 6        | 15                 | 5              | 8      | 3         | 1620                |
| 7        | 16                 | 5              | 10     | 3         | 1680                |
| 8        | 17                 | 5              | 11     | 3         | 1620                |
| 9        | 5                  | 3              | 14     | 3         | 2220                |
| 10       | 6                  | 3              | 16     | 3         | 1620                |
| 11       | 7                  | 3              | 24     | 3         | 2280                |
| 12       | 2                  | 2              | 27     | 3         | 1620                |
| 13       | 3                  | 2              | 35     | 3         | 2220                |
| 14       | 4                  | 2              | 45     | 3         | 1500                |
| 15       | 1                  | 1              | 50     | 3         | 2100                |
| 16       | 1                  | 1              | 5      | 1         | 1980                |
| .....    |                    |                |        |           |                     |
| 53       | 1                  | 1              | 49     | 1         | 1800                |
| .....    |                    |                |        |           |                     |

### **c) Outputs file per run**

Each run has its own excel file defined by (day, sequence and configuration), where the results are exported from Matlab to this excel file, this file includes the following:

- 1) The BlockPosition Matrix
- 2) The HoistCarryJob Matrix
- 3) The BlockHoist Matrix
- 4) The TLS, TPF, TLS and TLF Matrices (Events Times Matrices – current stage (s) wise)
- 5) The TPF\_K and TPF\_K Matrices (Events Times Matrices – current position (k) wise)
- 6) Utilized Position
- 7) Utilized Hoist Matrix
- 8) Position Gantt Chart Matrix
- 9) Occupancy Matrix
- 10) Waiting Matrix
- 11) Validation Results

The details of these matrices are explained in Table (5.4).

Table (5.4): Details of the Used Matrices in the Algorithm

| Matrix                                    | Rows and Columns                                                      | Size                                                     | Objective and the Value(s) Used                                                                                                                                                                                      |
|-------------------------------------------|-----------------------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Duration Treatment (DT)</b>            | Row: recipe no.<br>Col: stage no.                                     | (Number of recipes , Number of stages) =(30 , 27)        | <b>Objective:</b><br>To refer to the treatment duration for a certain recipe in a certain stage.                                                                                                                     |
| <b>Hoist Movement Travel (MT) From-To</b> | Row: starting position no. (from)<br>Col: finishing position no. (to) | (Number of positions , Number of positions) = (60 , 60)  | <b>Objective:</b><br>To refer to the travel duration of a loaded hoist move from a certain position to another position.                                                                                             |
| <b>BlockPosition</b>                      | Row: position no.<br>Col.: one unit of time (second)                  | (Number of positions , Time Interval)<br>= (60 , 100000) | <b>Objective:</b><br>To block every second whenever a position is busy with a current job.<br><b>Blocking:</b><br>Position (TPS to TPF): JobID<br>Transferor : JobID + 100<br>Transferor Cartage Return: JobID + 200 |

Continue Table (5.4): Details of the Used Matrices in the Algorithm

| Matrix               | Rows and Columns                                      | Size                                                            | Objective and the Value(s) Used                                                                                                                                                                                                                                                                             |
|----------------------|-------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>BlockHoist</b>    | Row: hoist no.<br>Col.: one unit of time (one second) | (Number of<br>Hoists +1 , Time<br>Interval)<br>= (5+1 , 100000) | <b>Objective:</b><br>To block the time when the loaded hoist starts picking up ( <b>TLS</b> ) and the time when the loaded hoist ends dipping/dropping ( <b>TLF</b> ).<br><b>Blocking:</b><br><b>TLS</b> : the current position ( <b>k</b> )<br><b>TLF</b> : the next position ( <b>v</b> )                 |
| <b>HoistCarryJob</b> | Row: Hoist no.<br>Col.: one unit of time (one second) | (Number of<br>Hoists +1 , Time<br>Interval)<br>= (5+1 , 100000) | <b>Objective:</b><br>To block every second while a hoist is busy with a current job, including the preceding waiting or empty hoist move.<br><b>Blocking:</b><br>Loaded Hoist ( <b>TLS</b> to <b>TLF</b> ): <b>JobID</b><br>Waiting/Empty Hoist ( <b>TLS</b> – 20seconds to <b>TLS</b> ): <b>JobID</b> +300 |

Continue Table (5.4): Details of the Used Matrices in the Algorithm

| Matrix                                                                          | Rows and Columns                                     | Size                                                  | Objective and the Value(s) Used                                                                                          |
|---------------------------------------------------------------------------------|------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| <b>TPS, TPF, TLS and TLS</b><br>(Events Times Matrices – current stage (s) wise | Each one:<br>Row: Job priority<br>Col.: Stage no.    | (Number of Jobs , Number of Stages)<br>= (45+ , 27)   | <b>Objective:</b><br>To record the time when that event happened and the stage of that event.<br>(in seconds).           |
| <b>TPS_K and TPF_K</b><br>Events Times Matrices – current position wise         | Each one:<br>Row: Job priority<br>Col.: Position no. | Number of Jobs , Number of Positions) =<br>(45+ , 60) | <b>Objective:</b><br>To record the time when that event happened and the position at which it happened.<br>(in seconds). |

Continue Table (5.4): Details of the Used Matrices in the Algorithm

| Matrix                             | Rows and Columns                                                                                                                                                                                                                           | Size                                                             | Objective and the Value(s) Used                                                           |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| <b>Utilized Position</b>           | Row: Job priority<br>Col: Stage no.                                                                                                                                                                                                        | (Number of Jobs , Number of Stages)<br>= (45+ , 27)              | <b>Objective:</b><br>To indicate which position was used to process a job in every stage. |
| <b>Utilized Hoist</b>              | Row: Job Priority<br>Col: Stage no.                                                                                                                                                                                                        | (Number of Jobs , Number of Stages)<br>= (45 + , 27)             | <b>Objective:</b><br>To indicate which hoist was used to carry a job from every stage.    |
| <b>Position Gantt Chart Matrix</b> | Row: Position no.<br>Col: couple of gap and duration for each job, starting from the first priority job to last priority job.<br>Where gap is a period of time when the position is idle, and duration is when it is in occupied by a job. | (Number of Positions , (2 × Number of Jobs)<br>= (60 , 2 × 45 +) | <b>Objective:</b><br>To be used to plot the Gantt Chart for the positions in excel.       |

Continue Table (5.4): Details of the Used Matrices in the Algorithm

| Matrix                        | Rows and Columns                                                                                                                                                                                                                                                                                                                                                                                                                                             | Size                                                                                                      | Objective and the Value(s) Used                                                                                                                                                                    |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Used Percentage Matrix</b> | <p>Row: Position no.</p> <p>Col: there are four columns one used for the total treatment durations, one used for the gaps between treatments (i.e. total idle duration between the treatments without the first gap), one used for the first gap (the idle time from day starting till the position received the first job), and the last column is for the remaining time for each position, when the last received job finishes to the end of the day.</p> | <p>(Number of Positions , <math>2 \times \text{Number of Jobs}</math>)</p> <p><math>= (60 , 4)</math></p> | <p><b>Objective:</b></p> <p>To calculate and plot the total treatments duration, the gaps in between treatments, the first gap and the remaining time for each position as a percentage.</p>       |
| <b>Waiting Matrix</b>         | <p>Row: Job priority</p> <p>Col: Waiting Stage no.</p>                                                                                                                                                                                                                                                                                                                                                                                                       | <p>(Number of Jobs , Number of Waiting Stages)</p> <p><math>= (45+ , 5)</math></p>                        | <p><b>Objective:</b></p> <p>To calculate and plot the waiting duration spent in each waiting stage per job. In-addition to average and total waiting for each waiting stage and for every day.</p> |

## 5.4. Structure of the Algorithm

This section consists of two sub-sections. In the first sub-section, a general structure of the algorithm is explained along with some important notations used in the algorithm (refer to Appendix 2 for all the notations used in the algorithm). While in the second sub-section, a more detailed structure is given.

### 5.4.1 General structure

According to the algorithm, the anodizing process line is divided into five sections, this division is based on the waiting stages (stages where waiting is transition between main sections).

- 1) Section 1: from Outside the plant to the Loading Stage
- 2) Section 2: from the Loading Stage to Input Buffers 1
- 3) Section 3: from Input Buffers 1 to Input Buffers 2
- 4) Section 4: from Input Buffers 2 to Output Buffers
- 5) Section 5: from Output Buffers to the Unloading Stage

The waiting stages serve as checkpoints, so whenever a violation occurs, the violating job is returned to the last visited waiting stage.

Referring back to Chapter 3, there are three types of operations: the position treatment; the loaded hoist move; and the empty hoist move; each type has a starting point and a finishing point. This means there are six events per job for each stage of its path:  $TPS(p,s)$ ,  $TPF(p,s)$ ,  $TLS(p,s)$ ,  $TLF(p,s)$ ,  $TES(p,s)$ , and  $TEF(p,s)$ .

Where:

**TPS(p,s)**: is the process (treatment) starting time of the  $p^{\text{th}}$  priority job at the  $s^{\text{th}}$  stage.

**TPF(p,s)**: is the process (treatment) finishing time of the  $p^{\text{th}}$  priority job at the  $s^{\text{th}}$  stage.

**TLS(p,s)**: is the loaded hoist starting time of the  $p^{\text{th}}$  priority job that belongs to the  $s^{\text{th}}$  stage.

**TLF(p,s)**: is the loaded hoist finishing time of the  $p^{\text{th}}$  priority job that belongs to the  $s^{\text{th}}$  stage.

**TES(p,s)**: is the empty hoist starting time that is going for the  $p^{\text{th}}$  priority job at the  $s^{\text{th}}$  stage.

**TEF(p,s)**: is the empty hoist finishing time that is going for the  $p^{\text{th}}$  priority job at the  $s^{\text{th}}$  stage.

The events of TES and TEF are not calculated, because the starting position is unviable. Thus the duration is held constant (20 seconds), this duration is estimated from all the possible loaded hoist moves durations. This means in the case the empty move is between close positions, it will be slower than the average move, and vice versa, in case the positions are far from each other, the empty move will be faster than the average move.

Excluding TES and TEF from the calculations, four events must be calculated (TPS, TPF, TLS, and TLF). The coded algorithm will start by calculating the TPS, TPF, and TLS using Equations (4.2, 4.11 and 4.13). In order to calculate TLF, the next position and the hoist must be determined and available to be used, then TLF can be calculated using Equation (4.12). This means the

processing operation is considered first, followed by the loaded hoist move that will transport the job from the current stage to the next stage. The algorithm will number each loaded hoist move with the same number of the stage from which the current job is taken from. For example when a job finishes Stage no. 6 (Alkaline), then the loaded hoist operation that follows will have the same stage number of the treatment operation (i.e. Stage no. 6).

However there are few modifications of the real plant, for instance, the first stage considered in the model is outside the process line where there is no hoist to move the job from outside to one of the loading stations, thus a dummy hoist (hoist no. 6) is added to perform this vicious move. As for the last stage (unloading), movement of the job from the unloading stage to outside the process line is not considered in the model, so no loaded hoist operation is required.

Figure (5.2) shows the general structure of the algorithm. The algorithm starts with the first priority job, which is picked up from Input Buffer Zone 2 and carried by hoist no. 2 to the first stage (Alkaline). Thus, blocking hoist no. 2 to move the job from the buffer to position no. 18 (the first tank for the Alkaline stage) and its preceding empty move. As for the waiting duration for this job, it is 20 seconds (refer to Equation 4.2).

The algorithm continues with the job of priority (1) until the last stage (unloading stage), as it does so, the time required for the job to finish all the stages is determined by calculating the time for each stage. After that this accumulated time is set to zero again to schedule the next job.

When it comes to the second job (the job of priority no. 2) and the other jobs, the algorithm will work with this job by trying to assign the position of the

next stage and the hoist that will be used to move it from the current position to the next position. This is done by checking the availability of both (the position and the hoist), if one of them or both were not available, then the schedule of this job is deleted from time of the latest visited waiting stage to the time of violation, and the job is returned to that latest waiting stage where it will be delayed there for 20 seconds, and the procedure starts over again. This procedure will be repeated until the current job is treated at the last stage. And once again time is set to zero, to schedule the next priority job, until all the jobs are completed.

In case the job schedule was successful (both the next position and the hoist are available) and as long this is the case, then the algorithm deals with the job from one stage to another by blocking (filling) the row of the current position in the BlockPosition Matrix with the job ID. The algorithm also blocks the row of the utilized hoist in the matrix HoistCarryJob with job ID, and blocks the matrix BlockHoist with the current position and the next position number.

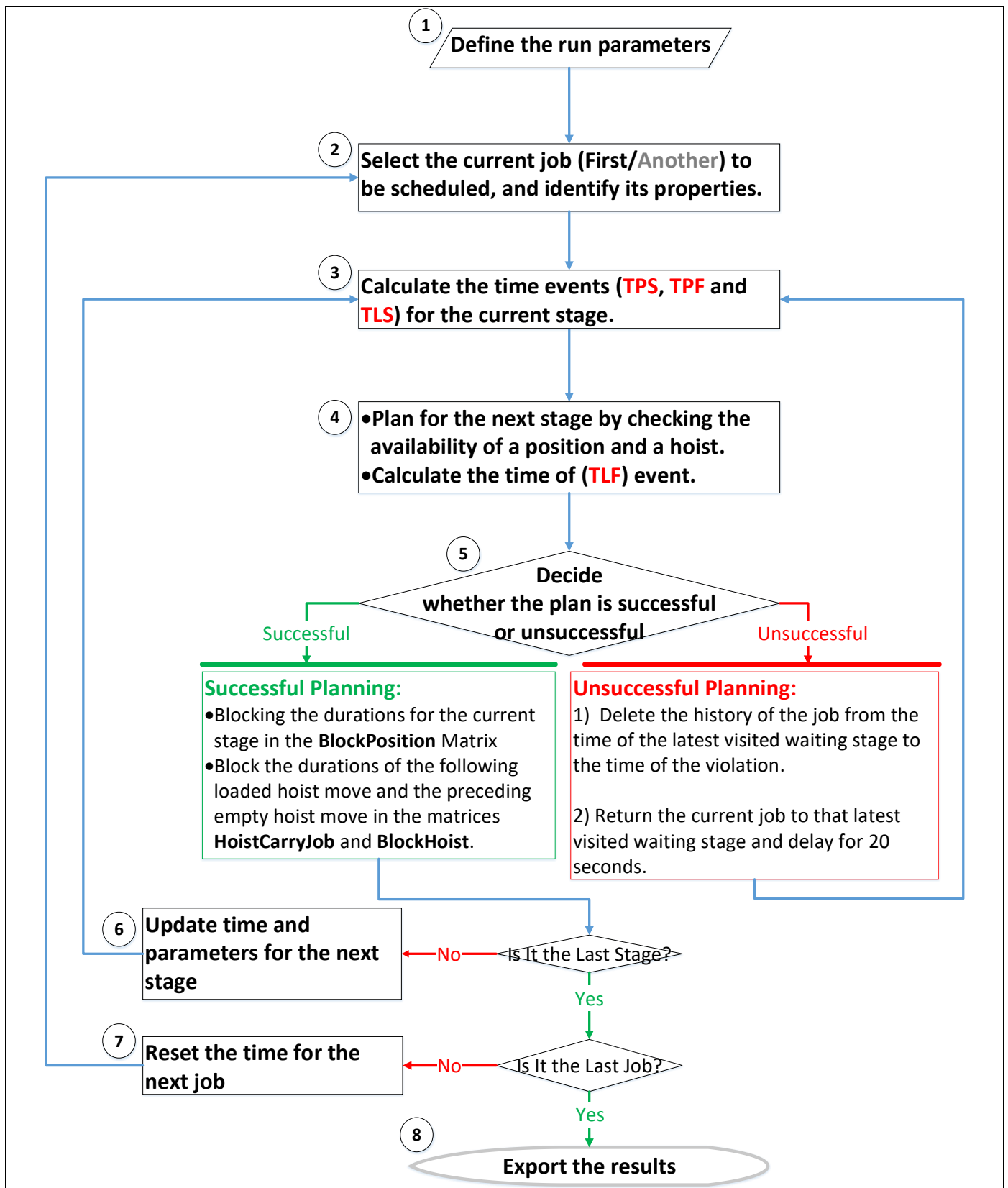


Figure (5.2): The General Structure of the Scheduling Algorithm

### 5.4.2 Detailed Structure

The algorithmic general procedure applied for each are eight steps:

1. Define the run parameters.
2. Select the current job to be scheduled, and identify its properties.
3. Calculate the time events for the current stage.
4. Plan for the next stage.
5. Decide whether the plan is successful or un-successful.
6. Update the parameters for the next stage.
7. Reset time for the next job.
8. Export the results.

The algorithm for the extra experimentations phase (phase 3) is quite similar to that for phases 1 and 2, but with additional commands to add more jobs until the time of the day (16 hours = 57600 seconds) is over.

The jobs that are chosen to be added in-addition to the actual number of jobs in each day are jobs which requiring recipes 3 and 6. The reason for selecting these two recipes is because they are the most commonly used. The first job to be added will be the one that follows recipe no. 6, followed by two jobs that follow recipe no. 3, and then adding again a job with recipe no. 6 and so on this cyclic scheduling is repeated until there is no more time left to process any more jobs.

Figure (5.3) illustrates the steps of the detailed structure of the algorithm, the steps are detailed in the next page.

### **Step 1: Define the run parameters:**

From the Main input file, the following information for the selected run are identified:

- Day number
- Sequence of the jobs, based on jobs prioritization.
- Configuration, thus co-responding Possible Positions (PP) cell array is selected.
- Total number of jobs, the maximum number of jobs is known.
- The actual makespan at the anodizing stage (in seconds)
- Name of the inputs file, thus the co-responding inputs are specified.
- Name of the outputs file, thus the co-responding outputs file is specified.

### **Step 2: Selecting the current job to be scheduled, and identifying its properties:**

After choosing the inputs file, the following information are determined for each job:

- Job Priority (**p**)
- Job ID (**JobID**)
- Recipe ID (**r**) and recipe type (**r\_type**).
- Starting Stage (**SS**)
- Starting Position (**k**)
- Anodizing Treatment Duration (**ANOD**)
- The Actual Starting Time at the Anodizing (**TPS\_ Actual**)
- The Actual Finishing Time at the Anodizing (**TPF\_ Actual**)

### Step 3: Calculate time events for the current stage:

In this step, the current stage and the current position must be known.

- The initial stage and initial position are determined from the input data.
- The following stages and positions are determined from the updates in Step 6.

The events **TPS**, **TPF**, and **TLS** for the current stage are calculated:

- For the starting stage, is calculated using Equation (5.1) similar to  $(T_{p,i,r,s,k}^{PS})$  for Equation (4.2)

$$TPS = 20 \text{ seconds} \quad (5.1)$$

Where this 20 seconds duration is reserved for any empty hoist move.

- For the following stages, TPS is calculated using Equation (5.2) similar to Equation (4.13).

$$TPS \text{ of the current stage} = TLF \text{ of the previous stage} \quad (5.2)$$

Although TLF event occurs at the current stage, but its stage number belong to the previous stage.

- Equation (5.3) is similar to Equation (4.2) to obtained  $(T_{p,i,r,s,k}^{PF})$

$$TPF(p, s) = TPS(p, s) + DT(r, s) \quad (5.3)$$

Where  $DT(r, s)$ : is the duration of the  $s^{th}$  stage for recipe ( $r$ ).

In some cases,  $DT(r, s)$  is adjusted, for example the, duration of hot sealing stage is based on the selected tank.

- Equation (5.4) is similar to Equation (4.11) to obtained  $(T_{p,i,r,s,k}^{LS,h})$

$$TLS(p, s) = TPF(p, s) \quad (5.4)$$

In this step, if the stage is a waiting stage, then the time when the current job visits this stage and the position at which it is placed, must be saved in order to refer back to this information if the job caused a violation (Step 5.2).

#### Step 4: Planning for the next stage:

In this step, the next position and the selected hoist must be available for use, otherwise, the plan is not successful.

4.1. Identify the next stage (**ns**) from the recipe type (**r\_type**).

4.2. Select the first possible position as the initial position (**vc**), from the **Possible Position (PP)** cell array (@ **r\_type** and @ **ns**).

4.3. Calculate the time for the two events (**TPS** and **TPF** of the next stage), using Equations (5.5 and 5.6) similar to Equations (4.13 and 4.2).

$$TPS(p, ns) = TPF(p, s) + pickup + MT(k, vc) + dipping \quad (5.5)$$

$$TPF(p, ns) = TPS(p, ns) + DT(ns, r) \quad (5.6)$$

Where  $MT(k, vc)$ : is the loaded hoist duration from position (**k**) to (**vc**).

4.4. Checking the availability of the selected position (**vc**) between the time **TPS(p,ns)** and **TPF(p,ns)**:

- If all the elements are zero, then the position is free to receive a new job.

Action →  $v = vc$  proceed with Step 4.5.

- If one of the elements is not zero, then the position is still busy with a previous job.

Action → Repeat Step 4.2 with another position (if any).

- If there is another position

Action: →  $v = vc$  proceed with Step 4.5.

- If there is/are no other position(s)

Action: → Go to Step 5.2

4.5. Calculate the time of **TLF(p,s)** using Equation (5.7) similar to Equation (4.12):

$$TLF(p, s) = TLS(p, s) + pickup + MT(k, v) + dipping \quad (5.7)$$

#### 4.6. Select the hoist range:

- If **k** or **v** are outside an overlap zone,  
Action → Select the range that covers both of the positions (**k** and **v**)
- If **k** and **v** in an overlap zone,  
Action → select the range with the lowest hoist number.

#### 4.7. Checking the availability of the hoist

- If outside the overlap zone:  
Action → Select the main hoist, and check the hoist availability in the matrices:
  - **HoistCarryJob** between the time **TLS(p,s)** and **TLF(p,s)**
    - If all elements are zero, then the hoist is free to be used  
Action → Go to Step 5.1
    - If one element is not zero, then the hoist is busy  
Action → Go to Step 5.2
- If inside the overlap zone:  
Action → Select the (other overlapping/main\*) hoist, and check its availability.
  - **HoistCarryJob** between the time **TLS(p,s)** and **TLF(p,s)**
    - If all elements are zero, then the hoist is free to be used  
Action → Check **BlockHoist** Matrix
    - If one element is not zero, then the hoist is busy  
Action → Go to Step 5.2

\* main means is for the hoist of the selected range, while the other overlapping hoist is the neighboring hoist that shares part of the main hoist range.

- BlockHoist, @  $TLF(p,s)$  and @  $TLF(p,s)$ 
  - If position @  $TLF(p,s) \neq k - 1|k|k + 1$  and  
 $@TLF(p,s) \neq v - 1|v|v + 1$  , then no  
Collision,  
Action → Go to Step 5.1
  - If not, then a Collision case,  
Action → Repeat from Step 4.7 with the Main  
Hoist
    - If the main hoist is available for use, then  
Action → Go to Step 5.1
    - If the main hoist is not available for use,  
then  
Action → Go to Step 5.2

### Step 5: Deciding whether successful or unsuccessful plan:

At this Step, the algorithm is split into two branches: if both (the next position and the hoist) are ready for use, then the planning is successful; if one of them is not ready, then the planning is un-successful.

#### 5.1. Successful Planning:

In this step the three dynamic matrices are blocked for the current job at the current stage, and proceed with step 6:

- **BlockPosition:** blocked for:
  - **JobID:** @ current position ( $k$ ) and  
@ times between  $TPS(p,s)$  and  $TPF(p,s)$
  - **JobID+100:** @ Transferor position, for picking up  
@ times between  $TPF(p,s)+1$  and  $TPF(p,s)+1+pickup$

- **JobID+200**: @ Transferor position, for cartage returning  
@ times between  $TPF(p,s)+2+pickup$  and  $TPF(p,s) + 2 + pickup + returning$
- The only next stage that is blocked along with current stage is the last stage (Unloading).
- **HoistCarryJob**: blocked for:
  - JobID: @ used hoist (**h**) and  
@ times between  $TLS(p,s)$  and  $TLF(p,s)$
  - JobID+300: for empty hoist move @ used hoist (**h**) &  
@ times between  $TLS(p,s)-20$  and  $TLS(p,s)-1$
- **BlockHoist**: blocked for::
  - Current position (**k**) @ used hoist (**h**) and @  $TLS(p,s)$
  - Next position (**v**) @ used hoist (**h**) and @  $TLF(p,s)$

## 5.2. Un-Successful Planning:

In this step, the previous schedule for the current job from the latest waiting stage to the time of the violation is un-blocked and the job is returned to the latest waiting stage for a delay to start again from Step 3

- **BlockPosition**: un-block (delete) **JobID**, **JobID+100**, **JobID+200**  
from the time of the latest waiting stage to the violation time.
- **HoistCarryJob**: unblock (delete) **JobID**, **JobID+300**  
from the time of the empty move for latest waiting stage to the violation time.
- **BlockHoist**: unblock (delete) from all position visited by the current hoist (referring to the same elements in the HoistCarryJob Matrix), from the time of the empty move for latest waiting stage to the violation time.

### Step 6: Update for the next stage:

- If the current stage was the last stage  
Action → Proceed with Step 7
- If the current stage is not the last stage  
Action → Do the following  
After completing Step 5.1, the next stage will be updated to the current stage, and repeat Step 3:
  - Next stage (**ns**) becomes the current stage,  
Minding the skipped stage as per the recipe ID (**r**)
  - Next positions (**v**) becomes the current position (**k**)
  - **TPS** for next stage is now for the current stage and it equals to **TLF(p,s)** of the current stage, which now the previous stage.

### Step 7: Set time for next job:

- If the current job is the last job  
Action → Export the results to excel
- If the current job is not the last job  
Action → set the starting time of the waiting stages to zero, to work with the next job. Repeat from Step 2.

### Step 8: Exporting the outputs to excel files to plot the graphs

After completing the exportation, work with the next run. Repeat from Step 1.

The full code of the scheduling algorithm for the Further Experimentation phase (Phase 3) can be seen in Appendices (3), along with the code for exporting the results to the excel files. The full code for the other phases (Phases 1 and 2) can be seen in the attached CD.

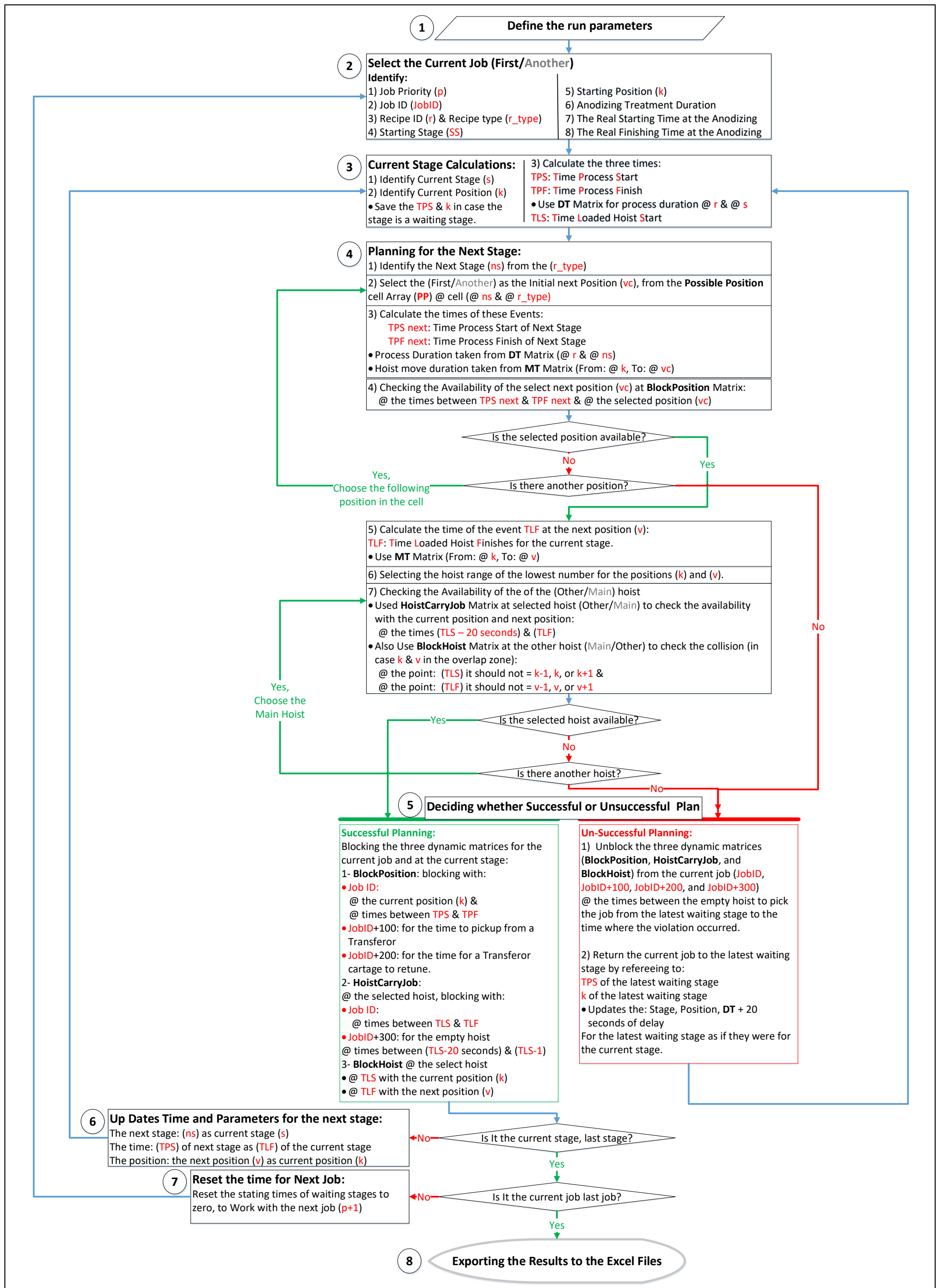


Figure (5.2): Detailed Structure for the Scheduling Algorithm

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# **Chapter Six**

## **Validation and Evaluation of the Algorithm**

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**6.1. Introduction**

**6.2. Algorithm Validation**

**6.3. Results Evaluation**

## Chapter Six

### Validation and Evaluation of the Algorithm

#### 6.1. Introduction

This chapter aims to validate the results obtained by the algorithm for the twelve selected days and evaluate them using Combination no.1 (the actual combination of the actual job sequence and tanks configuration) alone.

In the validation part, two sets are compared, the first (Set 1) uses the actual anodizing durations while the other set (Set 2) uses the average anodizing durations. The set that scored more minimum makespans is selected for the rest of the analyses. Gantt charts are used to show if the algorithm is able to generate reasonable schedules.

On the other hand, the jobs flow times in the anodizing stage and the makespan with the number of jobs produced in each day are studied to evaluate the algorithm performs. In-addition, the waiting durations at the waiting stages and utilization of the different positions are also analyzed to identify the busy stages and the stage of the main bottleneck problem.

Table (6.1) shows the actual makespan at the anodizing stage and the number of jobs produced in each day. The data in Table (6.1) are the fixed input data to test the performance of Combination no. 1 and the other combinations as well.

Table (6.1): The Fixed Input Data for all Combinations

| Day No. | Date<br>(day-month-year) | Actual<br>Makespan<br>At the<br>Anodizing<br>in seconds | Matt<br>Finish –<br>Small<br>Hollow<br>Sections | Matt<br>Finish –<br>Ordinary<br>Sections | Color –<br>All<br>Sections | Total<br>Number<br>of Jobs |
|---------|--------------------------|---------------------------------------------------------|-------------------------------------------------|------------------------------------------|----------------------------|----------------------------|
| 1       | 08-04-15                 | 51,900<br>(14:25:00)*                                   | 19                                              | 20                                       | 14                         | 53                         |
| 2       | 13-04-15                 | 52,740<br>(14:39:00)                                    | 29                                              | 6                                        | 20                         | 55                         |
| 3       | 23-04-15                 | 53,340<br>(14:49:00)                                    | 0                                               | 17                                       | 31                         | 48                         |
| 4       | 01-06-17                 | 53,940<br>(14:59:00)                                    | 0                                               | 34                                       | 12                         | 46                         |
| 5       | 02-06-17                 | 53,100<br>(14:45:00)                                    | 13                                              | 27                                       | 6                          | 46                         |
| 6       | 09-06-17                 | 54,060<br>(15:01:00)                                    | 3                                               | 15                                       | 28                         | 46                         |
| 7       | 11-06-17                 | 57,240<br>(15:54:00)                                    | 5                                               | 9                                        | 31                         | 45                         |
| 8       | 17-06-17                 | 54,420<br>(15:07:00)                                    | 35                                              | 13                                       | 2                          | 50                         |
| 9       | 19-06-17                 | 56,460<br>(15:41:00)                                    | 25                                              | 7                                        | 15                         | 47                         |
| 10      | 24-06-17                 | 55,800<br>(15:30:00)                                    | 23                                              | 2                                        | 24                         | 49                         |
| 11      | 27-06-17                 | 56,280<br>(15:38:00)                                    | 24                                              | 8                                        | 20                         | 52                         |
| 12      | 29-06-17                 | 57,600<br>(16:00:00)                                    | 1                                               | 36                                       | 13                         | 50                         |

\*hrs:min:sec

## **6.2. Algorithm Validation**

In this section, the makespans of two sets of the anodizing durations (the actual anodizing durations and the average anodizing durations) are compared, to choose the set that scores more minimum makespans for the rest of the results analysis. Also, Gantt charts are presented as validation.

### **6.2.1 Comparing the results of the two sets of anodizing durations**

As discussed in sub-section 3.7.2, a combination is defined by a number that represents the used job sequence and the configuration that is dealt with, Also it was stated that Combination no.1 is for the actual sequence and the actual configuration.

The first phase has two sets of anodizing durations, in each set the algorithm will simulate the 12 days with combination no. 1. The aim of the two sets is to minimize the actual makespan, but the only difference is using the corresponding anodizing duration for each job. In the first set, the algorithm will use the actual anodizing duration for each job, while in the second set the algorithm will use an average anodizing duration (40 minutes) for each job. This average duration of 40 minutes is based on subject experts' experience,

The makespans of the first set are presented in Table (6.2), while those of the second set (average anodizing durations) are presented in Table (6.3).

The actual makespan at the last stage is an estimated makespan for both sets, which is calculated from the anodizing makespan (including the durations of all the preceding anodizing) and adding an estimated duration to the actual finishing time for the last job according to the sequence. This estimated

duration is the summation of the durations for remaining stages after anodizing to the end of the processing line, including the average durations of the hoist travel from stage to stage. The estimated durations for all the recipes can be seen in Appendix (4).

In Tables (6.2) and (6.3) the makespans differences are calculated, that show the difference between the makespan obtained by the algorithm and the actual makespan for each day for both stages (the anodizing stage and the last stage).

The makespan difference at the anodizing stage is calculated for each day using Equation (6.1), Equation (6.1) is used for either Set 1 or for Set 2.

$$\begin{aligned}
 (\text{Anodizing Makespan Differnce})_{(set\ 1/set\ 2)} = \\
 (\text{Actual Anodizing Makespan})_{(set\ 1/set\ 2)} - \\
 (\text{Algorithm Anodizing Makespan})_{(set\ 1/set\ 2)}
 \end{aligned} \tag{6.1}$$

Also, in these two tables, the difference makespan at the last stage for each day is calculated using Equation (6.2). This equation is also used for both sets.

$$\begin{aligned}
 (\text{Last stage Makespan Differnce})_{(set\ 1/set\ 2)} = \\
 (\text{Actual Last Stage Makespan})_{(set\ 1/set\ 2)} - \\
 (\text{Algorithm Last Stage Makespan})_{(set\ 1/set\ 2)}
 \end{aligned} \tag{6.2}$$

Table (6.2): The Results of Set 1 (the Actual Anodizing Durations)  
(seconds)

| Day | Anodizing Makespan    |                      |                               | Last Stage Makespan   |                      |                               | Computational time |
|-----|-----------------------|----------------------|-------------------------------|-----------------------|----------------------|-------------------------------|--------------------|
|     | Actual                | Algorithm            | Difference.<br>(Equation 6.1) | Actual<br>(estimated) | Algorithm            | Difference.<br>(Equation 6.2) |                    |
| 1   | 51,900<br>(14:25:00)* | 47,936<br>(13:18:56) | 3,964<br>(1:06:04)            | 56,156<br>(15:35:56)  | 52,421<br>(14:33:41) | 3,753<br>(1:02:33)            | 173<br>(0:02:53)   |
| 2   | 52,740<br>(14:39:00)  | 50,119<br>(13:55:19) | 2,621<br>(0:43:41)            | 56,576<br>(15:42:56)  | 54,184<br>(15:03:04) | 2,392<br>(0:39:52)            | 230<br>(0:03:50)   |
| 3   | 53,340<br>(14:49:00)  | 48,334<br>(13:25:34) | 5,006<br>(1:23:26)            | 57,596<br>(15:59:56)  | 52,829<br>(14:40:29) | 4,767<br>(1:19:27)            | 225<br>(0:03:45)   |
| 4   | 53,940<br>(14:59:00)  | 41,576<br>(11:32:56) | 12,164<br>(3:22:44)           | 59,096<br>(16:24:56)  | 46,960<br>(13:02:40) | 12,136<br>(3:22:16)           | 158<br>(0:02:38)   |
| 5   | 53100<br>(14:45:00)   | 41,268<br>(11:27:48) | 11832<br>(3:17:12)            | 58256<br>(16:10:56)   | 46,651<br>(12:57:31) | 11605<br>(3:13:25)            | 133<br>(0:02:13)   |
| 6   | 54,060<br>(15:01:00)  | 46,162<br>(12:49:22) | 7,898<br>(2:11:38)            | 59,216<br>(16:26:56)  | 51,546<br>(14:19:06) | 7,670<br>(2:07:50)            | 178<br>(0:02:58)   |
| 7   | 57,240<br>(15:54:00)  | 41,921<br>(11:38:41) | 15,319<br>(4:15:19)           | 62,396<br>(17:19:56)  | 45841<br>(12:44:01)  | 16555<br>(4:35:55)            | 153<br>(0:02:33)   |
| 8   | 54,420<br>(15:07:00)  | 45,809<br>(12:43:29) | 8,611<br>(2:23:31)            | 59,576<br>(16:32:56)  | 48,807<br>(13:33:27) | 10,769<br>(2:59:29)           | 162<br>(0:02:42)   |
| 9   | 56460<br>(15:41:00)   | 43,000<br>(11:56:40) | 13460<br>(3:44:20)            | 61822<br>(17:10:22)   | 47350<br>(13:09:10)  | 14472<br>(4:01:12)            | 153<br>(0:02:33)   |
| 10  | 55800<br>(15:30:00)   | 44,029<br>(12:13:49) | 11771<br>(3:16:11)            | 59536<br>(16:32:16)   | 48,992<br>(13:36:32) | 10544<br>(2:55:44)            | 163<br>(0:02:43)   |
| 11  | 56,280<br>(15:38:00)  | 45,770<br>(12:42:50) | 10,510<br>(2:55:10)           | 61,016<br>(16:56:56)  | 50,733<br>(14:05:33) | 10,283<br>(2:51:23)           | 162<br>(0:02:42)   |
| 12  | 57,600<br>(16:00:00)  | 44,199<br>(12:16:39) | 13,401<br>(3:43:21)           | 62,962<br>(17:29:22)  | 49,926<br>(13:52:06) | 13,036<br>(3:37:16)           | 138<br>(0:02:18)   |

\*hrs:min:sec

Table (6.3): The Results of Set 2 (the Average Anodizing Durations)  
(seconds)

| Day | Anodizing Makespan   |                     |                               | Last Stage Makespan |                     |                               | Computational time |
|-----|----------------------|---------------------|-------------------------------|---------------------|---------------------|-------------------------------|--------------------|
|     | Real                 | Algorithm           | Difference.<br>(Equation 6.1) | Real<br>(estimated) | Algorithm           | Difference.<br>(Equation 6.2) |                    |
| 1   | 51900<br>(14:25:00)* | 48913<br>(13:35:13) | 2987<br>(0:49:47)             | 56156<br>(15:35:56) | 53409<br>(14:50:09) | 2747<br>(0:45:47)             | 226<br>(0:03:46)   |
| 2   | 52740<br>(14:39:00)  | 51819<br>(14:23:39) | 921<br>(0:15:21)              | 56576<br>(15:42:56) | 55883<br>(15:31:23) | 693<br>(0:11:33)              | 203<br>(0:03:23)   |
| 3   | 53340<br>(14:49:00)  | 48781<br>(13:33:01) | 4559<br>(1:15:59)             | 57596<br>(15:59:56) | 53264<br>(14:47:44) | 4332<br>(1:12:12)             | 214<br>(0:03:34)   |
| 4   | 53940<br>(14:59:00)  | 42602<br>(11:50:02) | 11258<br>(3:07:38)            | 59096<br>(16:24:56) | 48065<br>(13:21:05) | 11031<br>(3:03:51)            | 176<br>(0:02:56)   |
| 5   | 53100<br>(14:45:00)  | 43114<br>(11:58:34) | 9986<br>(2:46:26)             | 58256<br>(16:10:56) | 46100<br>(12:46:20) | 12156<br>(3:22:36)            | 153<br>(0:02:33)   |
| 6   | 54060<br>(15:01:00)  | 42551<br>(11:49:11) | 11509<br>(3:11:49)            | 59216<br>(16:26:56) | 47934<br>(13:18:54) | 11282<br>(3:08:02)            | 186<br>(0:03:06)   |
| 7   | 57240<br>(15:54:00)  | 42077<br>(11:41:17) | 15163<br>(4:12:43)            | 62396<br>(17:19:56) | 47463<br>(13:11:03) | 14933<br>(4:08:53)            | 168<br>(0:02:48)   |
| 8   | 54420<br>(15:07:00)  | 42453<br>(11:47:33) | 11967<br>(3:19:27)            | 59576<br>(16:32:56) | 47837<br>(13:17:17) | 11739<br>(3:15:39)            | 146<br>(0:02:26)   |
| 9   | 56460<br>(15:41:00)  | 43576<br>(12:06:16) | 12884<br>(3:34:44)            | 61822<br>(17:10:22) | 47937<br>(13:18:57) | 14904<br>(4:08:24)            | 154<br>(0:02:34)   |
| 10  | 55800<br>(15:30:00)  | 45150<br>(12:32:30) | 10650<br>(2:57:30)            | 60536<br>(16:48:56) | 50114<br>(13:55:14) | 10422<br>(2:53:42)            | 164<br>(0:02:44)   |
| 11  | 56280<br>(15:38:00)  | 46794<br>(12:59:54) | 9486<br>(2:38:06)             | 61016<br>(16:56:56) | 51757<br>(14:22:37) | 9259<br>(2:34:19)             | 171<br>(0:02:51)   |
| 12  | 57600<br>(16:00:00)  | 45909<br>(12:45:09) | 11691<br>(3:14:51)            | 62962<br>(17:29:22) | 49238<br>(13:40:38) | 13724<br>(3:48:44)            | 164<br>(0:02:44)   |

\*hrs:min:sec

Table (6.4) provides the difference between the two sets of algorithm makespan, this difference is referred to as the “difference of algorithm makespan”, let’s call it (DALM). Equation (6.3) is used for the anodizing stage, while Equation (6.4) is used for the last stage.

$$(DALM)_{Anodizing} = (Algorithm\ Anodizing\ Makespan)_{set\ 2} - (Algorithm\ Anodizing\ Makespan)_{set\ 1} \quad (6.3)$$

$$(DALM)_{Last\ stage} = (Algorithm\ Last\ Stage\ Makespan)_{set\ 2} - (Algorithm\ Last\ Stage\ Makespan)_{set\ 1} \quad (6.4)$$

In Equations (6.3) and (6.4), the makespan difference of Set 1 is subtracted from Set 2, because it is expected that the runs with the average durations (i.e. Set 2) will obtain higher makespans than the runs with actual durations (i.e. Set 1), due to the fact that none of the actual durations in the twelve (12) days was higher than average duration (40 minutes).

This means, if DALM is negative, then the run with average durations obtains a less makespan than the run with actual durations, this not so surprising since longer treatment at the anodizing stage may give chance for the stages after the anodizing stage to become available again (not busy with previous jobs) and reduce the potentiality of creating a bottleneck problem after the anodizing stage.

In Table (6.4), it can be seen that only two days out the twelve days, the DALM at the anodizing stage was negative. On the other hand, only four out of the twelve days, the DALM at the last stage was negative. This that the makespan for the set with actual anodizing duration (Set 1) is more likely to score more than the set with the average anodizing durations (Set 2), from the perceptive of producing shorter makespans. Thus, the actual anodizing

durations (Set 1) are in favor to be used in the simulation model, because they represent the real schedule. So from here on-ward the actual anodize durations will be used for validation, evaluation, and experimentation.

Table (6.4): Differences of the Algorithm Makespans of the Two Sets  
(seconds)

| Day | Anodizing Stage                                        |                                           | Last Stage                                             |                                           |
|-----|--------------------------------------------------------|-------------------------------------------|--------------------------------------------------------|-------------------------------------------|
|     | Difference.<br>Algorithm<br>Makespan<br>(Equation 6.3) | Set 2 has lower<br>makespan than<br>Set 1 | Difference.<br>Algorithm<br>Makespan<br>(Equation 6.4) | Set 2 has lower<br>makespan than<br>Set 1 |
| 1   | 977<br>(0:16:17)*                                      | No                                        | 1,006<br>(0:16:46)                                     | No                                        |
| 2   | 1,700<br>(0:28:20)                                     | No                                        | 1,699<br>(0:28:19)                                     | No                                        |
| 3   | 447<br>(0:07:27)                                       | No                                        | 435<br>(0:07:15)                                       | No                                        |
| 4   | 906<br>(0:15:06)                                       | No                                        | 1,105<br>(0:18:25)                                     | No                                        |
| 5   | 1,846<br>(0:30:46)                                     | No                                        | -551<br>(-00:09:11)                                    | Yes                                       |
| 6   | -3,611<br>(-01:00:11)                                  | Yes                                       | -3,612<br>(-01:00:12)                                  | Yes                                       |
| 7   | 156<br>(0:02:36)                                       | No                                        | 1622<br>(0:27:02)                                      | No                                        |
| 8   | -3,356<br>(-00:55:56)                                  | Yes                                       | -970<br>(-00:16:10)                                    | Yes                                       |
| 9   | 576<br>(0:09:36)                                       | No                                        | 587<br>(0:09:47)                                       | No                                        |
| 10  | 1,121<br>(0:18:41)                                     | No                                        | 1,122<br>(0:18:42)                                     | No                                        |
| 11  | 1,024<br>(0:17:04)                                     | No                                        | 1,024<br>(0:17:04)                                     | No                                        |
| 12  | 1,710<br>(0:28:30)                                     | No                                        | -688<br>(-00:11:28)                                    | Yes                                       |

\*hrs:min:sec

### 6.2.2 Gantt charts

The aim of viewing the Gantt charts for the 12 runs (12 days) is to confirm that the algorithm is working properly in producing realistic and acceptable schedules. The reality and acceptability of the Gantt charts and schedules can be examined quickly by checking if all the jobs are shown along with their all stages, and they are shown in their correct duration.

In this sub-section only two days are selected to view their Gantt charts, these two days are day no. 2 and day no. 8. For the Gantt charts of all the 12 days, reference is made in Appendix (5).

Figures (6.1) and (6.4) show the full Gantt charts for day no.2 and day no. 8, respectively. Figures (6.2) and (6.3) show enlargement for Figure 6.1 (Day no. 2) for the periods (00:00 to 4:00) and (12:00 to 16:00), respectively. Similarly, Figures (6.5) and (6.6) show enlargement for Figure 6.4 (Day no. 8) for the periods (00:00 to 4:00) and (12:00 to 16:00), respectively. Also in Figures (6.1) and (6.4), the progress for jobs no. 1, 26 and 50 are tracked by boarding the durations of their treatments.

Tables (6.5) and (6.6) track the movements of jobs no. (1, 26, 50) in Figures (6.1) and (6.4) for Days no. (2 and 8), respectively. The movements are tracked providing the times in which each job started (TPS) and finished (TPF) in each stage along with the position at which the job been treated st, and the duration spent in that position. The times and durations in Tables (6.5) and (6.6) are in the hrs:min:sec format.

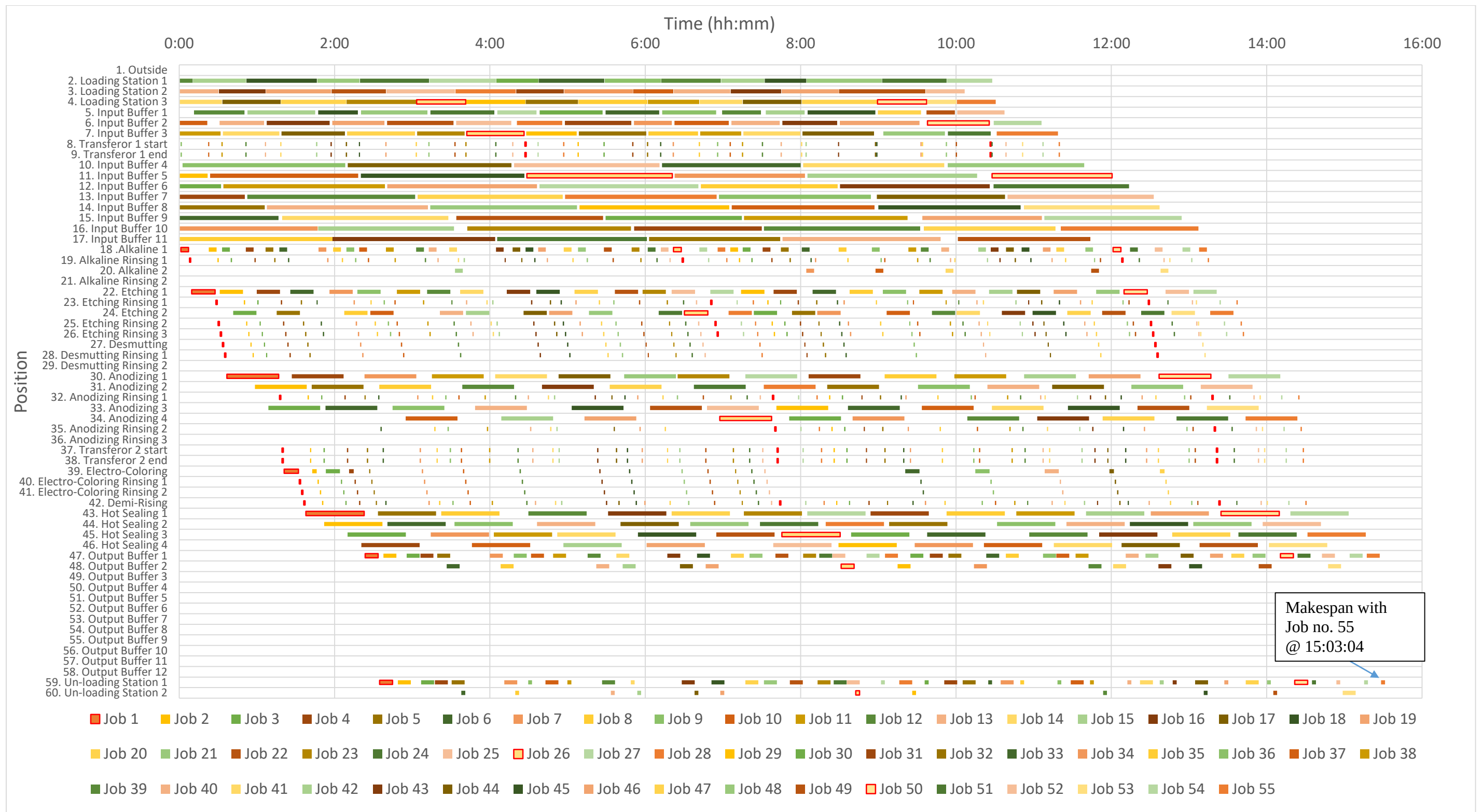


Figure (6.1): Day 02 (13-04-15) [Seq. 1 and Conf. 1 with 55 Jobs] - Full Gantt Chart

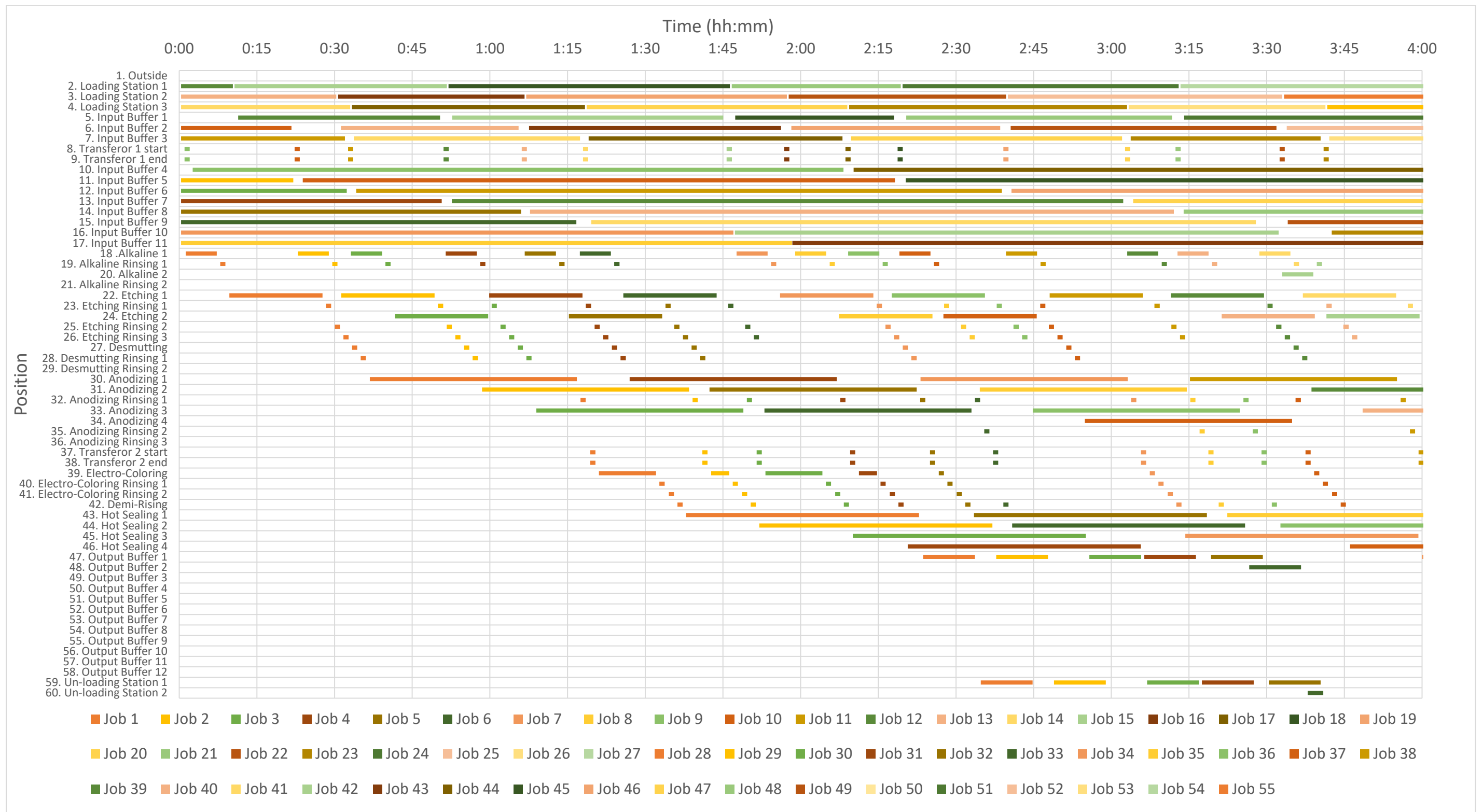


Figure (6.2): Day 02 (13-04-15) [Seq. 1 and Conf. 1 with 55 Jobs] - Gantt Chart (Period 00:00 to 4:00)

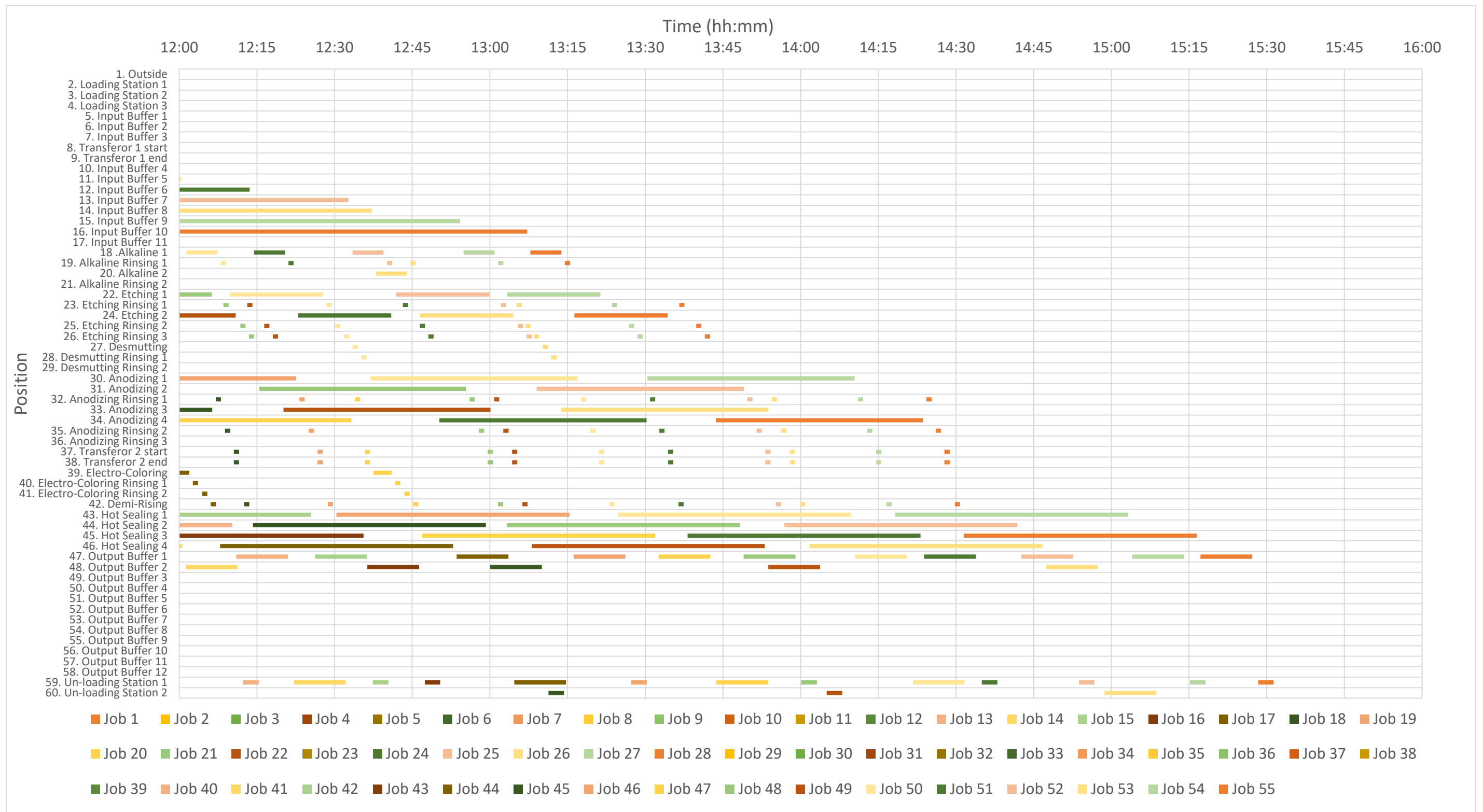


Figure (6.3): Day 02 (13-04-15) [Seq. 1 and Conf. 1 with 55 Jobs] - Gantt Chart (Period 12:00 to 16:00)

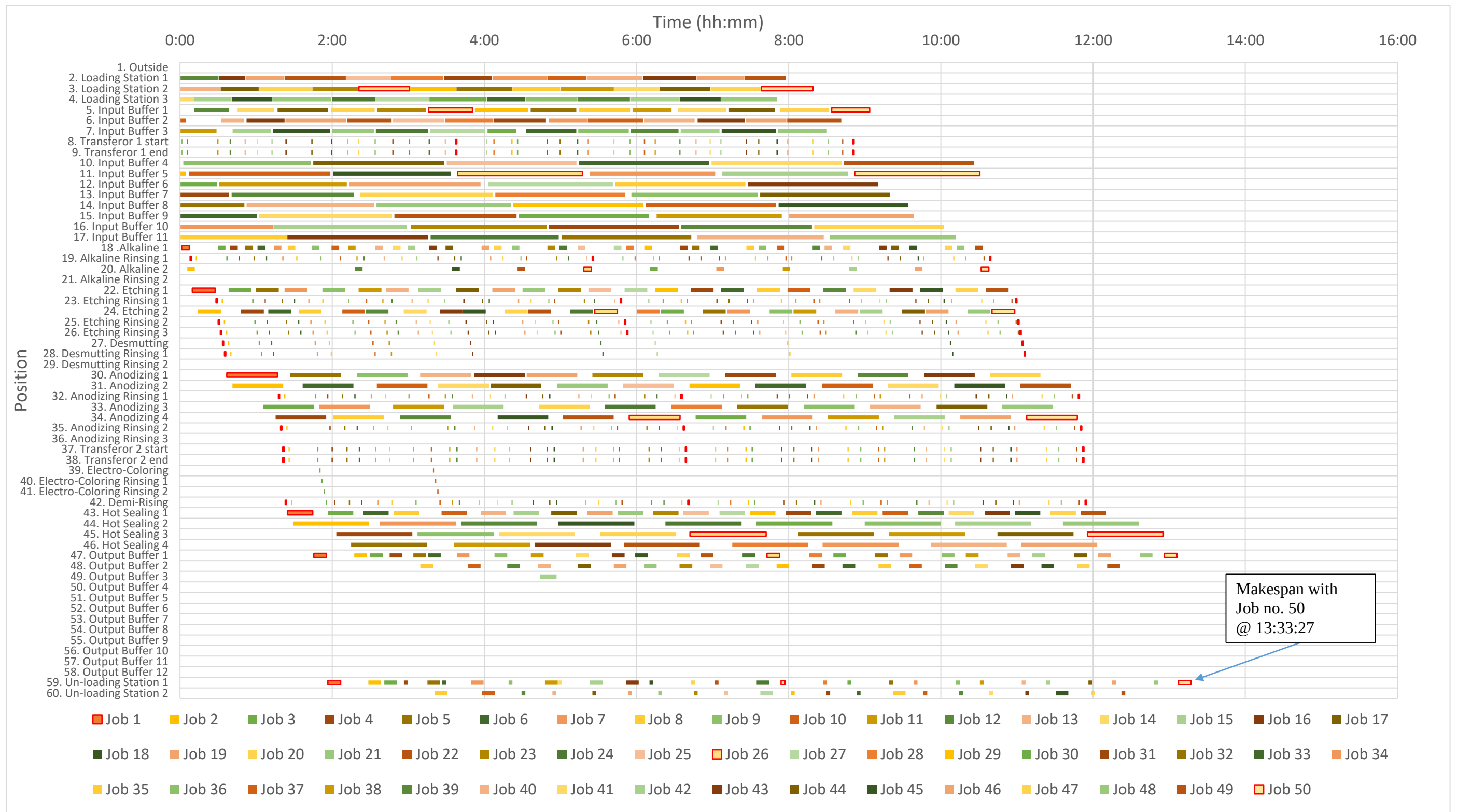


Figure (6.4): Day 08 (17-06-17) [Seq. 1 and Conf. 1 with 50 Jobs] - Full Gantt Chart

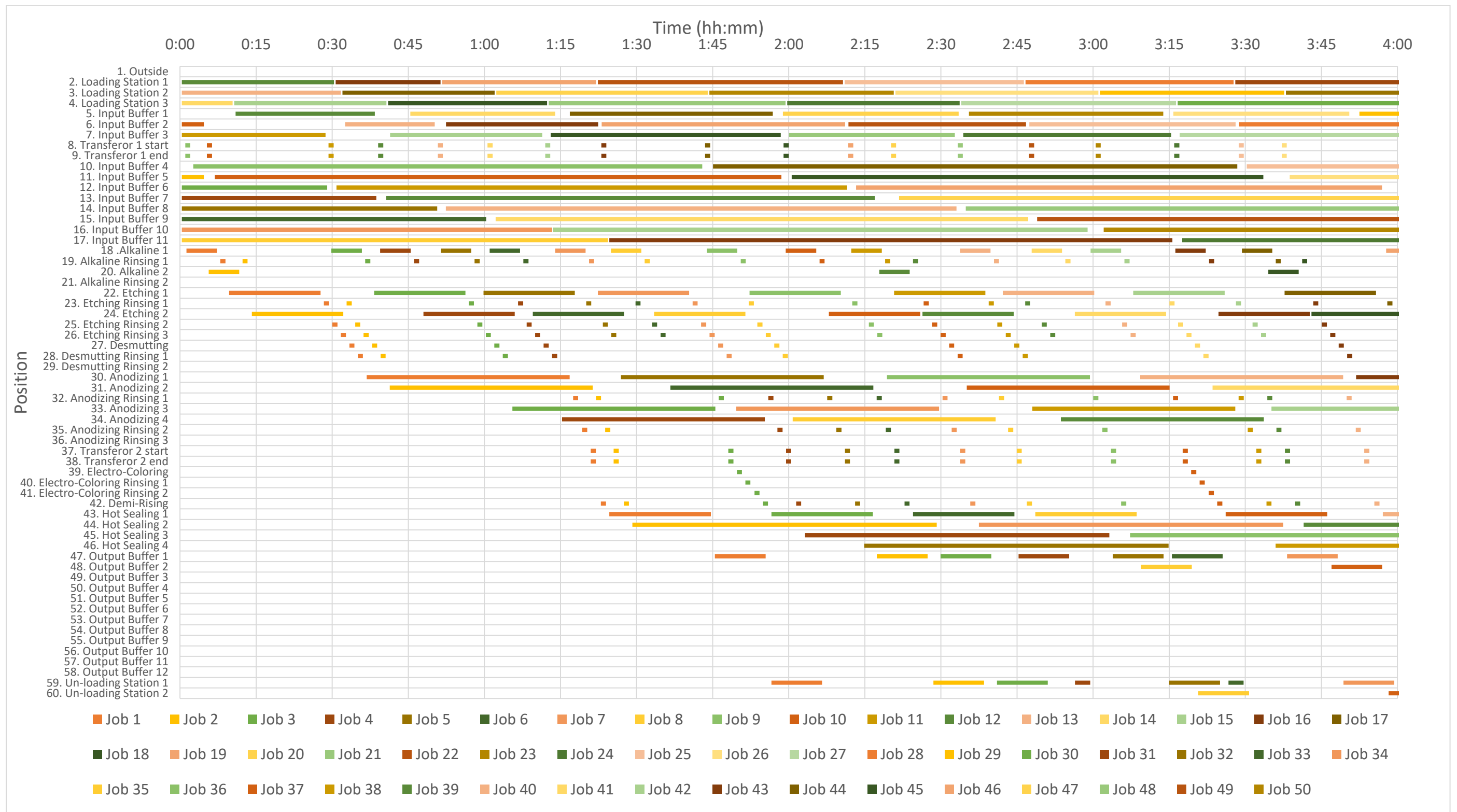


Figure (6.5) Day 08 (17-06-17) [Seq. 1 and Conf. 1 with 50 Jobs] - Gantt Chart (Period 00:00 to 4:00)

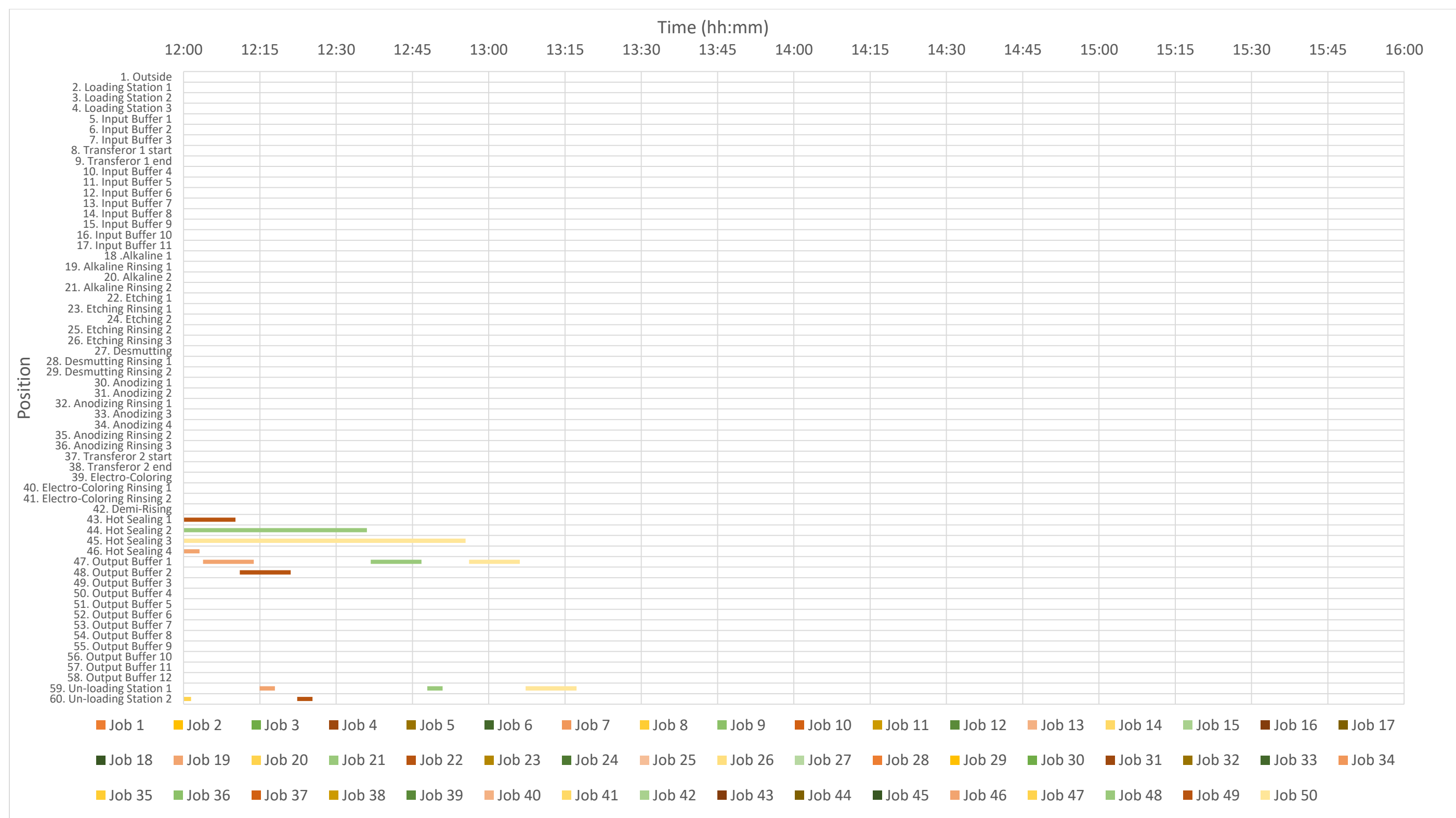


Figure (6.6): Day 08 (17-06-17) [Seq. 1 and Conf. 1 with 50 Jobs] - Gantt Chart (Period 12:00 to 16:00)

Table (6.5): Jobs no. 1, 26 and 50 Progress in Day no. 2

| Stage | Job 1   |         |          |          | Job 26  |         |          |          | Job 50   |          |          |          |
|-------|---------|---------|----------|----------|---------|---------|----------|----------|----------|----------|----------|----------|
|       | TPS     | TPF     | Duration | Position | TPS     | TPF     | Duration | Position | TPS      | TPF      | Duration | Position |
| 1     | 0:00:00 | 0:00:00 | 0:00:00  |          | 0:00:21 | 3:03:01 | 3:02:40  | 1        | 0:00:21  | 8:59:01  | 8:58:40  | 1        |
| 2     | 0:00:00 | 0:00:00 | 0:00:00  |          | 3:03:21 | 3:41:21 | 0:38:00  | 4        | 8:59:21  | 9:37:21  | 0:38:00  | 4        |
| 3     | 0:00:00 | 0:00:00 | 0:00:00  |          | 3:42:04 | 4:26:24 | 0:44:20  | 7        | 9:38:01  | 10:25:41 | 0:47:40  | 6        |
| 4     | 0:00:00 | 0:00:00 | 0:00:00  |          | 4:26:59 | 4:27:59 | 0:01:00  | 8        | 10:26:17 | 10:27:17 | 0:01:00  | 8        |
| 5     | 0:00:21 | 0:00:21 | 0:00:00  | 10       | 4:28:34 | 6:20:54 | 1:52:20  | 11       | 10:27:52 | 12:00:32 | 1:32:40  | 11       |
| 6     | 0:01:16 | 0:07:16 | 0:06:00  | 18       | 6:21:46 | 6:27:46 | 0:06:00  | 18       | 12:01:24 | 12:07:24 | 0:06:00  | 18       |
| 7     | 0:07:56 | 0:08:56 | 0:01:00  | 19       | 6:28:26 | 6:29:26 | 0:01:00  | 19       | 12:08:04 | 12:09:04 | 0:01:00  | 19       |
| 8     | 0:09:41 | 0:27:41 | 0:18:00  | 22       | 6:30:17 | 6:48:17 | 0:18:00  | 24       | 12:09:49 | 12:27:49 | 0:18:00  | 22       |
| 9     | 0:28:21 | 0:29:21 | 0:01:00  | 23       | 6:48:57 | 6:49:57 | 0:01:00  | 23       | 12:28:29 | 12:29:29 | 0:01:00  | 23       |
| 10    | 0:30:02 | 0:31:02 | 0:01:00  | 25       | 6:50:32 | 6:51:32 | 0:01:00  | 23       | 12:30:10 | 12:31:10 | 0:01:00  | 25       |
| 11    | 0:31:42 | 0:32:42 | 0:01:00  | 26       | 6:52:13 | 6:53:13 | 0:01:00  | 25       | 12:31:50 | 12:32:50 | 0:01:00  | 26       |
| 12    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 6:53:48 | 6:54:48 | 0:01:00  | 25       | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 13    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 6:55:28 | 6:56:28 | 0:01:00  | 26       | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 14    | 0:33:23 | 0:34:23 | 0:01:00  | 27       | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 12:33:31 | 12:34:31 | 0:01:00  | 27       |
| 15    | 0:35:03 | 0:36:03 | 0:01:00  | 28       | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 12:35:11 | 12:36:11 | 0:01:00  | 28       |
| 16    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 17    | 0:36:48 | 1:16:48 | 0:40:00  | 30       | 6:57:35 | 7:37:35 | 0:40:00  | 34       | 12:36:56 | 13:16:56 | 0:40:00  | 30       |
| 18    | 1:17:29 | 1:18:29 | 0:01:00  | 32       | 7:38:16 | 7:39:16 | 0:01:00  | 32       | 13:17:37 | 13:18:37 | 0:01:00  | 32       |
| 19    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 7:40:04 | 7:41:04 | 0:01:00  | 35       | 13:19:25 | 13:20:25 | 0:01:00  | 35       |
| 20    | 1:19:23 | 1:20:23 | 0:01:00  | 37       | 7:41:45 | 7:42:45 | 0:01:00  | 37       | 13:21:06 | 13:22:06 | 0:01:00  | 37       |
| 21    | 1:21:04 | 1:32:04 | 0:11:00  | 39       | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 22    | 1:32:44 | 1:33:44 | 0:01:00  | 40       | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 23    | 1:34:32 | 1:35:32 | 0:01:00  | 41       | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 24    | 1:36:12 | 1:37:12 | 0:01:00  | 42       | 7:43:45 | 7:44:45 | 0:01:00  | 42       | 13:23:06 | 13:24:06 | 0:01:00  | 42       |
| 25    | 1:37:52 | 2:22:52 | 0:45:00  | 43       | 7:45:30 | 8:30:30 | 0:45:00  | 45       | 13:24:46 | 14:09:46 | 0:45:00  | 43       |
| 26    | 2:23:40 | 2:33:40 | 0:10:00  | 47       | 8:31:15 | 8:41:15 | 0:10:00  | 48       | 14:10:34 | 14:20:34 | 0:10:00  | 47       |
| 27    | 2:34:48 | 2:44:48 | 0:10:00  | 59       | 8:42:32 | 8:45:32 | 0:03:00  | 60       | 14:21:42 | 14:31:42 | 0:10:00  | 59       |

Table (6.6): Jobs no. 1, 26 and 50 Progress in Day no. 8

| Stage | Job 1   |         |          |          | Job 26  |         |          |          | Job 50   |          |          |          |
|-------|---------|---------|----------|----------|---------|---------|----------|----------|----------|----------|----------|----------|
|       | TPS     | TPF     | Duration | Position | TPS     | TPF     | Duration | Position | TPS      | TPF      | Duration | Position |
| 1     | 0:00:00 | 0:00:00 | 0:00:00  |          | 0:00:21 | 2:20:41 | 2:20:20  | 1        | 0:00:21  | 7:38:01  | 7:37:40  | 1        |
| 2     | 0:00:00 | 0:00:00 | 0:00:00  |          | 2:21:01 | 3:01:01 | 0:40:00  | 3        | 7:38:21  | 8:19:01  | 0:40:40  | 3        |
| 3     | 0:00:00 | 0:00:00 | 0:00:00  |          | 3:01:50 | 3:36:30 | 0:34:40  | 5        | 8:19:50  | 8:49:50  | 0:30:00  | 5        |
| 4     | 0:00:00 | 0:00:00 | 0:00:00  |          | 3:37:10 | 3:38:10 | 0:01:00  | 8        | 8:50:30  | 8:51:30  | 0:01:00  | 8        |
| 5     | 0:00:21 | 0:00:21 | 0:00:00  | 10       | 3:38:45 | 5:17:25 | 1:38:40  | 11       | 8:52:05  | 10:30:45 | 1:38:40  | 11       |
| 6     | 0:01:16 | 0:07:16 | 0:06:00  | 18       | 5:18:23 | 5:24:23 | 0:06:00  | 20       | 10:31:43 | 10:37:43 | 0:06:00  | 20       |
| 7     | 0:07:56 | 0:08:56 | 0:01:00  | 19       | 5:25:03 | 5:26:03 | 0:01:00  | 19       | 10:38:23 | 10:39:23 | 0:01:00  | 19       |
| 8     | 0:09:41 | 0:27:41 | 0:18:00  | 22       | 5:26:54 | 5:44:54 | 0:18:00  | 24       | 10:40:14 | 10:58:14 | 0:18:00  | 24       |
| 9     | 0:28:21 | 0:29:21 | 0:01:00  | 23       | 5:45:34 | 5:46:34 | 0:01:00  | 23       | 10:58:54 | 10:59:54 | 0:01:00  | 23       |
| 10    | 0:30:02 | 0:31:02 | 0:01:00  | 25       | 5:47:09 | 5:48:09 | 0:01:00  | 23       | 11:00:35 | 11:01:35 | 0:01:00  | 25       |
| 11    | 0:31:42 | 0:32:42 | 0:01:00  | 26       | 5:48:50 | 5:49:50 | 0:01:00  | 25       | 11:02:15 | 11:03:15 | 0:01:00  | 26       |
| 12    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 5:50:25 | 5:51:25 | 0:01:00  | 25       | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 13    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 5:52:05 | 5:53:05 | 0:01:00  | 26       | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 14    | 0:33:23 | 0:34:23 | 0:01:00  | 27       | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 11:03:56 | 11:04:56 | 0:01:00  | 27       |
| 15    | 0:35:03 | 0:36:03 | 0:01:00  | 28       | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 11:05:36 | 11:06:36 | 0:01:00  | 28       |
| 16    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 17    | 0:36:48 | 1:16:48 | 0:40:00  | 30       | 5:54:12 | 6:34:12 | 0:40:00  | 34       | 11:07:33 | 11:47:33 | 0:40:00  | 34       |
| 18    | 1:17:29 | 1:18:29 | 0:01:00  | 32       | 6:34:53 | 6:35:53 | 0:01:00  | 32       | 11:48:14 | 11:49:14 | 0:01:00  | 32       |
| 19    | 1:19:17 | 1:20:17 | 0:01:00  | 35       | 6:36:41 | 6:37:41 | 0:01:00  | 35       | 11:50:02 | 11:51:02 | 0:01:00  | 35       |
| 20    | 1:20:58 | 1:21:58 | 0:01:00  | 37       | 6:38:22 | 6:39:22 | 0:01:00  | 37       | 11:51:43 | 11:52:43 | 0:01:00  | 37       |
| 21    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 22    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 23    | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00 | 0:00:00 | 0:00:00  | 0        | 0:00:00  | 0:00:00  | 0:00:00  | 0        |
| 24    | 1:22:58 | 1:23:58 | 0:01:00  | 42       | 6:40:22 | 6:41:22 | 0:01:00  | 42       | 11:53:43 | 11:54:43 | 0:01:00  | 42       |
| 25    | 1:24:38 | 1:44:38 | 0:20:00  | 43       | 6:42:07 | 7:42:07 | 1:00:00  | 45       | 11:55:28 | 12:55:28 | 1:00:00  | 45       |
| 26    | 1:45:26 | 1:55:26 | 0:10:00  | 47       | 7:42:48 | 7:52:48 | 0:10:00  | 47       | 12:56:09 | 13:06:09 | 0:10:00  | 47       |
| 27    | 1:56:34 | 2:06:34 | 0:10:00  | 59       | 7:53:56 | 7:56:56 | 0:03:00  | 59       | 13:07:17 | 13:17:17 | 0:10:00  | 59       |

## **6.3. Results Evaluation**

After contentment that the algorithm is able to acceptable schedules, the evaluation of results is the next step. The evaluation will take two forms, both will be analyzed to come out with how accurate the algorithm in producing practical anodizing schedules. For this evaluation Combination no. 1, which is composed of Sequence 1 and Configuration 1 is used.

One form to evaluate the results is by comparing the actual and the algorithm starting and the finishing times at the anodizing stage for each day. The other evaluation form is by analyzing the makespans between the algorithm and the actual at the anodizing stage along with the number of jobs produced in each day in one single chart.

### **6.3.1 Evaluation of job flow times**

The first form is evaluating the times of the jobs generated by the algorithm at the anodizing stage with the actual times. The reason for limiting this evaluation on the anodizing stage alone is because it is the only stage with available actual data.

The first form charts can be seen in Figures (6.7) and (6.8) for day no 2 and 8, respectively. The charts for the other days can be seen in Appendix (6). In Figures (6.7) and (6.8), only the anodizing finishing times (i.e. the anodizing finishing times by the algorithm and the ones from the actual data) are plotted, while the starting times are not plotted. The reason for this is because the actual anodizing durations are used in the algorithm as well, so the difference (finishing time – starting time) by the algorithm or by the actual data is the same.

As it can be seen from Figures (6.7) and (6.8), the algorithm is able to reduce the anodizing makespan, where the difference between the (starting or finishing time) of the last job is positive (the last column is lightly colored and positive).

Furthermore, it is noticeable, most of the jobs, especially the ones that are introduced later into the plant (i.e. the ones with the lower priority) have finished the anodizing stage earlier than the actual time, which was reflected in obtaining a positive difference (lightly colored columns). This difference is the between the time given by the algorithm subtracted from the time of the actual data, Equation (6.5) illustrates how this difference is calculated for each job.

$$Differnce_{job\ i} = Algorithm\ Finishing\ Time_{job\ i} - Actaul\ Finishing\ Time_{job\ i} \quad (6.5)$$

On the other hand, there are jobs which obtained a negative difference (dark colored columns), especially the early jobs (i.e. the ones with the higher priority). This may be related to several reasons, one of them is that the durations used in the other stages preceding to the anodizing stage are not accurate (less than the average durations used), another reason might be related in how the jobs were originally distributed among the tanks preceding to the anodizing stage and the way the hoists were assigned in a such a way the made the actual timings better than the ones generated by the algorithm. To the known the exact reasons for why some of the jobs, the actual timing was better than the one produced by the algorithm, more analysis is required, which was not considered in this study, due to the lack of time to complete this thesis.

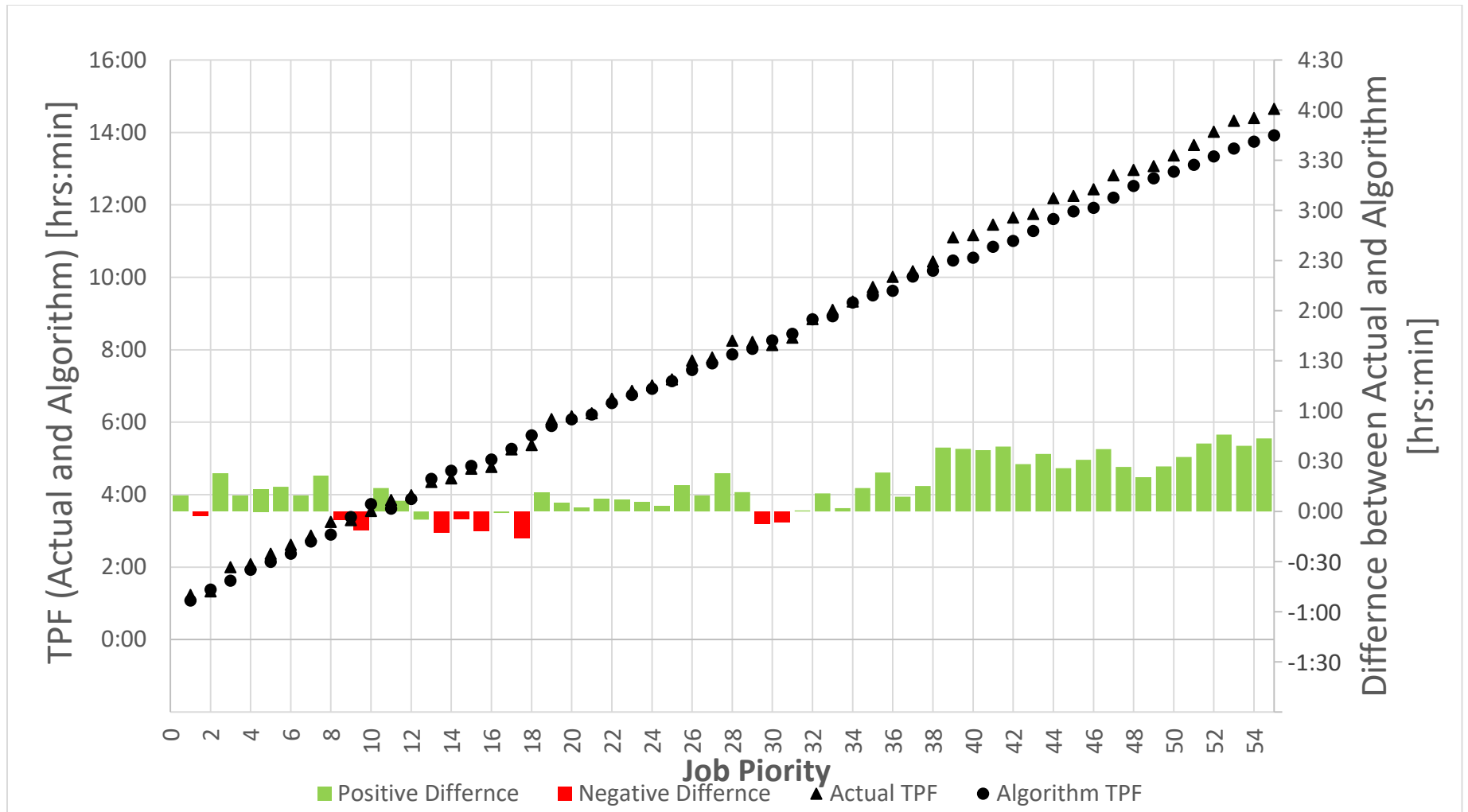


Figure 6.7: Day no. 2 Job Flow Time at the Anodizing Stage Evaluation Chart

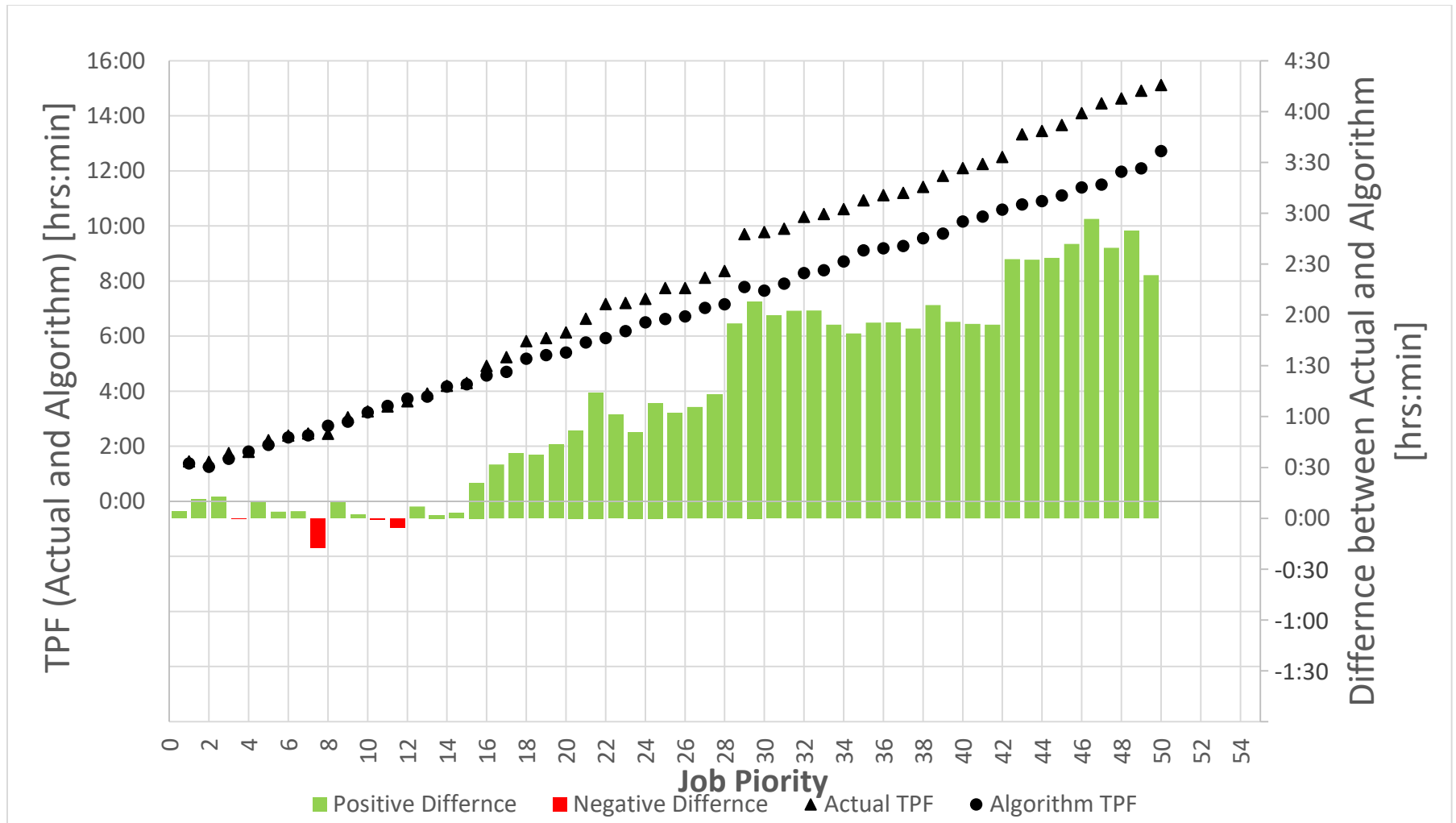


Figure 6.8: Day no. 8 Job Flow Time at the Anodizing Stage Evaluation Chart

Table (6.7) provides all the calculated differences for all the jobs flow time at the anodizing stage using Equation (6.5). The differences are presented in a form of durations (hrs:min:sec). If the difference is are positive (non-shaded cell), then the algorithm reduced the finishing time and vice versa if the difference is negative (shaded cell). The reasons why the actual timing was better than the one by the algorithm for some of the jobs are the same reasons which are explained for Figures (6.7) and (6.8) on page 130.

In Table 6.8, the Makespan (%) is calculated using Equation (6.6)

$$\text{Makespan Percentage} = \frac{\text{Last Job Differnce}}{\text{Actual Makespan}} \times 100\% \quad (6.6)$$

Where: Last Job Difference: is the difference calculated by Equation (6.5).

Table (6.8) illustrates the averages, the largest and the lowest of the all the differences duration in each day. There are four types of daily averages in Table 6.8. The first is the average of the absolute differences, this average is calculated by summing the absolute values of the differences. The second is the normal average which is calculated by taking the summation of the differences. The third is for only the positive differences and the last is only for the negative differences.

Table (6.9) extracts the main outcome from Table (6.8), the most important are those for the last job which are the differences of the makespans (shaded cells). The results show that the algorithm is able to reduce the makespan of each of the 12 days by an average difference of 02:42:10 (hrs:min:sec) which is around 18%, the maximum makespan reduction is 04:15:19 or (26.76%) in Day no. 7, while the minimum makespan reduction is 00:43:41 or (4.97%) in Day no. 2; However, this percentage can be misleading, due to the fact the breakdown times are not considered, which will be affecting the percentages.

Furthermore, from Table (6.8) it can be observed that the difference between the averages of the absolute differences and the averages of the differences is quite the same. This also reflected in the co-responding durations in Table (6.9).

Also, in Tables (6.8) and (6.9), it can be seen that the average duration of the positive differences is always higher the average duration of the negative differences, it gives an indication that the algorithm mostly enters the jobs to the anodizing stage earlier than the actual times.

The highest difference that says the algorithm entered the job before the actual time can be read from the largest of the largest positive difference in Table (6.9), which is 4:30:27, this difference is very large and the reason for this might be the occurrence of breakdowns in the actual production. On the other hand, the worst difference is given by the largest of the largest negative differences, which is -1:39:56.

Table (6.7): Job Flow Differences between the Algorithm and the Actual Timings at the Anodizing Stage.

| Job no. | Job Flow Difference for each job (hrs:min:sec). |           |           |           |           |           |           |           |           |          |           |           |
|---------|-------------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|-----------|-----------|
|         | Day 1                                           | Day 2     | Day 3     | Day 4     | Day 5     | Day 6     | Day 7     | Day 8     | Day 9     | Day 10   | Day 11    | Day 12    |
| 1       | -00:04:46                                       | 00:09:12  | 00:03:12  | 00:13:12  | 00:01:14  | 00:23:12  | -00:04:48 | 00:04:12  | -00:11:46 | 00:33:12 | -00:30:46 | 00:08:12  |
| 2       | -00:04:52                                       | -00:02:48 | -00:04:28 | 00:03:06  | -00:00:18 | 00:40:06  | -00:07:40 | 00:11:00  | -00:11:52 | 00:38:46 | 00:13:08  | 00:14:40  |
| 3       | -00:03:31                                       | 00:22:32  | 00:00:32  | 00:09:09  | -00:15:42 | 00:29:49  | 00:01:09  | 00:12:29  | 00:08:09  | 00:34:58 | 00:16:31  | 00:04:38  |
| 4       | -00:04:03                                       | 00:09:18  | -00:02:02 | 00:02:23  | -00:08:26 | 00:54:55  | 00:14:35  | -00:00:28 | 00:03:37  | 00:51:40 | 00:08:55  | 00:09:52  |
| 5       | -00:01:19                                       | 00:13:18  | -00:11:36 | 00:08:44  | -00:19:45 | 00:42:01  | 00:14:01  | 00:10:06  | 00:25:03  | 00:28:24 | 00:10:03  | 00:08:35  |
| 6       | 00:14:52                                        | 00:14:40  | -00:18:02 | 00:08:38  | 00:03:43  | 00:46:12  | 00:35:23  | 00:03:54  | 00:23:14  | 00:42:38 | 00:03:29  | 00:15:35  |
| 7       | 00:07:53                                        | 00:09:31  | -00:21:09 | 00:12:22  | -00:00:12 | 00:38:11  | 00:19:11  | 00:04:08  | 00:43:53  | 00:45:02 | 00:03:44  | -00:05:49 |
| 8       | 00:11:40                                        | 00:21:20  | -00:12:28 | 00:12:46  | -00:13:23 | 00:56:58  | 00:37:23  | -00:17:28 | 00:40:05  | 00:42:32 | 00:06:45  | -00:00:37 |
| 9       | -00:03:43                                       | -00:05:01 | -00:15:23 | 00:14:14  | -00:01:01 | 00:30:17  | 00:36:08  | 00:09:17  | 01:00:48  | 00:52:48 | 00:06:53  | 00:02:28  |
| 10      | 00:04:15                                        | -00:11:16 | -00:26:45 | 00:24:06  | 00:10:29  | 00:39:15  | 00:54:20  | 00:02:04  | 00:57:00  | 00:43:55 | 00:10:23  | 00:02:38  |
| 11      | 00:05:50                                        | 00:14:01  | -00:17:52 | 00:19:28  | -00:14:12 | 00:32:19  | 00:42:08  | -00:00:41 | 01:22:47  | 00:44:02 | 00:14:30  | 00:06:25  |
| 12      | 00:12:05                                        | 00:06:23  | -00:25:05 | -00:06:36 | 00:08:57  | 00:50:12  | 00:53:35  | -00:05:23 | 01:12:46  | 00:55:43 | -00:03:14 | 00:12:29  |
| 13      | 00:01:23                                        | -00:04:57 | -00:06:19 | 00:43:26  | -00:14:00 | 00:35:18  | 00:40:12  | 00:06:57  | 01:33:21  | 00:50:45 | -00:09:07 | 00:37:01  |
| 14      | 00:05:27                                        | -00:12:33 | -00:23:49 | 00:08:31  | 00:25:57  | 00:51:13  | 00:41:30  | 00:01:53  | 01:34:15  | 01:00:56 | -00:03:51 | 00:44:41  |
| 15      | -00:12:40                                       | -00:04:33 | -00:10:32 | 00:20:01  | 00:11:59  | 00:50:54  | 00:44:30  | 00:03:05  | 01:45:13  | 00:50:43 | -00:01:10 | 00:20:53  |
| 16      | -00:11:28                                       | -00:11:57 | -00:24:14 | 00:12:40  | 00:24:08  | 00:39:26  | 00:36:54  | 00:20:56  | 01:40:45  | 01:21:04 | -00:04:14 | 00:50:59  |
| 17      | 00:03:28                                        | -00:01:02 | -00:20:27 | 00:24:50  | 00:27:08  | 00:31:24  | 00:35:41  | 00:31:44  | 01:59:30  | 01:08:52 | -00:06:39 | 00:54:52  |
| 18      | 00:05:14                                        | -00:15:59 | -00:21:31 | 00:21:58  | 00:29:49  | 00:53:58  | 00:47:48  | 00:38:24  | 02:00:14  | 01:02:47 | -00:00:43 | 00:56:45  |
| 19      | -00:11:55                                       | 00:11:05  | -00:18:41 | 00:16:12  | 00:29:55  | 00:51:46  | 00:41:46  | 00:37:15  | 02:18:57  | 01:17:48 | -00:05:49 | 00:59:31  |
| 20      | 00:21:17                                        | 00:05:08  | -00:33:21 | 00:19:16  | 00:47:43  | 00:50:39  | 00:34:04  | 00:43:30  | 02:13:41  | 01:04:27 | -00:03:47 | 00:57:44  |
| 21      | 00:01:14                                        | 00:02:12  | -00:31:42 | 00:16:44  | 00:53:18  | 00:39:47  | 00:40:03  | 00:51:47  | 02:44:20  | 01:10:30 | -00:10:10 | 00:39:43  |
| 22      | 00:05:27                                        | 00:07:24  | -00:25:22 | 00:26:40  | 01:00:29  | 00:58:49  | 00:29:57  | 01:14:10  | 02:34:40  | 01:17:49 | 00:04:03  | 00:55:11  |
| 23      | 00:07:50                                        | 00:06:49  | -00:36:38 | 00:25:18  | 01:04:51  | 00:26:38  | 00:44:51  | 01:01:20  | 03:34:57  | 01:25:12 | -00:02:36 | 01:01:20  |
| 24      | 00:02:48                                        | 00:05:35  | -00:44:34 | 00:48:06  | 01:33:18  | 00:49:41  | 00:53:25  | 00:50:53  | 03:44:42  | 01:34:45 | 00:06:35  | 01:00:40  |
| 25      | 00:00:13                                        | 00:03:00  | -00:35:31 | 00:57:40  | 01:24:31  | 00:20:49  | 01:11:28  | 01:07:55  | 03:49:51  | 01:51:01 | 00:02:11  | 00:59:19  |
| 26      | 00:04:17                                        | 00:15:27  | -00:33:27 | 00:52:44  | 02:24:32  | 00:27:41  | 03:17:29  | 01:01:58  | 04:08:35  | 02:15:44 | 00:17:27  | 01:09:38  |
| 27      | 00:20:23                                        | 00:09:31  | -00:26:08 | 01:53:41  | 02:24:44  | -00:08:19 | 02:43:37  | 01:05:45  | 04:20:00  | 02:19:24 | 00:24:44  | 01:07:57  |
| 28      | 00:11:45                                        | 00:22:43  | 00:20:18  | 02:08:52  | 02:30:04  | 00:56:43  | 02:59:45  | 01:12:52  | 04:14:03  | 02:01:52 | 00:25:37  | 01:07:42  |
| 29      | 00:21:06                                        | 00:11:27  | -00:35:38 | 01:58:19  | 02:26:13  | 00:35:11  | 02:49:04  | 01:55:02  | 04:20:30  | 02:01:07 | 00:19:57  | 01:32:13  |
| 30      | 00:42:20                                        | -00:07:31 | -00:34:19 | 02:09:46  | 02:54:58  | 00:52:11  | 02:49:43  | 02:08:01  | 04:25:57  | 02:09:21 | 00:27:10  | 01:28:20  |
| 31      | 00:46:29                                        | -00:06:18 | -00:18:14 | 01:54:48  | 02:35:34  | 00:37:07  | 02:49:04  | 01:59:42  | 04:22:19  | 01:59:57 | 00:51:44  | 01:30:07  |
| 32      | 00:56:06                                        | 00:00:36  | 00:06:39  | 02:06:45  | 02:28:32  | 00:36:35  | 02:58:35  | 02:02:27  | 04:04:21  | 01:54:28 | 00:52:21  | 01:29:32  |
| 33      | 00:56:09                                        | 00:10:42  | 00:16:06  | 01:54:35  | 02:35:18  | 00:40:26  | 03:03:25  | 02:02:35  | 04:30:27  | 02:15:27 | 00:55:21  | 01:45:25  |
| 34      | 00:44:33                                        | 00:01:54  | 00:31:03  | 01:59:23  | 02:35:32  | 01:02:43  | 03:05:48  | 01:54:12  | 04:16:59  | 01:53:03 | 00:56:30  | 01:52:45  |
| 35      | 00:47:55                                        | 00:13:58  | 00:33:19  | 01:39:36  | 01:47:04  | 00:58:25  | 03:11:01  | 01:49:08  | 04:15:44  | 01:44:19 | 01:01:45  | 01:55:44  |
| 36      | 00:47:09                                        | 00:23:15  | 00:39:41  | 02:38:49  | 02:37:16  | 01:26:00  | 03:20:14  | 01:55:27  | 04:16:17  | 02:20:03 | 01:10:44  | 02:00:28  |
| 37      | 00:44:28                                        | 00:08:43  | 00:39:06  | 02:48:18  | 02:55:09  | 01:03:01  | 03:30:17  | 01:55:38  | 04:06:40  | 02:09:49 | 00:59:23  | 00:09:00  |
| 38      | 00:37:24                                        | 00:15:07  | 00:51:54  | 02:41:45  | 02:41:50  | 01:08:25  | 03:49:24  | 01:52:02  | 04:11:21  | 02:22:44 | 01:16:28  | 02:01:27  |
| 39      | 00:47:05                                        | 00:38:07  | 00:55:51  | 02:40:05  | 02:48:00  | 01:13:05  | 03:38:04  | 02:05:54  | 04:03:33  | 02:27:15 | 01:24:02  | 02:21:44  |
| 40      | 00:23:13                                        | 00:37:23  | 00:49:03  | 03:20:43  | 02:49:59  | 01:26:11  | 03:54:39  | 01:55:58  | 04:14:13  | 02:27:41 | 01:26:25  | 02:17:22  |
| 41      | 00:30:32                                        | 00:36:38  | 01:02:56  | 03:08:56  | 02:59:41  | 01:45:59  | 03:55:01  | 01:54:41  | 03:51:01  | 02:29:50 | 01:35:39  | 02:29:58  |
| 42      | 00:35:51                                        | 00:38:48  | 00:54:18  | 03:36:14  | 03:04:35  | 01:40:29  | 04:14:52  | 01:54:15  | 03:50:08  | 02:28:07 | 01:42:18  | 02:28:04  |
| 43      | 00:36:08                                        | 00:28:14  | 00:40:06  | 03:33:35  | 03:02:52  | 02:17:26  | 03:53:29  | 02:32:58  | 03:43:17  | 02:34:32 | 01:41:17  | 02:41:34  |
| 44      | 00:29:32                                        | 00:34:19  | 01:48:53  | 03:36:22  | 03:17:44  | 02:22:56  | 04:07:43  | 02:32:36  | 03:49:31  | 02:32:34 | 01:52:02  | 02:38:41  |
| 45      | 00:30:41                                        | 00:25:49  | 01:14:47  | 03:39:35  | 03:17:59  | -01:39:56 | 04:15:19  | 02:33:39  | 03:26:28  | 02:43:50 | 02:03:35  | 02:46:57  |
| 46      | 00:33:59                                        | 00:30:51  | 01:28:03  | 03:26:04  | 03:17:12  | 02:11:38  |           | 02:41:50  | 03:31:35  | 02:40:30 | 00:04:40  | 03:01:17  |
| 47      | 00:32:34                                        | 00:37:15  | 01:17:18  |           |           |           |           | 02:56:40  | 03:44:20  | 03:00:36 | 02:12:38  | 03:01:17  |
| 48      | 00:22:00                                        | 00:26:37  | 01:23:26  |           |           |           |           | 02:39:41  |           | 03:00:50 | 02:10:41  | 03:24:19  |
| 49      | 00:26:50                                        | 00:20:02  |           |           |           |           |           | 02:49:42  |           | 03:16:11 | 02:29:17  | 03:50:08  |
| 50      | 00:56:12                                        | 00:26:56  |           |           |           |           |           | 02:23:31  |           |          | 02:44:44  | 03:43:21  |
| 51      | 01:12:35                                        | 00:32:34  |           |           |           |           |           |           |           |          | 02:55:07  |           |
| 52      | 01:02:59                                        | 00:40:37  |           |           |           |           |           |           |           |          | 02:55:10  |           |
| 53      | 01:06:04                                        | 00:45:56  |           |           |           |           |           |           |           |          |           |           |
| 54      |                                                 | 00:39:12  |           |           |           |           |           |           |           |          |           |           |
| 55      |                                                 | 00:43:41  |           |           |           |           |           |           |           |          |           |           |

Table (6.8): Averages, Largest, and Lowest Differences from Table 6.6 (Anodizing Stage)

|                                             |                                                  | Day 1     | Day 2     | Day 3     | Day 4     | Day 5     | Day 6     | Day 7     | Day 8     | Day 9     | Day 10   | Day 11    | Day 12    |
|---------------------------------------------|--------------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|-----------|-----------|
| <b>Makespan for the last job</b>            | <b>Last Job Difference (Makespan Difference)</b> | 01:06:04  | 00:43:41  | 01:23:26  | 03:26:04  | 03:17:12  | 02:11:38  | 04:15:19  | 02:23:31  | 03:44:20  | 03:16:11 | 02:55:10  | 03:43:21  |
|                                             | <b>Actual Makespan</b>                           | 14:25:00  | 14:39:00  | 14:49:00  | 14:59:00  | 14:45:00  | 15:01:00  | 15:54:00  | 15:07:00  | 15:41:00  | 15:30:00 | 15:38:00  | 16:00:00  |
|                                             | <b>Makespan Difference (%)</b>                   | 7.64%     | 4.97%     | 9.39%     | 22.92%    | 23.06%    | 14.61%    | 26.76%    | 15.82%    | 24.07%    | 21.07%   | 18.67%    | 23.27%    |
| <b>Difference of Flow Time for All Jobs</b> | <b>Average of Absolute Differences</b>           | 00:23:41  | 00:17:29  | 00:32:45  | 01:20:33  | 01:29:33  | 00:55:32  | 01:50:52  | 01:13:45  | 02:44:19  | 01:39:59 | 00:46:39  | 01:19:43  |
|                                             | <b>Average of Differences</b>                    | 00:21:29  | 00:14:26  | 00:06:17  | 01:20:15  | 01:25:46  | 00:50:49  | 01:50:19  | 01:12:47  | 02:43:18  | 01:39:59 | 00:43:30  | 01:19:27  |
|                                             | <b>Average of Positive Differences</b>           | 00:27:13  | 00:19:57  | 00:46:50  | 01:22:11  | 01:48:59  | 00:55:35  | 01:55:44  | 01:19:38  | 02:51:05  | 01:39:59 | 00:58:36  | 01:22:54  |
|                                             | <b>Largest Positive Difference</b>               | 01:12:35  | 00:45:56  | 01:48:53  | 03:39:35  | 03:17:59  | 02:22:56  | 04:15:19  | 02:56:40  | 04:30:27  | 03:16:11 | 02:55:10  | 03:50:08  |
|                                             | <b>Smallest Positive Difference</b>              | 00:00:13  | 00:00:36  | 00:00:32  | 00:02:23  | 00:01:14  | 00:20:49  | 00:01:09  | 00:01:53  | 00:03:37  | 00:28:24 | 00:02:11  | 00:02:28  |
|                                             | <b>Averages of Negative Differences</b>          | -00:06:29 | -00:07:38 | -00:22:41 | -00:06:36 | -00:09:40 | -00:54:07 | -00:06:14 | -00:06:00 | -00:11:49 |          | -00:06:51 | -00:03:13 |
|                                             | <b>Largest Negative Difference</b>               | -00:12:40 | -00:15:59 | -00:44:34 | -00:06:36 | -00:19:45 | -01:39:56 | -00:07:40 | -00:17:28 | -00:11:52 |          | -00:30:46 | -00:05:49 |
|                                             | <b>Smallest Negative Difference</b>              | -00:01:19 | -00:01:02 | -00:02:02 | -00:06:36 | -00:00:12 | -00:08:19 | -00:04:48 | -00:00:28 | -00:11:46 |          | -00:00:43 | -00:00:37 |

Table (6.9): Main Outcomes of the Differences between the Algorithm and the Actual Timings at the Anodizing Stage

|                                             |                                                      |                  |
|---------------------------------------------|------------------------------------------------------|------------------|
| <b>Makespan for the last job</b>            | <b>Average of Makespan Differences (%)</b>           | 17.69%           |
|                                             | <b>Average of Makespan Differences (hrs:min:sec)</b> | <b>02:42:10</b>  |
|                                             | <b>Minimum Makespan Difference</b>                   | <b>00:43:41</b>  |
|                                             | <b>Maximum Makespan Difference</b>                   | <b>04:15:19</b>  |
| <b>Difference of Flow Time for All Jobs</b> | <b>Average of Averages of Absolute Differences</b>   | <b>01:12:54</b>  |
|                                             | <b>Average of Averages of Differences</b>            | <b>01:09:02</b>  |
|                                             | <b>Average of Averages of Positive Differences</b>   | <b>01:19:03</b>  |
|                                             | <b>Largest of the Largest Positive Differences</b>   | <b>04:30:27</b>  |
|                                             | <b>Smallest of Smallest Positive Differences</b>     | <b>00:00:13</b>  |
|                                             | <b>Average of Averages of Negative Differences</b>   | <b>-00:12:51</b> |
|                                             | <b>Largest of the Largest Negative Differences</b>   | <b>-01:39:56</b> |
|                                             | <b>Smallest of Smallest Negative Differences</b>     | <b>-00:00:12</b> |

### **6.3.2 Evaluation of anodizing makespans and number of jobs**

The second form of validation is a single chart that shows two times for all of the twelve days: the actual makespan at the anodizing stage and the algorithm makespan at the anodizing stage. These times were plotted along with the corresponding number of jobs, and the three types sections, namely: matt small hollow section (recipe no. 1), matt ordinary section (recipes no. 2 and 3), and all colored sections (recipes no. 4 to 30), as shown in Figure (6.9).

The figure aims to evaluate the makespans and to justify why the actual makespans at the anodizing for are relatively long by studying the number of jobs processed in those days and their types.

In Figure (6.9), it can be seen that for days 1, 2 and 3, the algorithm anodizing makespans are relatively longer than the other days, in-addition the gaps (difference) between the actual makespans and the algorithm makespans are shorter than the other days. This does not mean that the algorithm performance in reducing the makespan is less in those three days, in fact, it might be the opposite and the reasons for this are related to the breakdown times, number and verity of treated jobs in each day.

In days 1, 2 and 3 the number of jobs of matt finish-small hollow section combined with the number of colored sections is high. Days 9, 10 and 11 also have the same thing, but they differ from days 1, 2 and 3 for the likelihood of longer breakdown times, which is reflected on the high actual makespan.

Figure (6.9) suggest that the best day from year 2015 is day no.2 and the best day in year 2017 is day no. 8 because both of them have a verity of jobs and the gap between the actual and algorithm makespans is the shortest.

Table (6.10) shows the makespans times and the number of jobs in Figure (6.9).

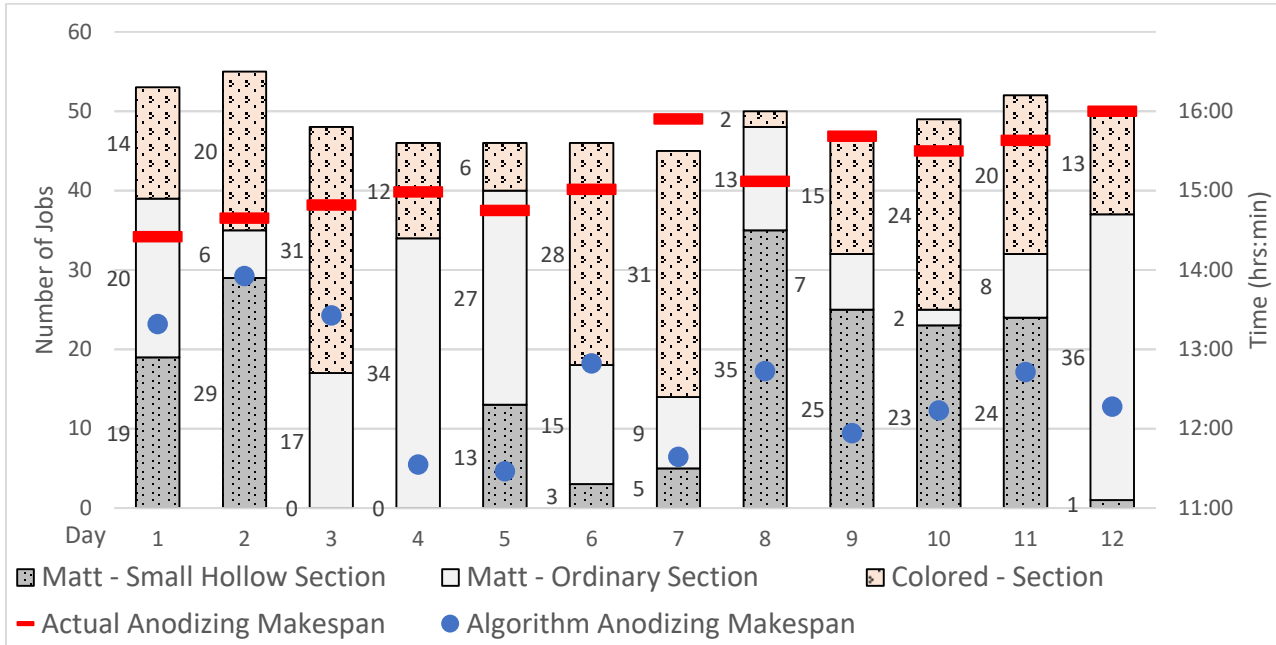


Figure (6.9): Evaluation (makespans vs. number of jobs)

Table (6.10): Evaluation (makespans vs. number of jobs)

| Day | Time related to Anodizing Stage<br>(hrs:min) |                        |            | Number of Jobs                      |                                 |                      |       |
|-----|----------------------------------------------|------------------------|------------|-------------------------------------|---------------------------------|----------------------|-------|
|     | The Actual Makespan                          | The Algorithm Makespan | Difference | Matt Finish – Small Hollow Sections | Matt Finish – Ordinary Sections | Color – All Sections | Total |
| 1   | 14:25                                        | 13:18                  | 1:06       | 19                                  | 20                              | 14                   | 53    |
| 2   | 14:39                                        | 13:55                  | 0:43       | 29                                  | 6                               | 20                   | 55    |
| 3   | 14:49                                        | 13:25                  | 1:23       | 0                                   | 17                              | 31                   | 48    |
| 4   | 14:59                                        | 11:32                  | 3:26       | 0                                   | 34                              | 12                   | 46    |
| 5   | 14:45                                        | 11:27                  | 3:17       | 13                                  | 27                              | 6                    | 46    |
| 6   | 15:01                                        | 12:49                  | 2:11       | 3                                   | 15                              | 28                   | 46    |
| 7   | 15:54                                        | 11:38                  | 4:15       | 5                                   | 9                               | 31                   | 45    |
| 8   | 15:07                                        | 12:43                  | 2:23       | 35                                  | 13                              | 2                    | 50    |
| 9   | 15:41                                        | 11:56                  | 3:44       | 25                                  | 7                               | 15                   | 47    |
| 10  | 15:30                                        | 12:13                  | 3:16       | 23                                  | 2                               | 24                   | 49    |
| 11  | 15:38                                        | 12:42                  | 2:55       | 24                                  | 8                               | 20                   | 52    |
| 12  | 16:00                                        | 12:16                  | 3:43       | 1                                   | 36                              | 13                   | 50    |

### 6.3.3 Waiting stages results

The point of studying the durations in the waiting stages is to see which of the waiting stages the jobs stay more than in the other waiting stages, and in which the jobs stay less. This is because the shorter the total waiting duration in any stage, the better schedule the algorithm is able to give, minding that the algorithm idea is based on delaying the violating jobs, thus long delays (more waiting time) are expected. This necessitates the need for another complimentary algorithm capable of choosing the best position and/or hoist that reduces the makespan (less waiting duration). However, even with such complimentary algorithm, the reduction in makespan is expected to be insignificant, because choosing a better position and/or better hoist to do the job is not that critical in this anodizing plant, due to the small differences between alternative hoists travel durations and alternative position (treatment) durations. Nevertheless, such results will be left out for further study in the future.

Tables (6.11) and (6.12) shows the results of jobs waiting durations within the different waiting stages while they are being treated. Table (6.11) shows the total durations of the different waiting stages for each of the twelve days. Also, it shows the average daily waiting duration at each of these waiting stages. Whereas Tables (6.12) shows for each day the average waiting duration per job at each of the five waiting stages, as well as the job average daily duration at each of these waiting stages. Minding that the waiting durations for the Loading stage and for the Output Buffer Zone does not include the original waiting duration, which is 10 or 3 minutes for jigging the jobs in the Loading stage and 10 minutes for cooling the jobs in the Output Buffer Zone.

From the tables, it is clear that the stage with longest waiting durations is the outside stage, whereas the output buffer zone is almost with zero waiting (without the original 10 minutes).

Excluding the Outside waiting stage, the Input Buffer Zone 2 has the highest daily average of waiting time (83:01:05), which is reflected into job average waiting time in this stage of (1:41:51).

The summation of the job average waiting times of the three in-process waiting stages, namely; Loading, Input Buffer Zone 1, and Input Buffer Zone 2, is 2:32:58 as can be obtained from the last row of Table (6.12).

From above it is clear that the waiting time in the Input Buffer Zone 2 should be reduced. This can be done by identifying and overcoming the bottleneck stage to speed the flow of the jobs through the different stages

Table (6.11): The Daily Total Durations of the Different Waiting Stages

| Day                          | Total Waiting Durations (hrs:min:sec) |                 |                     |                     |                    |
|------------------------------|---------------------------------------|-----------------|---------------------|---------------------|--------------------|
|                              | Outside                               | Loading         | Input Buffer Zone 1 | Input Buffer Zone 2 | Output Buffer Zone |
| 1                            | 179:52:20                             | 17:08:20        | 28:48:40            | 90:37:40            | 0:00:00            |
| 2                            | 211:07:20                             | 15:10:40        | 31:40:00            | 96:26:20            | 0:00:00            |
| 3                            | 141:58:00                             | 21:02:20        | 28:26:00            | 89:20:40            | 0:02:20            |
| 4                            | 125:39:40                             | 17:58:00        | 24:30:40            | 79:30:40            | 0:03:00            |
| 5                            | 114:15:00                             | 14:06:40        | 23:54:40            | 78:02:20            | 0:14:40            |
| 6                            | 125:21:20                             | 17:04:40        | 24:37:20            | 77:34:20            | 0:09:40            |
| 7                            | 113:50:20                             | 15:49:40        | 24:02:40            | 76:00:20            | 0:00:20            |
| 8                            | 136:57:40                             | 6:44:20         | 24:09:20            | 76:56:00            | 0:03:20            |
| 9                            | 124:26:20                             | 12:25:20        | 25:23:00            | 80:22:00            | 0:08:00            |
| 10                           | 142:52:00                             | 11:46:00        | 26:35:00            | 82:13:00            | 0:07:20            |
| 11                           | 166:25:00                             | 15:19:40        | 27:44:20            | 86:05:20            | 0:00:20            |
| 12                           | 144:14:40                             | 18:46:40        | 26:09:20            | 83:04:20            | 0:04:20            |
| <b>Daily Average Waiting</b> | <b>143:54:58</b>                      | <b>15:16:52</b> | <b>26:20:05</b>     | <b>83:01:05</b>     | <b>0:04:27</b>     |

Table (6.12): The Job Daily Averages of Durations at the Different Waiting Stage

| Day                                | Average Waiting Durations (hrs:min:sec) |                |                     |                     |                    |
|------------------------------------|-----------------------------------------|----------------|---------------------|---------------------|--------------------|
|                                    | Outside                                 | Loading        | Input Buffer Zone 1 | Input Buffer Zone 2 | Output Buffer Zone |
| 1                                  | 3:23:38                                 | 0:19:24        | 0:32:37             | 1:42:36             | 0:00:00            |
| 2                                  | 3:50:19                                 | 0:16:33        | 0:34:33             | 1:45:12             | 0:00:00            |
| 3                                  | 2:57:27                                 | 0:26:18        | 0:35:33             | 1:51:41             | 0:00:03            |
| 4                                  | 2:43:54                                 | 0:23:26        | 0:31:58             | 1:43:43             | 0:00:04            |
| 5                                  | 2:29:01                                 | 0:18:24        | 0:31:11             | 1:41:47             | 0:00:19            |
| 6                                  | 2:43:30                                 | 0:22:17        | 0:32:07             | 1:41:11             | 0:00:13            |
| 7                                  | 2:31:47                                 | 0:21:06        | 0:32:04             | 1:41:20             | 0:00:00            |
| 8                                  | 2:44:21                                 | 0:08:05        | 0:28:59             | 1:32:19             | 0:00:04            |
| 9                                  | 2:38:51                                 | 0:15:51        | 0:32:24             | 1:42:36             | 0:00:10            |
| 10                                 | 2:54:56                                 | 0:14:24        | 0:32:33             | 1:40:40             | 0:00:09            |
| 11                                 | 3:12:01                                 | 0:17:41        | 0:32:00             | 1:39:20             | 0:00:00            |
| 12                                 | 2:53:06                                 | 0:22:32        | 0:31:23             | 1:39:41             | 0:00:05            |
| <b>Average of Averages</b>         | <b>2:55:14</b>                          | <b>0:18:50</b> | <b>0:32:17</b>      | <b>1:41:51</b>      | <b>0:00:06</b>     |
| <b>In-process waiting duration</b> | -                                       | <b>2:32:58</b> |                     |                     | -                  |

### **6.3.4 Utilization of the different positions**

The aim of this sub-section is to study the utilization of the different positions and hence their stages to identify the critical ones that causing bottlenecks. Similarly, the ones which are poorly utilized will be identified.

Tables (6.13) and (6.14) shows for each position the percentage distribution of the two shifts time (16 hours) categorized into the following four durations: the idle time before treatment; idle time in-between treatments; idle time after finishing treatments of all jobs; and finally treatment total time.

The tables show the results for two days schedule namely, Days 2 and 8, whereas the results of the other days are included in Appendix (7). Figures (6.10) and (6.11) show the results in Tables (6.13) and (6.14), respectively.

The percentage of treatments total times and the percentage idle of gaps between the treatments indicate the level of utilization of the position.

In Tables (6.13), (6.14), the positions of the Hot Sealing stage (43, 44, 45 and 46), the Anodizing stage (30, 31, 33 and 34), and the Etching stage (22 and 24) are the busiest positions. The daily average utilization of the Hot Sealing, Anodizing, and Etching positions are around 57%, 38%, and 49%, respectively. The percentage of the anodizing stage is lower than the Etching stage is because the fourth anodizing tank (position no. 34) is not used in day 2; however, the first anodizing tank (position no. 30) has high percentage, thus the anodizing stage will be considered as the second busiest stage in this study.

Because the lack on time only the Anodizing and Hot Sealing (the most two busiest stages in the plant) are selected for further analysis in this study to examine whether or not they constrain the plant productivity, i.e. causing bottleneck problem.

Table (6.13): Results of Utilization of the Different Positions in Day no.2

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing                | 30           | 3.83%               | 20.63%                | 14.08%           | 61.46%               |
| Loading              | 02           | 0.04%               | 0.49%                 | 35.69%           | 63.78%               |                          | 31           | 4.88%               | 29.01%                | 12.99%           | 53.13%               |
|                      | 03           | 0.04%               | 0.49%                 | 33.82%           | 65.66%               |                          | 33           | 6.09%               | 48.71%                | 15.31%           | 29.90%               |
|                      | 04           | 0.04%               | 0.45%                 | 37.85%           | 61.67%               |                          | 34           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Input Buffers Zone 1 | 05           | 0.04%               | 4.80%                 | 31.63%           | 63.54%               | Anodizing Rinsing        | 32           | 6.92%               | 74.53%                | 12.81%           | 5.73%                |
|                      | 06           | 0.04%               | 4.01%                 | 30.57%           | 65.38%               |                          | 35           | 7.11%               | 76.62%                | 12.63%           | 3.65%                |
|                      | 07           | 0.04%               | 2.92%                 | 32.84%           | 64.20%               |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 64.60%                | 30.40%           | 4.90%                | Transferor 2             | 37 and 38    | 7.28%               | 74.53%                | 12.45%           | 5.73%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.88%                 | 27.04%           | 71.04%               | Electro-Coloring         | 39           | 0.00%               | 68.70%                | 22.97%           | 8.33%                |
|                      | 11           | 0.04%               | 1.63%                 | 24.69%           | 73.65%               | Electro-Coloring Rinsing | 40           | 0.00%               | 75.12%                | 22.80%           | 2.08%                |
|                      | 12           | 0.04%               | 1.38%                 | 25.98%           | 72.60%               |                          | 41           | 0.00%               | 75.31%                | 22.61%           | 2.08%                |
|                      | 13           | 0.04%               | 2.51%                 | 23.01%           | 74.44%               | Demi-Rinsing             | 42           | 7.49%               | 74.53%                | 12.24%           | 5.73%                |
|                      | 14           | 0.04%               | 1.55%                 | 21.92%           | 76.49%               | Hot Sealing              | 43           | 7.67%               | 15.58%                | 11.13%           | 65.63%               |
|                      | 15           | 0.04%               | 1.35%                 | 20.77%           | 77.85%               |                          | 44           | 8.51%               | 16.06%                | 9.80%            | 65.63%               |
|                      | 16           | 0.04%               | 0.94%                 | 19.37%           | 79.65%               |                          | 45           | 9.73%               | 16.08%                | 8.57%            | 65.63%               |
|                      | 17           | 0.04%               | 1.07%                 | 28.20%           | 70.69%               |                          | 46           | 10.52%              | 21.07%                | 7.47%            | 60.94%               |
| Alkaline             | 18           | 0.13%               | 49.31%                | 18.68%           | 31.88%               | Output Buffers Zone      | 47           | 12.44%              | 32.24%                | 6.36%            | 48.96%               |
|                      | 20           | 24.16%              | 23.31%                | 50.03%           | 2.50%                |                          | 48           | 13.28%              | 58.89%                | 19.50%           | 8.33%                |
| Alkaline Rinsing     | 19           | 0.83%               | 74.94%                | 18.51%           | 5.73%                |                          | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 24.80%                | 17.95%           | 56.25%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 2.06%               | 34.53%                | 16.54%           | 46.88%               |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 3.12%               | 74.95%                | 16.20%           | 5.73%                |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 74.95%                | 15.86%           | 5.73%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 74.95%                | 15.69%           | 5.73%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 51.39%                | 18.39%           | 2.71%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 51.39%                | 18.21%           | 2.71%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 47.56%                | 5.93%            | 32.92%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 63.26%                | 19.05%           | 3.23%                |

Table (6.14): Results of Utilization of the Different Positions in Day no.8

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing                | 30           | 3.83%               | 13.93%                | 20.47%           | 61.77%               |
| Loading              | 02           | 0.04%               | 0.42%                 | 46.77%           | 52.78%               |                          | 31           | 4.88%               | 20.15%                | 24.45%           | 50.52%               |
|                      | 03           | 0.04%               | 0.42%                 | 46.32%           | 53.23%               |                          | 33           | 6.09%               | 24.05%                | 30.59%           | 39.27%               |
|                      | 04           | 0.04%               | 0.42%                 | 48.61%           | 50.94%               |                          | 34           | 0.00%               | 54.07%                | 39.26%           | 6.67%                |
| Input Buffers Zone 1 | 05           | 0.04%               | 2.31%                 | 40.75%           | 56.91%               | Anodizing Rinsing        | 32           | 6.92%               | 67.57%                | 20.30%           | 5.21%                |
|                      | 06           | 0.04%               | 4.45%                 | 41.83%           | 53.68%               |                          | 35           | 7.11%               | 67.78%                | 20.11%           | 5.00%                |
|                      | 07           | 0.04%               | 2.37%                 | 42.98%           | 54.62%               |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 54.95%                | 40.57%           | 4.38%                | Transferor 2             | 37 and 38    | 7.28%               | 67.57%                | 19.93%           | 5.21%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.28%                 | 31.39%           | 67.29%               | Electro-Coloring         | 39           | 0.00%               | 20.54%                | 79.25%           | 0.21%                |
|                      | 11           | 0.04%               | 1.67%                 | 27.91%           | 70.38%               | Electro-Coloring Rinsing | 40           | 0.00%               | 20.72%                | 79.08%           | 0.21%                |
|                      | 12           | 0.04%               | 1.83%                 | 39.52%           | 58.61%               |                          | 41           | 0.00%               | 20.90%                | 78.89%           | 0.21%                |
|                      | 13           | 0.04%               | 2.19%                 | 38.43%           | 59.34%               | Demi-Rinsing             | 42           | 7.49%               | 67.57%                | 19.72%           | 5.21%                |
|                      | 14           | 0.04%               | 1.00%                 | 35.73%           | 63.23%               | Hot Sealing              | 43           | 7.67%               | 24.76%                | 17.57%           | 50.00%               |
|                      | 15           | 0.04%               | 0.89%                 | 36.99%           | 62.08%               |                          | 44           | 8.51%               | 11.61%                | 17.38%           | 62.50%               |
|                      | 16           | 0.04%               | 0.88%                 | 34.68%           | 64.41%               |                          | 45           | 9.73%               | 12.36%                | 21.66%           | 56.25%               |
|                      | 17           | 0.04%               | 0.68%                 | 31.64%           | 67.64%               |                          | 46           | 10.52%              | 20.97%                | 24.76%           | 43.75%               |
| Alkaline             | 18           | 0.13%               | 45.80%                | 27.19%           | 26.88%               | Output Buffers Zone      | 47           | 12.44%              | 39.01%                | 16.26%           | 32.29%               |
|                      | 20           | 24.16%              | 40.81%                | 30.66%           | 4.38%                |                          | 48           | 13.28%              | 51.18%                | 16.44%           | 19.10%               |
| Alkaline Rinsing     | 19           | 0.83%               | 66.95%                | 27.02%           | 5.21%                |                          | 49           | 0.00%               | 74.90%                | 24.06%           | 1.04%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 25.18%                | 25.07%           | 48.75%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 2.06%               | 24.42%                | 28.52%           | 45.00%               |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 3.12%               | 66.78%                | 24.89%           | 5.21%                |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 66.62%                | 24.72%           | 5.21%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 66.62%                | 24.54%           | 5.21%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 46.56%                | 24.37%           | 1.56%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 46.56%                | 24.19%           | 1.56%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 55.47%                | 15.83%           | 15.10%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 58.82%                | 15.27%           | 11.46%               |

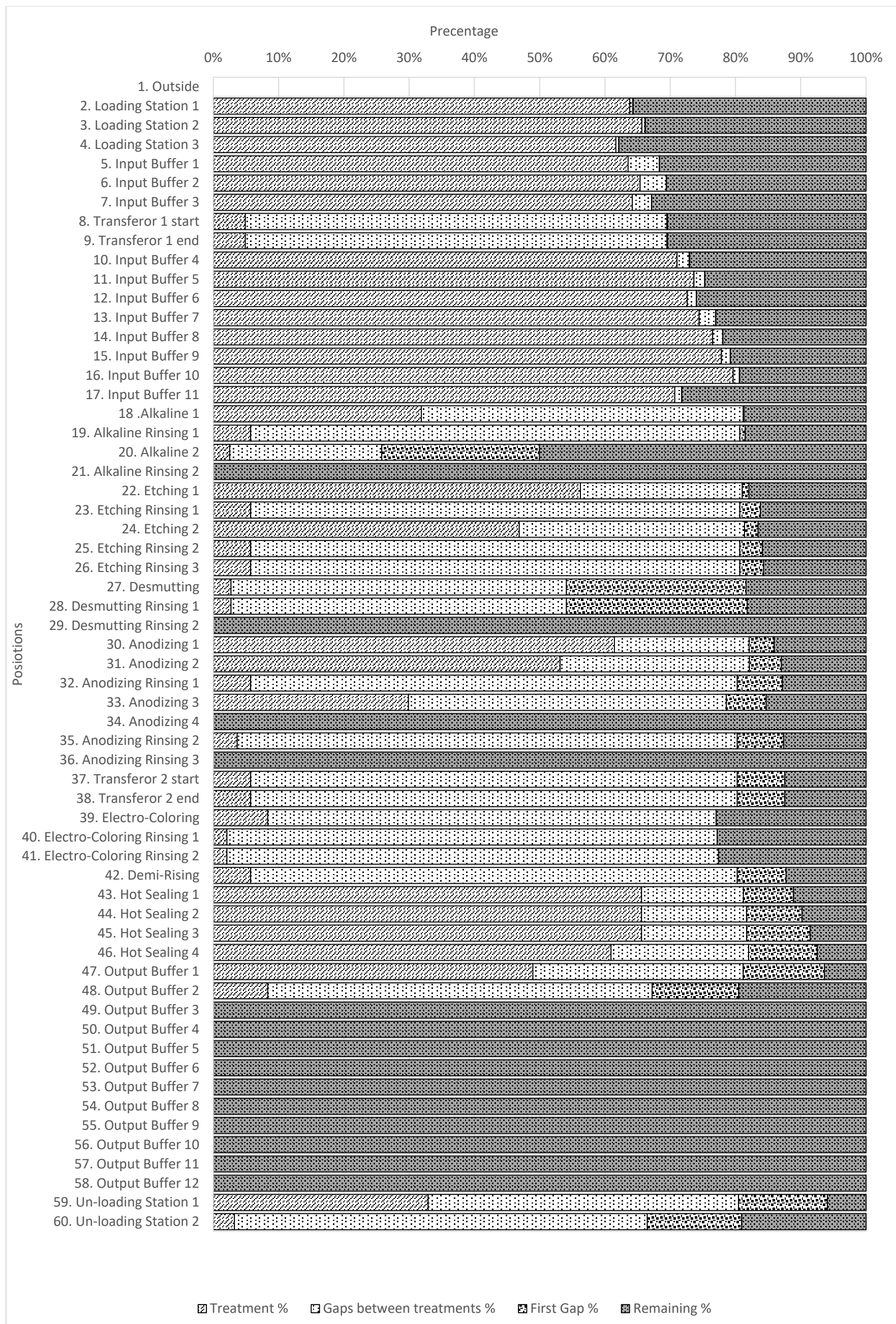


Figure (6.10): Day 02 – Utilization (Occupancy) Percentage per Position

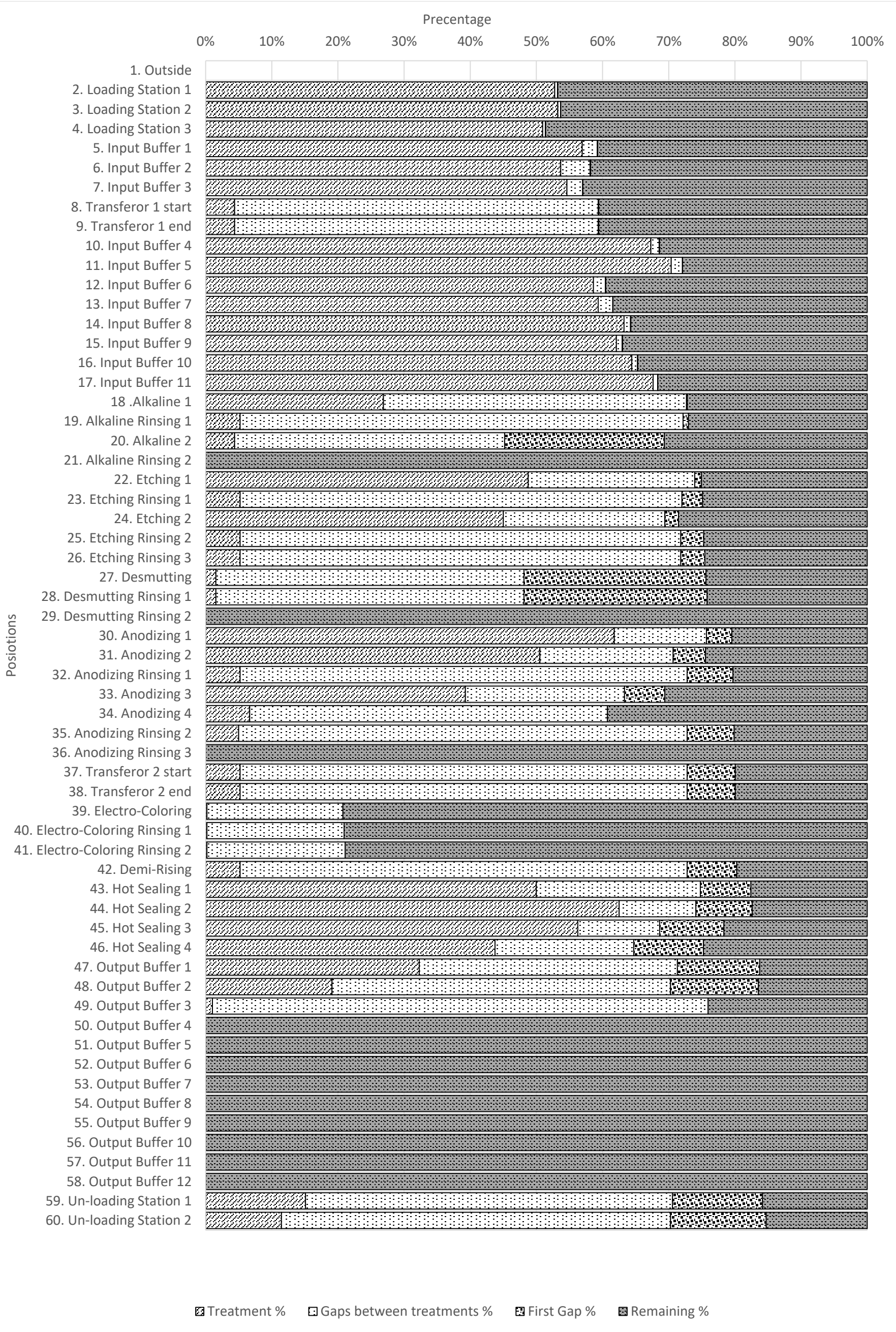


Figure (6.11): Day 08 – Utilization (Occupancy) Percentage per Position

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# **Chapter Seven**

## **Experimentation and Analysis of Results**

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**7.1. Introduction**

**7.2. Effect of Sequence for Fixed Configuration on  
the Makespan**

**7.3. Effect of Configuration for Fixed Sequence on  
the Makespan**

**7.4. Effect of Configuration and Sequence on the  
Makespan**

**7.5. Effect of Configuration and Sequence on  
Overcoming the Bottleneck Problem**

**7.6. Further Experimentations**

# **Chapter Seven**

## **Extermination and Analysis of Results**

### **7.1. Introduction**

The aim of this chapter is to test the effect of the nine different combinations mentioned in Section 3.7.2 to on reducing the makespan and on reducing the negative effect of the main bottleneck problem. These nine combinations include the Combination no. 1 (the actual combination of the actual jobs sequence and the actual tanks configuration). For the other eight combinations the jobs sequences and the tanks configurations changes.

Tables (7.1), (7.2) and (7.3) shows the results of three combinations, these combinations are 2, 5 and 9, the results of the eight combinations (2 to 9) can be seen in Appendix (8).

Furthermore, two combinations with actual configurations are selected in an attempt to test the algorithm ability to add more jobs, since it reduced the makespan. The performance of the two selected combinations will be measured through the percentage of time utilized from the whole time of two shifts (16 hours), and through the percentage of added jobs to the original number of jobs.

Before moving to the analyses in this chapter, it worth mentioning that average computation time for each run in all of the nine combinations for all the twelve days is 2.5 minutes. The computation time for each run does not include the time for exporting the results to the excel files.

Table (7.1): Main Results for Combination 2

| Run | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|-----|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
|     |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 1   | 1   | 14:25:00           | 12:48:43  | 1:36:17     | 15:35:56            | 14:03:29  | 1:32:27     | 0:02:50            |
| 2   | 2   | 14:39:00           | 13:38:40  | 1:00:20     | 15:42:56            | 14:46:37  | 0:56:19     | 0:03:00            |
| 3   | 3   | 14:49:00           | 12:53:55  | 1:55:05     | 15:59:56            | 14:08:40  | 1:51:16     | 0:03:00            |
| 4   | 4   | 14:59:00           | 11:09:11  | 3:49:49     | 16:24:56            | 12:38:54  | 3:46:02     | 0:02:16            |
| 5   | 5   | 14:15:00           | 11:13:06  | 3:01:54     | 15:40:56            | 12:42:50  | 2:58:06     | 0:02:02            |
| 6   | 6   | 15:01:00           | 12:54:27  | 2:06:33     | 16:26:56            | 14:24:11  | 2:02:45     | 0:02:43            |
| 7   | 7   | 15:54:00           | 11:25:29  | 4:28:31     | 17:19:56            | 12:55:12  | 4:24:44     | 0:02:13            |
| 8   | 8   | 15:07:00           | 11:36:05  | 3:30:55     | 16:32:56            | 13:05:49  | 3:27:07     | 0:02:06            |
| 9   | 9   | 15:32:00           | 11:41:02  | 3:50:58     | 17:01:22            | 12:36:32  | 4:24:50     | 0:02:10            |
| 10  | 10  | 15:31:00           | 11:48:47  | 3:42:13     | 16:49:56            | 12:31:32  | 4:18:24     | 0:02:20            |
| 11  | 11  | 15:38:00           | 11:52:33  | 3:45:27     | 16:56:56            | 13:15:16  | 3:41:40     | 0:02:10            |
| 12  | 12  | 16:00:00           | 11:41:38  | 4:18:22     | 17:29:22            | 13:17:06  | 4:12:16     | 0:02:35            |

Table (7.2): Main Results for Combination 5

| Run | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|-----|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
|     |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 37  | 1   | 14:25:00           | 11:34:12  | 2:50:48     | 15:46:52            | 13:02:10  | 2:44:42     | 0:02:01            |
| 38  | 2   | 14:39:00           | 13:23:12  | 1:15:48     | 16:00:52            | 14:51:10  | 1:09:42     | 0:02:36            |
| 39  | 3   | 14:49:00           | 13:27:52  | 1:21:08     | 16:23:52            | 15:08:50  | 1:15:02     | 0:02:59            |
| 40  | 4   | 14:59:00           | 11:28:19  | 3:30:41     | 16:25:52            | 12:21:30  | 4:04:22     | 0:02:07            |
| 41  | 5   | 14:15:00           | 13:23:59  | 0:51:01     | 15:51:52            | 14:26:58  | 1:24:54     | 0:02:46            |
| 42  | 6   | 15:01:00           | 12:26:32  | 2:34:28     | 16:30:22            | 14:02:00  | 2:28:22     | 0:02:29            |
| 43  | 7   | 15:54:00           | 11:50:59  | 4:03:01     | 17:20:52            | 12:44:11  | 4:36:41     | 0:02:17            |
| 44  | 8   | 15:07:00           | 11:23:44  | 3:43:16     | 16:33:52            | 12:16:44  | 4:17:08     | 0:02:03            |
| 45  | 9   | 15:32:00           | 11:01:59  | 4:30:01     | 17:01:22            | 11:57:28  | 5:03:54     | 0:02:02            |
| 46  | 10  | 15:31:00           | 12:34:33  | 2:56:27     | 17:00:22            | 14:10:00  | 2:50:22     | 0:02:27            |
| 47  | 11  | 15:38:00           | 13:25:03  | 2:12:57     | 17:07:22            | 14:20:45  | 2:46:37     | 0:02:42            |
| 48  | 12  | 16:00:00           | 11:41:00  | 4:19:00     | 17:36:52            | 12:43:59  | 4:52:53     | 0:02:23            |

Table (7.3): Main Results for Combination 9

| Run | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|-----|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
|     |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 85  | 1   | 14:25:00           | 11:46:38  | 2:38:22     | 15:28:56            | 12:54:23  | 2:34:33     | 0:02:21            |
| 86  | 2   | 14:39:00           | 14:37:23  | 0:01:37     | 15:42:56            | 15:22:39  | 0:20:17     | 0:03:26            |
| 87  | 3   | 14:49:00           | 13:26:01  | 1:22:59     | 15:59:56            | 14:40:46  | 1:19:10     | 0:02:57            |
| 88  | 4   | 14:59:00           | 11:27:04  | 3:31:56     | 16:24:56            | 12:56:47  | 3:28:09     | 0:02:11            |
| 89  | 5   | 14:15:00           | 11:13:07  | 3:01:53     | 15:33:56            | 11:56:05  | 3:37:51     | 0:02:04            |
| 90  | 6   | 15:01:00           | 12:15:27  | 2:45:33     | 16:19:56            | 12:58:24  | 3:21:32     | 0:02:32            |
| 91  | 7   | 15:54:00           | 11:23:10  | 4:30:50     | 17:12:56            | 12:45:54  | 4:27:02     | 0:02:13            |
| 92  | 8   | 15:07:00           | 11:05:41  | 4:01:19     | 16:25:56            | 11:48:26  | 4:37:30     | 0:02:03            |
| 93  | 9   | 15:32:00           | 10:48:54  | 4:43:06     | 16:50:56            | 12:11:39  | 4:39:17     | 0:01:59            |
| 94  | 10  | 15:31:00           | 11:32:28  | 3:58:32     | 16:49:56            | 12:15:25  | 4:34:31     | 0:02:11            |
| 95  | 11  | 15:38:00           | 12:14:02  | 3:23:58     | 16:56:56            | 12:56:59  | 3:59:57     | 0:02:50            |
| 96  | 12  | 16:00:00           | 12:55:07  | 3:04:53     | 17:18:56            | 13:38:05  | 3:40:51     | 0:02:44            |

## 7.2. Effect of Sequences for Fixed Configuration on the Makespan

Tables (7.4), (7.5) and (7.6) show the obtained makespan generated by the algorithm for each of the three sequences is for Configurations 1, 2 and 3, respectively, for the twelve days alongside with co-responding number of jobs produced and their types, namely: matt finish-small hollow section (M-SH); Matt finish-ordinary sections (M-OR); and colored sections (Color). Figures (7.1), (7.2) and (7.3) illustrate the results in Tables (7.4), (7.5) and (7.6), respectively. The shaded cells contain the minimum makespan.

Table (7.4): Sequences Effect with Configuration 1 on the Makespan

| Day | Makespan by Algorithm<br>(hrs:min:sec)<br>for Configuration 1 and |            |            | Number of Jobs                      |                                 |                      | Total |
|-----|-------------------------------------------------------------------|------------|------------|-------------------------------------|---------------------------------|----------------------|-------|
|     | Sequence 1                                                        | Sequence 2 | Sequence 3 | Matt Finish – Small Hollow Sections | Matt Finish – Ordinary Sections | Color – All Sections |       |
|     | S1                                                                | S2         | S3         | M-SH                                | M-OR                            | Color                |       |
|     | ▲                                                                 | —          | ●          | ▣                                   | □                               | ▤                    |       |
| 1   | 14:33:41                                                          | 15:08:09   | 13:45:07   | 19                                  | 20                              | 14                   | 53    |
| 2   | 15:03:04                                                          | 15:22:30   | 14:54:56   | 29                                  | 6                               | 20                   | 55    |
| 3   | 14:40:29                                                          | 14:29:11   | 14:40:09   | 0                                   | 17                              | 31                   | 48    |
| 4   | 13:02:40                                                          | 12:17:39   | 13:00:46   | 0                                   | 34                              | 12                   | 46    |
| 5   | 12:57:31                                                          | 14:26:58   | 12:29:41   | 13                                  | 27                              | 6                    | 46    |
| 6   | 14:19:06                                                          | 13:30:48   | 13:15:21   | 3                                   | 15                              | 28                   | 46    |
| 7   | 12:44:01                                                          | 12:43:31   | 13:07:55   | 5                                   | 9                               | 31                   | 45    |
| 8   | 13:33:27                                                          | 12:55:48   | 13:10:40   | 35                                  | 13                              | 2                    | 50    |
| 9   | 13:09:10                                                          | 12:51:17   | 13:03:40   | 25                                  | 7                               | 15                   | 47    |
| 10  | 13:36:32                                                          | 13:25:57   | 14:05:29   | 23                                  | 2                               | 24                   | 49    |
| 11  | 14:05:33                                                          | 14:33:23   | 13:25:05   | 24                                  | 8                               | 20                   | 52    |
| 12  | 13:52:06                                                          | 14:17:01   | 13:35:15   | 1                                   | 36                              | 13                   | 50    |

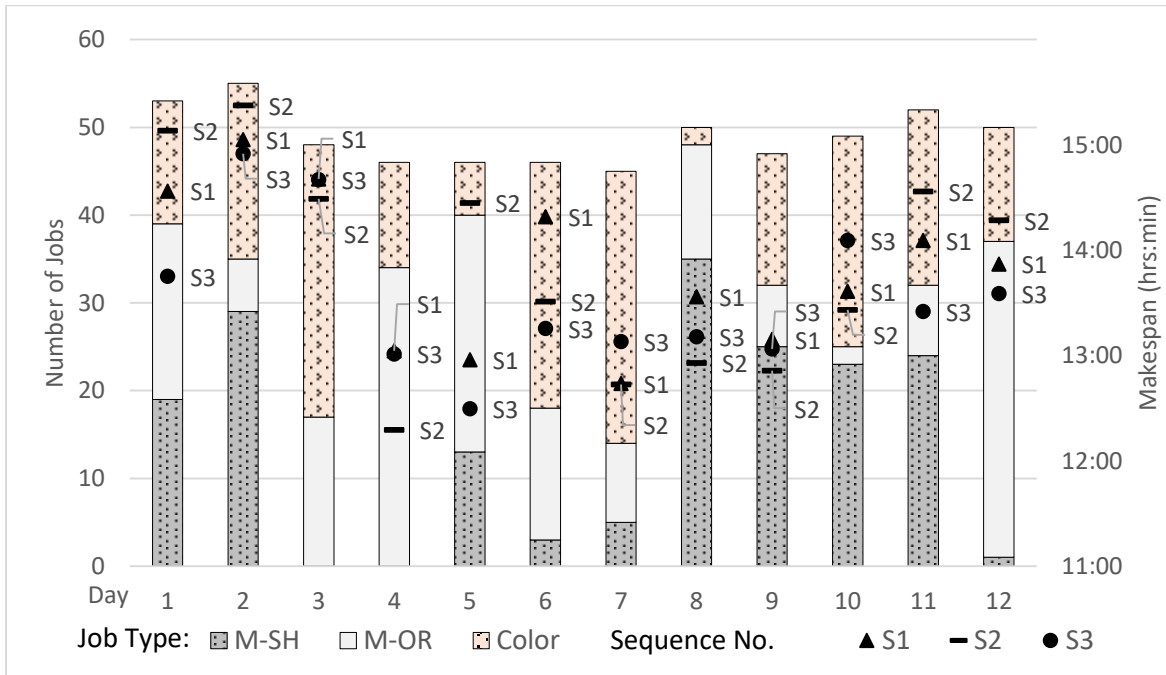


Figure (7.1): Sequences Effect with Configuration 1 on the Makespan.

Table (7.5): Sequences Effect with Configuration 2 on the Makespan

| Day | Makespan by Algorithm<br>(hrs:min:sec)<br>for Configuration 2 and |            |            | Number of Jobs                      |                                 |                      | Total |
|-----|-------------------------------------------------------------------|------------|------------|-------------------------------------|---------------------------------|----------------------|-------|
|     | Sequence 1                                                        | Sequence 2 | Sequence 3 | Matt Finish – Small Hollow Sections | Matt Finish – Ordinary Sections | Color – All Sections |       |
|     | S1                                                                | S2         | S3         | M-SH                                | M-OR                            | Color                |       |
|     | ▲                                                                 | —          | ●          | ▣                                   | □                               | ▤                    |       |
| 1   | 14:03:29                                                          | 13:02:10   | 13:02:12   | 19                                  | 20                              | 14                   | 53    |
| 2   | 14:46:37                                                          | 14:51:10   | 14:36:10   | 29                                  | 6                               | 20                   | 55    |
| 3   | 14:08:40                                                          | 15:08:50   | 14:38:59   | 0                                   | 17                              | 31                   | 48    |
| 4   | 12:38:54                                                          | 12:21:30   | 12:56:47   | 0                                   | 34                              | 12                   | 46    |
| 5   | 12:42:50                                                          | 14:26:58   | 11:56:05   | 13                                  | 27                              | 6                    | 46    |
| 6   | 14:24:11                                                          | 14:02:00   | 12:58:04   | 3                                   | 15                              | 28                   | 46    |
| 7   | 12:55:12                                                          | 12:44:11   | 11:43:07   | 5                                   | 9                               | 31                   | 45    |
| 8   | 13:05:49                                                          | 12:16:44   | 11:55:04   | 35                                  | 13                              | 2                    | 50    |
| 9   | 12:36:32                                                          | 11:57:28   | 12:16:15   | 25                                  | 7                               | 15                   | 47    |
| 10  | 12:31:32                                                          | 14:10:00   | 12:14:45   | 23                                  | 2                               | 24                   | 49    |
| 11  | 13:15:16                                                          | 14:20:45   | 13:35:12   | 24                                  | 8                               | 20                   | 52    |
| 12  | 13:17:06                                                          | 12:43:59   | 12:35:07   | 1                                   | 36                              | 13                   | 50    |

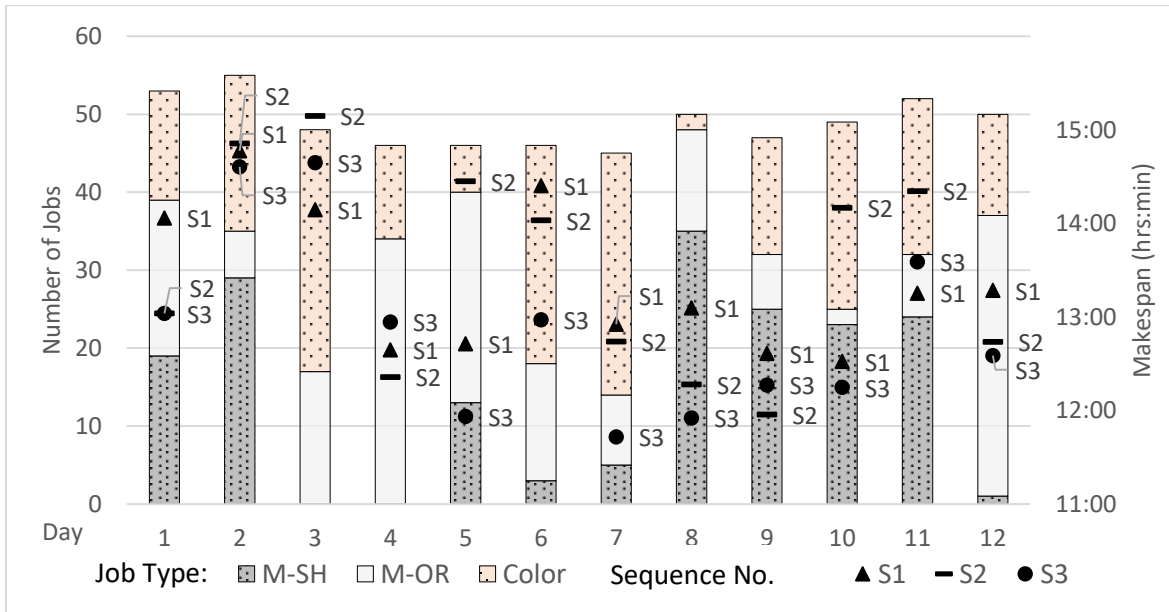


Figure (7.2): Sequences Effect with Configuration 2 on the Makespan

Table (7.6): Sequences Effect with Configuration 3 on the Makespan

| Day | Makespan by Algorithm<br>(hrs:min:sec)<br>for Configuration 3 and |            |            | Number of Jobs                      |                                 |                      | Total |
|-----|-------------------------------------------------------------------|------------|------------|-------------------------------------|---------------------------------|----------------------|-------|
|     | Sequence 1                                                        | Sequence 2 | Sequence 3 | Matt Finish – Small Hollow Sections | Matt Finish – Ordinary Sections | Color – All Sections |       |
|     | S1                                                                | S2         | S3         | M-SH                                | M-OR                            | Color                |       |
|     | ▲                                                                 | —          | ●          | ■                                   | □                               | ■                    |       |
| 1   | 14:03:29                                                          | 13:02:10   | 12:54:23   | 19                                  | 20                              | 14                   | 53    |
| 2   | 15:03:28                                                          | 15:16:28   | 15:22:39   | 29                                  | 6                               | 20                   | 55    |
| 3   | 14:08:40                                                          | 14:53:10   | 14:40:46   | 0                                   | 17                              | 31                   | 48    |
| 4   | 12:28:41                                                          | 12:21:50   | 12:56:47   | 0                                   | 34                              | 12                   | 46    |
| 5   | 12:51:10                                                          | 15:15:22   | 11:56:05   | 13                                  | 27                              | 6                    | 46    |
| 6   | 14:17:31                                                          | 14:02:20   | 12:58:24   | 3                                   | 15                              | 28                   | 46    |
| 7   | 12:04:48                                                          | 12:44:11   | 12:45:54   | 5                                   | 9                               | 31                   | 45    |
| 8   | 13:03:09                                                          | 12:17:04   | 11:48:26   | 35                                  | 13                              | 2                    | 50    |
| 9   | 12:36:40                                                          | 12:11:58   | 12:11:39   | 25                                  | 7                               | 15                   | 47    |
| 10  | 12:16:01                                                          | 14:10:41   | 12:15:25   | 23                                  | 2                               | 24                   | 49    |
| 11  | 13:51:57                                                          | 14:20:45   | 12:56:59   | 24                                  | 8                               | 20                   | 52    |
| 12  | 13:18:48                                                          | 12:44:19   | 13:38:05   | 1                                   | 36                              | 13                   | 50    |

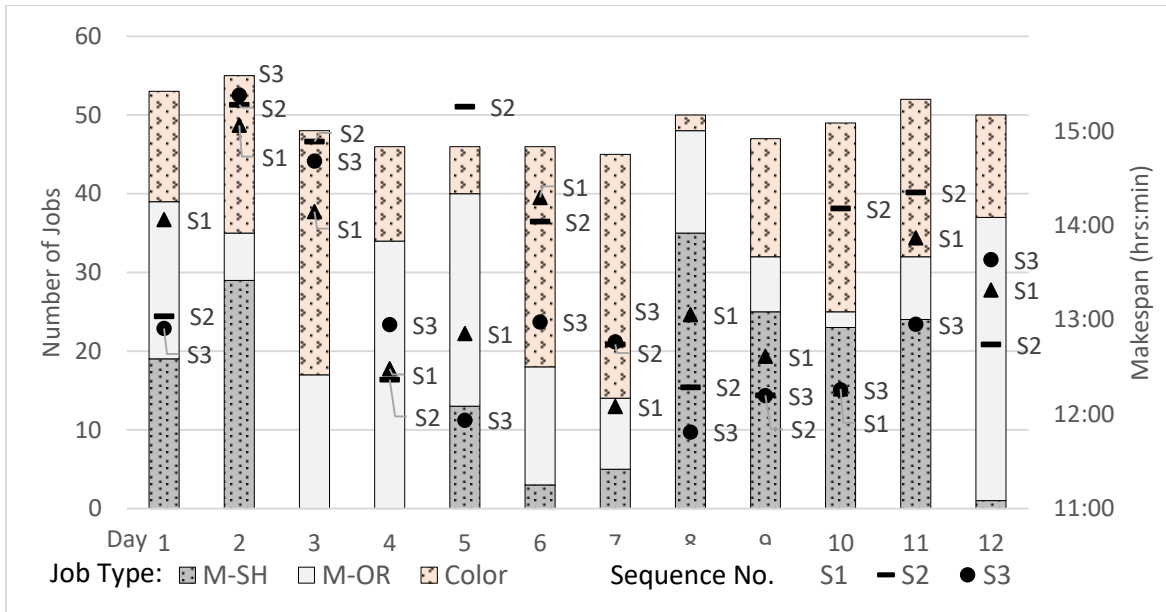


Figure (7.3): Sequences Effect with Configuration 3 on the Makespan

It can be noticed from Tables (7.4), (7.5) and (7.6) that Sequence no. 3 has better performance with respect to the makespan, irrespective of the given number of jobs for the three given types. For example day no. 1 and 6 differ on the number of colored sections, but both showed Sequence 3 with the minimum makespan. Tables (7.7) sum-up the total scores of each sequence obtained from Tables (7.4), (7.5) and (7.6), and it show Sequence no. 3 with the highest score.

Table (7.7): Score of minimum makespan from Tables (7.4), (7.5) and (7.6)

| <b>Fixed Configuration</b>  | <b>Sequence 1</b> | <b>Sequence 2</b> | <b>Sequence 3</b> | <b>Total Days</b> |
|-----------------------------|-------------------|-------------------|-------------------|-------------------|
| <b>Configuration 1</b>      | 0                 | 6                 | 6                 | 12                |
| <b>Configuration 2</b>      | 2                 | 3                 | 7                 | 12                |
| <b>Configuration 3</b>      | 3                 | 2                 | 7                 | 12                |
| <b>Sequence Total Score</b> | 6                 | 11                | <b>20</b>         | 36                |

It can be concluded from Table (7.7) that for a plant with a fixed configuration, it is most likely to process the jobs using the third sequence, which starts by processing the long recipes first and leave the short recipes to the last, irrespective of the number of jobs and their types. However a detailed analysis of the jobs number and their exact types may reveal different conclusion.

### **7.3. Effect of Configurations for Fixed Sequence on the Makespan**

In Tables (7.8), (7.9) and (7.10), each of the three configurations are tested for Sequences 1, 2 and 3, respectively. The number of jobs and their type are not independent of the configuration, so they are not plotted as in the previous sub-section, therefore, the analysis is focused only on the makespans times alone. The shaded cells contain the minimum makespan.

Table (7.8): Tanks Configuration Effect with Sequence 1 on the Makespan

| Day | Makespan by Algorithm (hrs:min:sec)<br>for Sequence 1 and |                    |                    |
|-----|-----------------------------------------------------------|--------------------|--------------------|
|     | Configuration<br>1                                        | Configuration<br>2 | Configuration<br>3 |
| 1   | 14:33:41                                                  | 14:03:29           | 14:03:29           |
| 2   | 15:03:04                                                  | 14:46:37           | 15:03:28           |
| 3   | 14:40:29                                                  | 14:08:40           | 14:08:40           |
| 4   | 13:02:40                                                  | 12:38:54           | 12:28:41           |
| 5   | 12:57:31                                                  | 12:42:50           | 12:51:10           |
| 6   | 14:19:06                                                  | 14:24:11           | 14:17:31           |
| 7   | 12:44:01                                                  | 12:55:12           | 12:04:48           |
| 8   | 13:33:27                                                  | 13:05:49           | 13:03:09           |
| 9   | 13:09:10                                                  | 12:36:32           | 12:36:40           |
| 10  | 13:36:32                                                  | 12:31:32           | 12:16:01           |
| 11  | 14:05:33                                                  | 13:15:16           | 13:51:57           |
| 12  | 13:52:06                                                  | 13:17:06           | 13:18:48           |

Table (7.9): Tanks Configuration Effect with Sequence 2 on the Makespan

| Day | Makespan by Algorithm (hrs:min:sec)<br>for Sequence 2 and |                    |                    |
|-----|-----------------------------------------------------------|--------------------|--------------------|
|     | Configuration<br>1                                        | Configuration<br>2 | Configuration<br>3 |
| 1   | 15:08:09                                                  | 13:02:10           | 13:02:10           |
| 2   | 15:22:30                                                  | 14:51:10           | 15:16:28           |
| 3   | 14:29:11                                                  | 15:08:50           | 14:53:10           |
| 4   | 12:17:39                                                  | 12:21:30           | 12:21:50           |
| 5   | 14:26:58                                                  | 14:26:58           | 15:15:22           |
| 6   | 13:30:48                                                  | 14:02:00           | 14:02:20           |
| 7   | 12:43:31                                                  | 12:44:11           | 12:44:11           |
| 8   | 12:55:48                                                  | 12:16:44           | 12:17:04           |
| 9   | 12:51:17                                                  | 11:57:28           | 12:11:58           |
| 10  | 13:25:57                                                  | 14:10:00           | 14:10:41           |
| 11  | 14:33:23                                                  | 14:20:45           | 14:20:45           |
| 12  | 14:17:01                                                  | 12:43:59           | 12:44:19           |

Table (7.10): Tanks Configuration Effect with Sequence 3 on the Makespan

| Day | Makespan by Algorithm (hrs:min:sec)<br>for Sequence 3 and |                    |                    |
|-----|-----------------------------------------------------------|--------------------|--------------------|
|     | Configuration<br>1                                        | Configuration<br>2 | Configuration<br>3 |
| 1   | 13:45:07                                                  | 13:02:12           | 12:54:23           |
| 2   | 14:54:56                                                  | 14:36:10           | 15:22:39           |
| 3   | 14:40:09                                                  | 14:38:59           | 14:40:46           |
| 4   | 13:00:46                                                  | 12:56:47           | 12:56:47           |
| 5   | 12:29:41                                                  | 11:56:05           | 11:56:05           |
| 6   | 13:15:21                                                  | 12:58:04           | 12:58:24           |
| 7   | 13:07:55                                                  | 11:43:07           | 12:45:54           |
| 8   | 13:10:40                                                  | 11:55:04           | 11:48:26           |
| 9   | 13:03:40                                                  | 12:16:15           | 12:11:39           |
| 10  | 14:05:29                                                  | 12:14:45           | 12:15:25           |
| 11  | 13:25:05                                                  | 13:35:12           | 12:56:59           |
| 12  | 13:35:15                                                  | 12:35:07           | 13:38:05           |

Table (7.11) shows the number of days where the makespan is minimum for each configuration and sequence. It can be noticed from the Tables (7.8), (7.9) and (7.10), that Configuration no.2 has achieved the minimum makespan in more days than the other configurations. It generates the minimum makespan 23 times for all the sequences, 16 out of which are generated only by this configuration while the rest are generated also by the other configurations as shown in Table (7.11). Configuration no. 3 generated the minimum makespan 14 times, 6 out of which are also generated by the other two configurations. Based on these results and in-addition to the fact that Configuration 2 is less in size than Configuration 3 by one Hot Sealing tank, it is preferred over Configuration 3. Thus it can be concluded that the best configuration design of the plant for any of the three sequences is Configuration 2.

Table (7.11): Score of Minimum Makespans for Tables (7.8), (7.9) and (7.10)

| Fixed Sequence         | Sequence 1 | Sequence 2  | Sequence 3 | Configuration Total Score  |
|------------------------|------------|-------------|------------|----------------------------|
| <b>Configuration 1</b> | 0          | 6<br>(5+1)* | 0          | 6<br>(5+1)                 |
| <b>Configuration 2</b> | 8<br>(6+2) | 7<br>(4+3)  | 8<br>(6+2) | <b>23</b><br><b>(16+7)</b> |
| <b>Configuration 3</b> | 6<br>(4+2) | 2<br>(0+2)  | 6<br>(4+2) | 14<br>(8+6)                |

\* Minimum makespan of one day out of 6 days results is obtained also by another configuration.

## 7.4. Effect of Configuration and Sequence on Makespan

Table (7.12) presents the makespans obtained by the algorithm for all the nine combinations, of the configurations and sequences. Figure (7.4) combines all the results in one chart, the chart also shows the number of jobs in each day and their types. What can be drawn from the chart is that Combination S3C2 (Sequence 3 and Configuration 2) is the best because for half of the days (6 days) generated the minimum makespan as indicated also by Table (6.11). It is followed by Combination S3C3 with a total of four times of shortest makespan (one of them is also obtained by S3C2), and one time for each of these combinations S1C2, S1C3, S2C1, and S2C2.

It can be concluded from Table (6.12) and Figure (7.4), that the best re-design of the plant is with Configuration 2, and the best jobs sequence is Sequence 3.

Table (7.12): Makespans for the Different Combinations

| Day   | Makespan by the Algorithm (hrs:min:sec) |          |          |          |          |          |          |            |            | Minimum Makespan |
|-------|-----------------------------------------|----------|----------|----------|----------|----------|----------|------------|------------|------------------|
|       | S1C1                                    | S1C2     | S1C3     | S2C1     | S2C2     | S2C3     | S3C1     | S3C2       | S3C3       |                  |
| 1     | 14:33:41                                | 14:03:29 | 14:03:29 | 15:08:09 | 13:02:10 | 13:02:10 | 13:45:07 | 13:02:12   | 12:54:23   | S3C3             |
| 2     | 15:03:04                                | 14:46:37 | 15:03:28 | 15:22:30 | 14:51:10 | 15:16:28 | 14:54:56 | 14:36:10   | 15:22:39   | S3C2             |
| 3     | 14:40:29                                | 14:08:40 | 14:08:40 | 14:29:11 | 15:08:50 | 14:53:10 | 14:40:09 | 14:38:59   | 14:40:46   | S1C2 & S1C3      |
| 4     | 13:02:40                                | 12:38:54 | 12:28:41 | 12:17:39 | 12:21:30 | 12:21:50 | 13:00:46 | 12:56:47   | 12:56:47   | S2C1             |
| 5     | 12:57:31                                | 12:42:50 | 12:51:10 | 14:26:58 | 14:26:58 | 15:15:22 | 12:29:41 | 11:56:05   | 11:56:05   | S3C2 & S3C3      |
| 6     | 14:19:06                                | 14:24:11 | 14:17:31 | 13:30:48 | 14:02:00 | 14:02:20 | 13:15:21 | 12:58:04   | 12:58:24   | S3C2             |
| 7     | 12:44:01                                | 12:55:12 | 12:04:48 | 12:43:31 | 12:44:11 | 12:44:11 | 13:07:55 | 11:43:07   | 12:45:54   | S3C2             |
| 8     | 13:33:27                                | 13:05:49 | 13:03:09 | 12:55:48 | 12:16:44 | 12:17:04 | 13:10:40 | 11:55:04   | 11:48:26   | S3C3             |
| 9     | 13:09:10                                | 12:36:32 | 12:36:40 | 12:51:17 | 11:57:28 | 12:11:58 | 13:03:40 | 12:16:15   | 12:11:39   | S2C2             |
| 10    | 13:36:32                                | 12:31:32 | 12:16:01 | 13:25:57 | 14:10:00 | 14:10:41 | 14:05:29 | 12:14:45   | 12:15:25   | S3C2             |
| 11    | 14:05:33                                | 13:15:16 | 13:51:57 | 14:33:23 | 14:20:45 | 14:20:45 | 13:25:05 | 13:35:12   | 12:56:59   | S3C3             |
| 12    | 13:52:06                                | 13:17:06 | 13:18:48 | 14:17:01 | 12:43:59 | 12:44:19 | 13:35:15 | 12:35:07   | 13:38:05   | S3C2             |
| Score | 0                                       | 1        | 1        | 1        | 1        | 0        | 0        | 6<br>(5+1) | 4<br>(3+1) |                  |

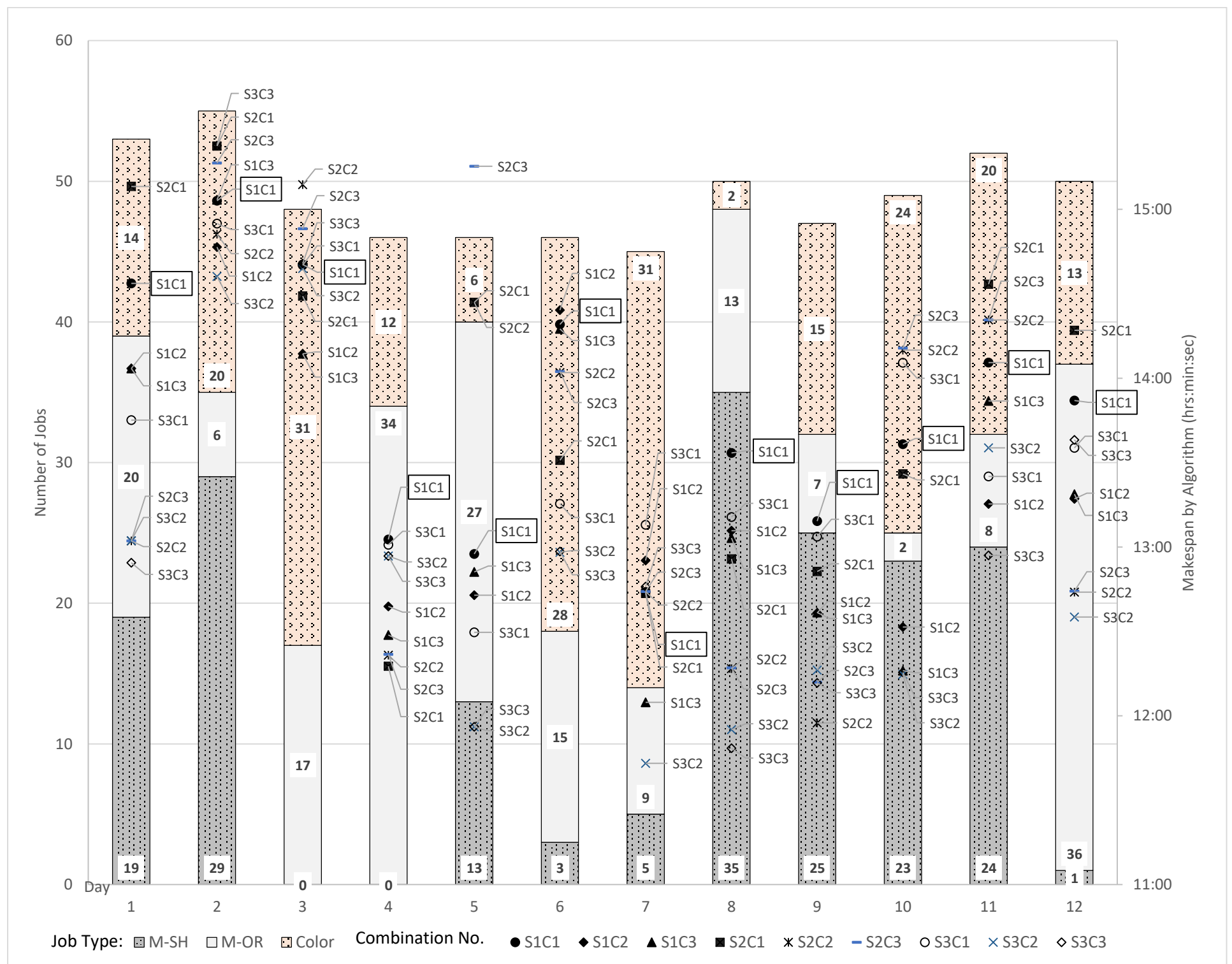


Figure (7.4): Effect of Sequence and Configuration on the Makespan

## **7.5. Effect of Configuration and Sequence on Overcoming the Bottleneck Problem**

The aim of this section is to see the effect of the combinations on the negative effect of the main bottleneck problem by observing the distribution of the daily average number of jobs (the average number of jobs of the twelve days) obtained by the algorithm for each combination.

Although, it will be more interesting to do this analysis including the daily average durations of the four types of time (the same durations that are used in the utilization of different positions in sub-section (6.3.4)), but is not considered, because it will be very detailed. Thus the analysis will focus on the daily average distribution of jobs in the Anodizing stage and the Hot Sealing stage; however, in Appendix (9), shows figures that combines these four types of time with the number of jobs.

Table (7.13) shows the distribution of the jobs done by the algorithm for all the nine combinations by taking the round-up daily average number of jobs treated in the anodizing tanks and the hot sealing tanks. Form the table, it can be noticed that the different sequences of the jobs are not that significant, while the differences by the configurations are quite noticeable.

It can be seen that the fifth anodizing tank (position no. 36) in Combinations (2, 3, 5, 6, 8 and 9) has no effect of speeding the flow of jobs based on the zero average values (i.e. it is never used). On the other hand, the sixth hot sealing tank (position no. 48) is in Combinations (3, 6 and 9) has a little effect, which is reflected on Combinations (3 and 9) with an around-up average of only one job. This means combinations with Configuration no. 2 without the fifth anodizing tanks are the best to reduce the negative effect of the main bottleneck at the Hot Sealing Stage.

Table (7.13): Average Number of Jobs (round-up) in Anodizing and Hot Sealing Tanks for the Nine Combinations

|             | Position No. | Average number of jobs per combination (Seq. /Conf.): |      |      |      |      |      |      |      |      |
|-------------|--------------|-------------------------------------------------------|------|------|------|------|------|------|------|------|
|             |              | 1                                                     | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    |
|             |              | S1C1                                                  | S1C2 | S1C3 | S2C1 | S2C2 | S2C3 | S3C1 | S3C2 | S3C3 |
| Anodizing   | 30           | 15                                                    | 19   | 19   | 19   | 19   | 19   | 19   | 19   | 19   |
|             | 31           | 13                                                    | 17   | 17   | 17   | 17   | 17   | 17   | 16   | 16   |
|             | 33           | 12                                                    | 12   | 12   | 12   | 11   | 11   | 12   | 13   | 12   |
|             | 34           | 10                                                    | 3    | 3    | 3    | 3    | 3    | 3    | 3    | 3    |
|             | 36           | -                                                     | 0    | 0    | -    | 0    | 0    | -    | 0    | 0    |
| Hot Sealing | 43           | 22                                                    | 20   | 20   | 22   | 21   | 21   | 22   | 21   | 21   |
|             | 44           | 10                                                    | 10   | 10   | 11   | 11   | 11   | 11   | 10   | 10   |
|             | 45           | 10                                                    | 9    | 9    | 10   | 10   | 10   | 10   | 9    | 9    |
|             | 46           | 8                                                     | 8    | 8    | 8    | 7    | 7    | 9    | 8    | 7    |
|             | 47           | -                                                     | 4    | 4    | -    | 3    | 3    | -    | 4    | 3    |
|             | 48           | -                                                     | -    | 1    | -    | -    | 0    | -    | -    | 1    |

## 7.6. Further Experimentations

In this section, additional jobs will be added to the actual number of jobs for each day in an attempt to fully utilize the remaining time from the two shifts in each day (16 hours). The aim of this is to see the algorithm ability to fully utilize the whole time of the two shifts (16 hours).

The less, the obtained makespan by the algorithm from the previous sections, the more remaining time is left to add more jobs. This means that the expected results may suggest the maximum number of jobs that can be added for the minimum makespans from the previous sections.

In this analysis the number of combinations for each day will be narrowed down to only two combinations out of the nine combinations, both of these two combinations

share the same configuration, which is the actual configuration (Configuration no. 1), but they are different in the selected sequence, one combination with the actual sequence (Sequence 1) and the other with the sequence that obtained the minimum makespan. In the following analysis, the first combination will be referred to as “the actual combination”, while the other combination with the minimum makespan will be referred to as “the minimum combination”.

The reason for narrowing down the number of combinations is to do this experimentation phase (adding more jobs) with the actual configuration (Configuration no. 1), which is the same configuration of the actual plant from the perspective of the number of anodizing and hot sealing tanks. Moreover, this configuration can be experimented with three sequences, so, the reasons for narrowing the number of sequences to only two sequences (the actual sequence and the sequence with the minimum makespan) are as follows. The reason for choosing sequence 1 is to test the model with actual sequence, and the reason for choosing the sequence that generated the minimum makespan is to test the algorithm ability to process the maximum number of jobs with the minimum makespan for each day with actual configuration.

The recipes for the additional jobs that are chosen to be extra added jobs are two, these two recipes are Recipe no. 3 and Recipe no. 6. A job that follows Recipe no. 3 is matt finish with an ordinary section, while a job that follows Recipe no. 6 is a colored finish (Col 16) with an ordinary section type. The reasons for choosing these two recipes are because they are the two most processed recipes and they are relatively the shortest recipes. Furthermore, the chosen recipes add variability to the extra jobs by choosing one recipe that is a matt finish (Recipe no 3) while the other is a colored finish (Recipe no.6).

The loop used to add the extra jobs starts with two jobs of Recipe no. 3 followed by one job of Recipe no. 6, then it starts again with another two jobs of Recipe no. 3 followed by another job of Recipe no. 6, and so on.

These jobs are added one by one, and each time an extra job is added the makespan is compared with the time of the two shifts (16 hours). If the makespan of the added job exceeds the time of the two shifts (16 hours), then the algorithm stops adding more jobs and will not count the additional job, which exceeds the time as one of the additional jobs. If the makespan does not exceed the threshold time of 16 hours, the algorithm will continue adding more jobs one by one according to the loop, until the makespan exceeds the two shifts time (16 hours), without counting the job that exceeds the 16 hours.

According to these settings, the makespans of the “minimum combination” obtained after adding the extra jobs are expected to be higher than the makespans of the “actual combination”. The reason for such expectation is, the less makespan before adding the extra jobs gives more time left to add more jobs. Moreover, the more likely that the time left out from adding jobs to the “minimum combination” is less than the time left out from the “actual combination”; However, this might not be true, due to the nature and number of the actual jobs and their sequence can make a difference.

Figure (7.5) ornaments this expectation of the results, where before adding the extra jobs, the makespan of the “minimum combination” is less than the makespan of the “actual combination” (this from the results of previous sections). However, after adding the extra jobs it is not certain that the makespan of the “actual combination” is going to be less than that of the “minimum combination”.

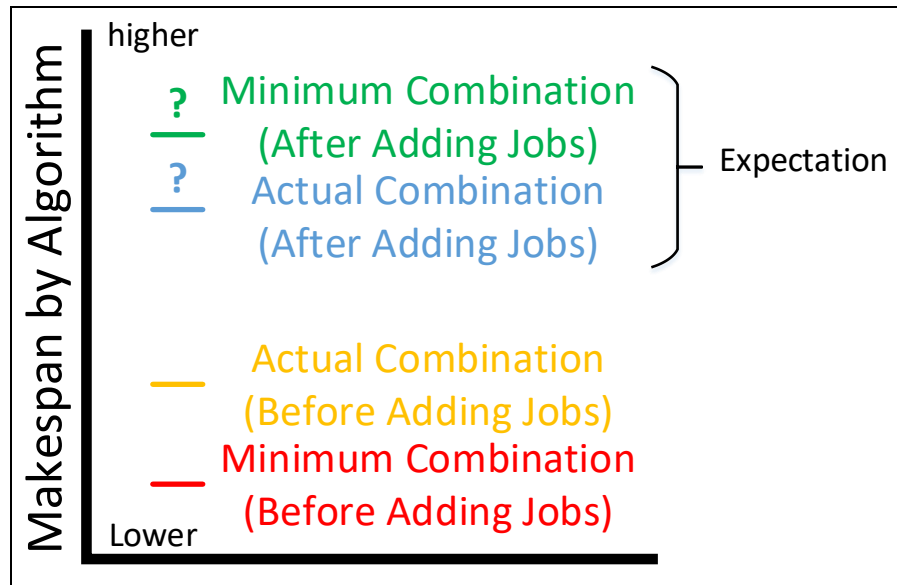


Figure (7.5): Expected Makespans Before and After Adding Jobs

Table (7.14) shows the results for the “actual combination” (the combination of Configuration 1 and Sequence 1) for all the twelve days, while Table (7.15) shows the results for the “the minimum combination” (the combination of Configuration 1 and the sequence that generated the minimum makespan) for each day, as for day no. 7 the sequence with minimum makespan happens to be the same as the actual sequence, which is Sequence 1. Figures (7.6) and (7.7) illustrates the results in Tables (7.14) and (7.15), respectively.

In each figure, three types of makespans are presented, the estimated actual makespan, the two makespans obtained by the algorithm before adding the extra jobs and after adding the extra jobs. The number of jobs and their types are plotted along with makespans.

Table (7.14): Further Experimentation Results (Configuration 1 with Sequence 1)

| Day | Sequence | Makespan (hrs:min:sec) |                    |                   | Number of Jobs                      |                                 |                      |                        |                  |                      |
|-----|----------|------------------------|--------------------|-------------------|-------------------------------------|---------------------------------|----------------------|------------------------|------------------|----------------------|
|     |          | Actual (Estimated)     | By Algorithm       |                   | Actual                              |                                 |                      | Added                  |                  | Total Number of Jobs |
|     |          |                        | Before Adding Jobs | After Adding Jobs | Matt Finish – Small Hollow Sections | Matt Finish – Ordinary Sections | Color – All Sections | Matt Finish – Recipe 3 | Color – Recipe 6 |                      |
| 1   | 1        | 15:35:56               | 14:50:09           | 15:48:14          | 19                                  | 20                              | 14                   | 3                      | 2                | 58                   |
| 2   | 1        | 15:42:56               | 15:31:23           | 15:53:35          | 29                                  | 6                               | 20                   | 2                      | 1                | 58                   |
| 3   | 1        | 15:59:56               | 14:47:44           | 15:58:44          | 0                                   | 17                              | 31                   | 4                      | 2                | 54                   |
| 4   | 1        | 16:24:56               | 13:21:05           | 15:20:50          | 0                                   | 34                              | 12                   | 8                      | 4                | 58                   |
| 5   | 1        | 15:40:56               | 12:48:20           | 15:16:56          | 13                                  | 27                              | 6                    | 8                      | 4                | 58                   |
| 6   | 1        | 16:26:56               | 13:18:54           | 15:54:34          | 3                                   | 15                              | 28                   | 6                      | 3                | 55                   |
| 7   | 1        | 17:19:56               | 13:11:03           | 15:22:20          | 5                                   | 9                               | 31                   | 9                      | 5                | 59                   |
| 8   | 1        | 16:32:56               | 13:17:17           | 15:08:11          | 35                                  | 13                              | 2                    | 4                      | 3                | 57                   |
| 9   | 1        | 16:45:22               | 13:01:58           | 15:43:25          | 25                                  | 7                               | 15                   | 8                      | 4                | 59                   |
| 10  | 1        | 16:48:56               | 13:55:14           | 15:39:42          | 23                                  | 2                               | 24                   | 6                      | 3                | 58                   |
| 11  | 1        | 16:56:56               | 14:22:37           | 15:48:56          | 24                                  | 8                               | 20                   | 6                      | 3                | 61                   |
| 12  | 1        | 17:29:22               | 13:40:38           | 15:31:43          | 1                                   | 36                              | 13                   | 6                      | 4                | 60                   |

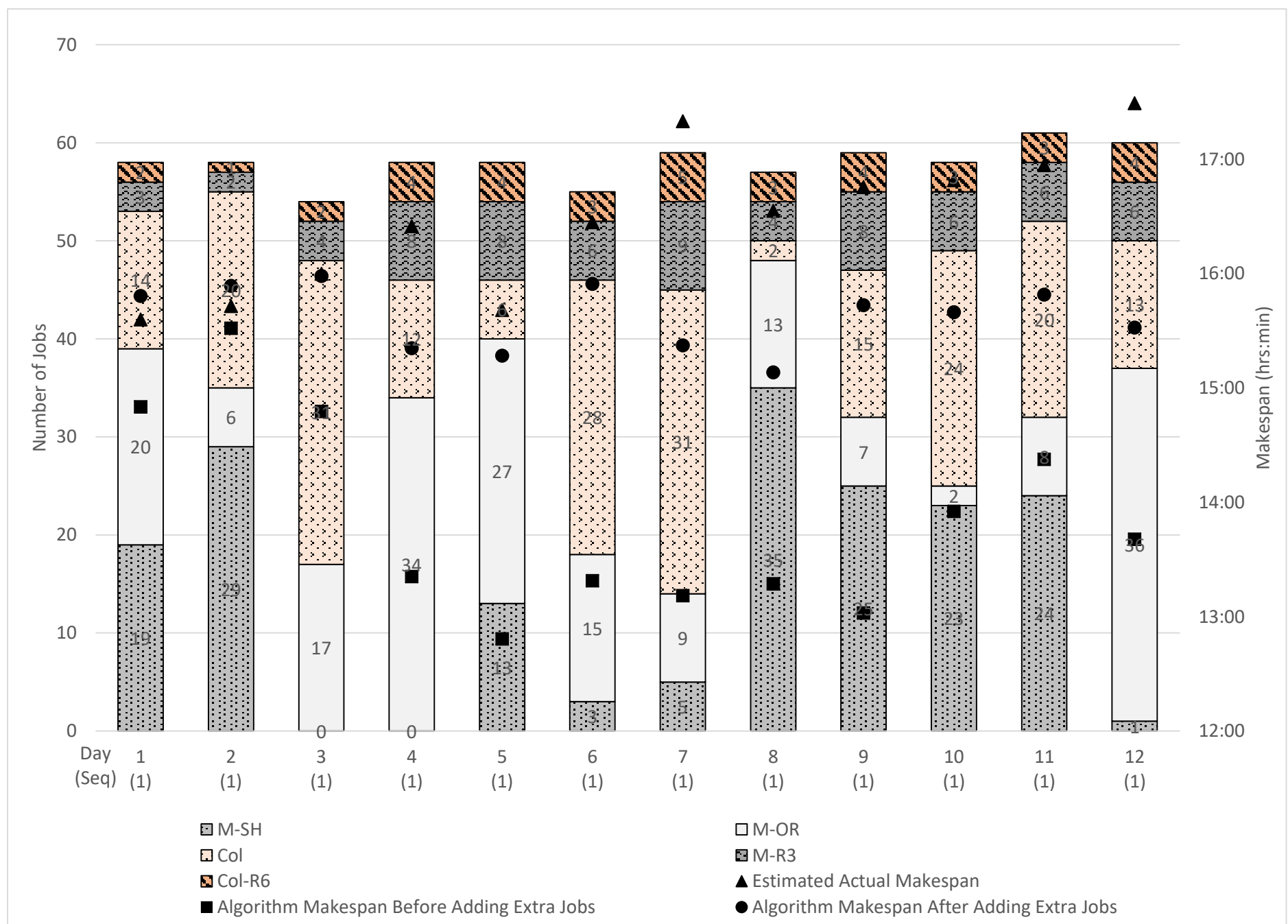


Figure (7.6): Further Experimentation Results (Configuration 1 with Sequence 1)

Table (7.15): Further Experimentation Results (Configuration 1 with the sequence of minimum makespan)

| Day | Sequence | Makespan (hrs:min:sec) |                    |                   | Number of Jobs                      |                                 |                      |                        |                  |                      |
|-----|----------|------------------------|--------------------|-------------------|-------------------------------------|---------------------------------|----------------------|------------------------|------------------|----------------------|
|     |          | Actual (Estimated)     | By Algorithm       |                   | Actual                              |                                 |                      | Added                  |                  | Total Number of Jobs |
|     |          |                        | Before Adding Jobs | After Adding Jobs | Matt Finish – Small Hollow Sections | Matt Finish – Ordinary Sections | Color – All Sections | Matt Finish – Recipe 3 | Color – Recipe 6 |                      |
| 1   | 3        | 15:28:56               | 13:45:07           | 15:50:42          | 19                                  | 20                              | 14                   | 6                      | 3                | 62                   |
| 2   | 3        | 15:42:56               | 14:54:56           | 15:52:23          | 29                                  | 6                               | 20                   | 2                      | 2                | 59                   |
| 3   | 2        | 16:23:52               | 14:29:11           | 15:59:03          | 0                                   | 17                              | 31                   | 6                      | 3                | 57                   |
| 4   | 2        | 16:25:52               | 12:17:39           | 15:53:36          | 0                                   | 34                              | 12                   | 8                      | 5                | 59                   |
| 5   | 3        | 15:33:56               | 12:29:41           | 15:32:42          | 13                                  | 27                              | 6                    | 10                     | 5                | 61                   |
| 6   | 3        | 16:19:56               | 13:15:21           | 15:41:34          | 3                                   | 15                              | 28                   | 6                      | 3                | 55                   |
| 7   | 1        | 17:19:56               | 13:11:03           | 15:22:20          | 5                                   | 9                               | 31                   | 9                      | 5                | 59                   |
| 8   | 2        | 16:33:52               | 12:55:48           | 15:22:48          | 35                                  | 13                              | 2                    | 8                      | 4                | 62                   |
| 9   | 2        | 16:45:22               | 12:51:17           | 15:26:20          | 25                                  | 7                               | 15                   | 9                      | 5                | 61                   |
| 10  | 2        | 16:59:22               | 13:25:57           | 15:24:24          | 23                                  | 2                               | 24                   | 6                      | 3                | 58                   |
| 11  | 3        | 16:56:56               | 13:25:05           | 15:42:58          | 24                                  | 8                               | 20                   | 6                      | 3                | 61                   |
| 12  | 3        | 17:18:56               | 13:35:15           | 15:14:39          | 1                                   | 36                              | 13                   | 6                      | 3                | 59                   |

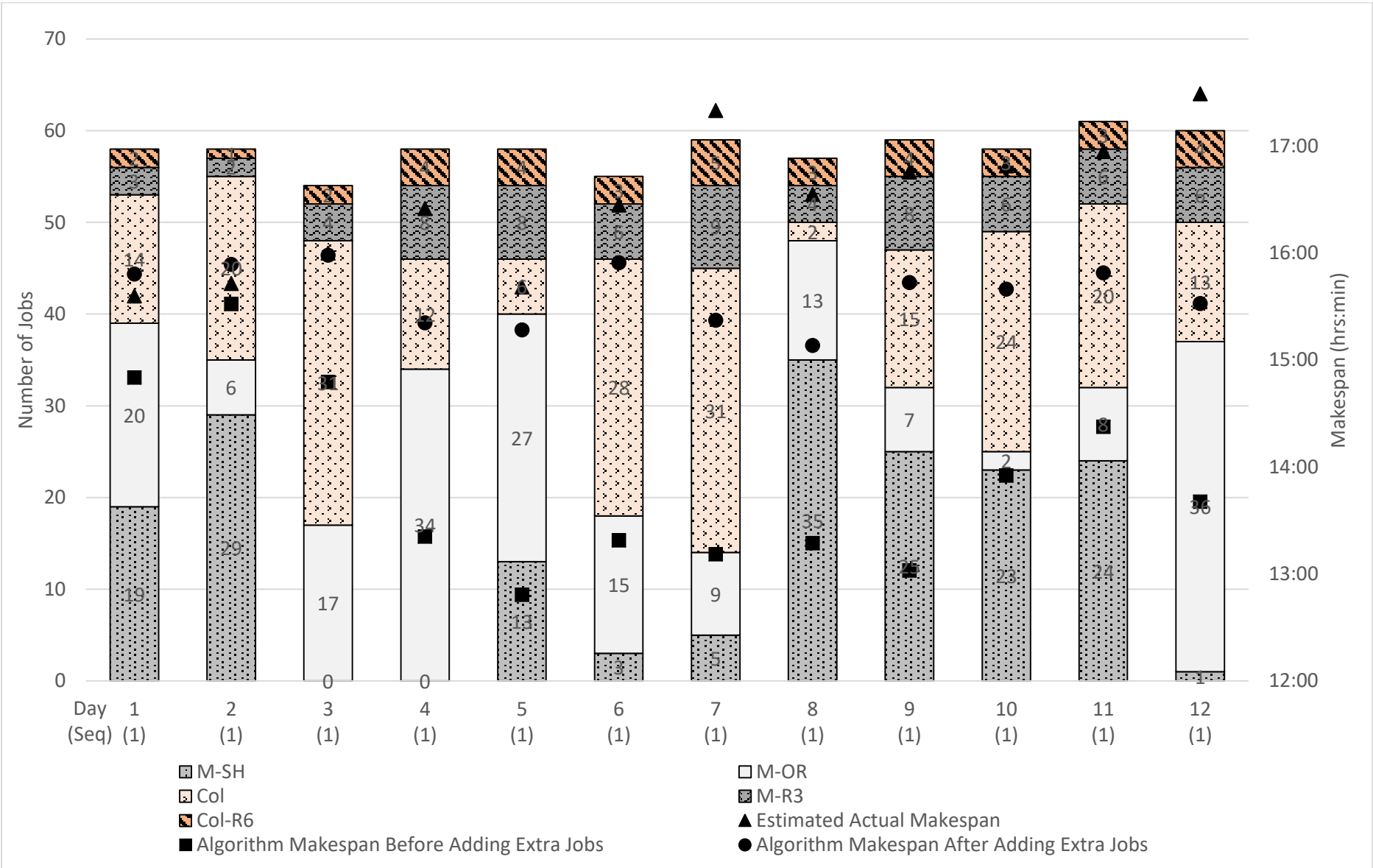


Figure (7.7): Further Experimentation Results (Configuration 1 with the sequence of minimum makespan)

Tables (7.16) and (7.17) show the ability of the algorithm to utilize the time for the “actual combination” and the “minimum combination”, respectively. The percentage of time utilization is calculated by using Equation (6.1) for each day.

$$\text{Time Utilitation \%} = \frac{\text{The Obtained Makespan by the Algorithm}}{\text{Total time of Two Shifts}} \times 100\% \quad (6.1)$$

Where:

The Obtained Makespan by the Algorithm can be the makespan before adding the extra jobs or the makespan after adding the extra jobs. The total time of two shifts is 16 hours (57600 seconds).

The time used in Equation (Eq. 6.1) is in seconds.

Moreover; Tables (7.16) and (7.17) show the percentage of the additional (extra) jobs that can be added, the percentage of added jobs is calculated by using Equation (6.2).

$$\text{Added Jobs \%} = \frac{\text{Additional Jobs added}}{\text{Actaul Number of Jobs}} \times 100\% \quad (6.2)$$

Where:

The Additional Jobs are the summation of the extra jobs that were added which follows recipes no. 3 and/or no. 6. The Actual number of Jobs is the original number of jobs before addition.

Table (7.16): Comparing the Algorithm Results of the Actual Combination  
(before and after adding the extra jobs)

| Day     | Makespan<br>(Seconds) |                      | Time Utilization<br>(%) |                      |                                   | Number<br>of Jobs     |                      | Added<br>Jobs<br>(%) |
|---------|-----------------------|----------------------|-------------------------|----------------------|-----------------------------------|-----------------------|----------------------|----------------------|
|         | Before<br>Adding Jobs | After<br>Adding Jobs | Before<br>Adding Jobs   | After<br>Adding Jobs | Difference<br>(After –<br>Before) | Before<br>Adding Jobs | After<br>Adding Jobs |                      |
| 1       | 53409                 | 56894                | 92.72%                  | 98.77%               | 6.05%                             | 53                    | 5                    | 9.43%                |
| 2       | 55883                 | 57215                | 97.02%                  | 99.33%               | 2.31%                             | 55                    | 3                    | 5.45%                |
| 3       | 53264                 | 57524                | 92.47%                  | 99.87%               | 7.40%                             | 48                    | 6                    | 12.50%               |
| 4       | 48065                 | 55250                | 83.45%                  | 95.92%               | 12.47%                            | 46                    | 12                   | 26.09%               |
| 5       | 46100                 | 55016                | 80.03%                  | 95.51%               | 15.48%                            | 46                    | 12                   | 26.09%               |
| 6       | 47934                 | 57274                | 83.22%                  | 99.43%               | 16.22%                            | 46                    | 9                    | 19.57%               |
| 7       | 47463                 | 55340                | 82.40%                  | 96.08%               | 13.68%                            | 45                    | 14                   | 31.11%               |
| 8       | 47837                 | 54491                | 83.05%                  | 94.60%               | 11.55%                            | 50                    | 7                    | 14.00%               |
| 9       | 46918                 | 56605                | 81.45%                  | 98.27%               | 16.82%                            | 47                    | 12                   | 25.53%               |
| 10      | 50114                 | 56382                | 87.00%                  | 97.89%               | 10.88%                            | 49                    | 9                    | 18.37%               |
| 11      | 51757                 | 56936                | 89.86%                  | 98.85%               | 8.99%                             | 52                    | 9                    | 17.31%               |
| 12      | 49238                 | 55903                | 85.48%                  | 97.05%               | 11.57%                            | 50                    | 10                   | 20.00%               |
| Average |                       |                      | 86.51%                  | <b>97.63%</b>        | <b>11.12%</b>                     | 49                    | 9                    | <b>18.79%</b>        |
| Maximum |                       |                      | 97.02%                  | <b>99.87%</b>        | <b>16.82%</b>                     | 55                    | 14                   | <b>31.11%</b>        |
| Minimum |                       |                      | 80.03%                  | <b>94.60%</b>        | <b>2.31%</b>                      | 45                    | 3                    | <b>5.45%</b>         |

Table (7.17): Comparing the Algorithm Results of the Minimum Combination  
(before and after adding the extra jobs)

| Day     | Makespan<br>(Seconds) |                      | Time Utilization<br>(%) |                      |                                   | Number<br>of Jobs     |                      | Added<br>Jobs<br>(%) |
|---------|-----------------------|----------------------|-------------------------|----------------------|-----------------------------------|-----------------------|----------------------|----------------------|
|         | Before<br>Adding Jobs | After<br>Adding Jobs | Before<br>Adding Jobs   | After<br>Adding Jobs | Difference<br>(After –<br>Before) | Before<br>Adding Jobs | After<br>Adding Jobs |                      |
| 1       | 49507                 | 57042                | 85.95%                  | 99.03%               | 13.08%                            | 53                    | 9                    | 16.98%               |
| 2       | 53696                 | 57143                | 93.22%                  | 99.21%               | 5.98%                             | 55                    | 4                    | 7.27%                |
| 3       | 52151                 | 57543                | 90.54%                  | 99.90%               | 9.36%                             | 48                    | 9                    | 18.75%               |
| 4       | 44259                 | 57216                | 76.84%                  | 99.33%               | 22.49%                            | 46                    | 13                   | 28.26%               |
| 5       | 44981                 | 55962                | 78.09%                  | 97.16%               | 19.06%                            | 46                    | 15                   | 32.61%               |
| 6       | 47721                 | 56494                | 82.85%                  | 98.08%               | 15.23%                            | 46                    | 9                    | 19.57%               |
| 7       | 47463                 | 55340                | 82.40%                  | 96.08%               | 13.68%                            | 45                    | 14                   | 31.11%               |
| 8       | 46548                 | 55368                | 80.81%                  | 96.13%               | 15.31%                            | 50                    | 12                   | 24.00%               |
| 9       | 46277                 | 55580                | 80.34%                  | 96.49%               | 16.15%                            | 47                    | 14                   | 29.79%               |
| 10      | 48357                 | 55464                | 83.95%                  | 96.29%               | 12.34%                            | 49                    | 9                    | 18.37%               |
| 11      | 48305                 | 56578                | 83.86%                  | 98.23%               | 14.36%                            | 52                    | 9                    | 17.37%               |
| 12      | 48915                 | 54879                | 84.92%                  | 95.28%               | 10.35%                            | 50                    | 9                    | 18.00%               |
| Average |                       |                      | 83.65%                  | <b>97.60%</b>        | <b>13.95%</b>                     | 49                    | 11                   | <b>21.83%</b>        |
| Maximum |                       |                      | 93.22%                  | <b>99.90%</b>        | <b>22.49%</b>                     | 55                    | 15                   | <b>32.61%</b>        |
| Minimum |                       |                      | 76.84%                  | <b>95.28%</b>        | <b>5.98%</b>                      | 45                    | 4                    | <b>7.27%</b>         |

The results in Tables (7.16) and (7.17) show that the two combinations have shown similar average time utilization percentages (the average of the twelve days) of 97.63% and 97.60%, respectively. The maximum utilization for the minimum combination and the actual combination are 99.87% and 99.90% respectively, while their minimum values are 94.60 % and 95.28 %, respectively.

In Tables (7.16) and (7.17), the difference of time utilization percentage between the makespans before adding the extra jobs and after adding the extra jobs is calculated for each day. In-addition to their averages, maximums, and minimums. The results show higher percentages for the “minimum combination” than with the “actual combination”. This means that with the “minimum combination”, the remaining time has been utilized slightly more efficiently than the “actual combination”. However, the percentages of additional jobs where the “minimum combination” show higher values than the “actual combination” with an average of 21.83% for the “minimum combination” and an average of 18.79% for the actual combination.

Table (7.18) shows the differences between the two combinations (the actual and the minimum), by subtracting the percentage of the “actual combination” from the percentage of the “minimum combination” for each day. The subtraction is done in this form based on the expectation which stated in Figure (7.5) when extra jobs are added. After the addition of extra jobs, the “minimum combination” generates higher percentages than the “actual combination”, since the “minimum combination” will have higher makespans than the actual makespan.

This expectation turns out not to be true all the time, for example in days no. 2, 6, 9, 10, 11 and 12 negative values are obtained.

All the percentages before adding the extra jobs (first column in Table 7.18) are negative, because in all days the makespans by the minimum combination are less than the actual, except for day no.7 which is the same in both combinations.

Table (7.18): Comparison of the Two Combinations Results (before and after adding the extra jobs)

| Day | Time Utilization (%)<br>Minimum Combination – Actual Combination |                      |            | Added<br>Jobs<br>(%) |
|-----|------------------------------------------------------------------|----------------------|------------|----------------------|
|     | Before<br>Adding Jobs                                            | After<br>Adding Jobs | Difference |                      |
| 1   | -6.77%                                                           | 0.26%                | 7.03%      | 7.55%                |
| 2   | -3.80%                                                           | -0.12%               | 3.67%      | 1.82%                |
| 3   | -1.93%                                                           | 0.03%                | 1.97%      | 6.25%                |
| 4   | -6.61%                                                           | 3.41%                | 10.02%     | 2.17%                |
| 5   | -1.94%                                                           | 1.64%                | 3.59%      | 6.52%                |
| 6   | -0.37%                                                           | -1.35%               | -0.98%     | 0.00%                |
| 7   | 0.00%                                                            | 0.00%                | 0.00%      | 0.00%                |
| 8   | -2.24%                                                           | 1.52%                | 3.76%      | 10.00%               |
| 9   | -1.11%                                                           | -1.78%               | -0.67%     | 4.26%                |
| 10  | -3.05%                                                           | -1.59%               | 1.46%      | 0.00%                |
| 11  | -5.99%                                                           | -0.62%               | 5.37%      | 0.00%                |
| 12  | -0.56%                                                           | -1.78%               | -1.22%     | -2.00%               |

In conclusion, the algorithm is able to increase the number of jobs in both combinations by an average percentage of 20.31%, an average percentage 18.79% for the actual combination and an average percentage 21.83% for the minimum combination. The algorithm is able to add more extra jobs for the minimum combination than the actual combination. On the other hand, from the perspective of generating higher makespan (higher time utilization), it is not necessary for the minimum combination to generate higher makespan than the actual combination.

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# **Chapter Eight:**

## **Conclusion, Recommendations, and Further Studies**

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**8.1. Conclusion**

**8.2. Recommendations**

**8.3. Suggestions for Further Studies**

## **Chapter Eight**

### **Conclusion, Recommendations and Further Studies**

#### **8.1. Conclusion**

In this thesis, a real anodizing plant is modeled to re-schedule the production of twelve days in an attempt to reduce the actual makespan for each day, increase the production, and to overcome the main bottleneck problem that exists in the real plant.

A mathematical model is proposed that describes the detailed movements in the system, yet this mathematical model is not fully translated in the programmed algorithm, due to its difficulty and limited time to finish this thesis; nevertheless, it is thought it might be useful for future expansion of this work.

The model is programmed using Matlab R2015b editor with an Intel (R) Core (TM) processor with a speed of (2.00 GHz to 2.60 GHz) and a RAM memory size of 8.00 GB. The algorithm computational times show it can obtain the results within 2.5 minutes for each run. The runs of the simulation were divided into three phases, where each phase has its own objectives.

The aim of the first phase is to choose one of two sets of the anodizing duration, where Set 1 is the set that uses the actual anodizing durations, while Set 2 uses the average anodizing durations. In-addition, to validates the generated schedules by the algorithm and evaluate them. Because of these objectives, the actual combination (Combination no. 1) is adopted.

The set with the actual anodizing durations (Set 1) is selected to do the rest of the analyses because it is more likely to give shorter makespan than Set 2. As for the validation part, the algorithm generates reasonable and acceptable Gantt charts.

Evaluating the makespans at the anodizing stage, revealed the ability of the algorithm to reduce the actual makespan by an average of 18%. Moreover, the duration of the treatment identified that the hot sealing is the main bottleneck stage that the plant is suffering from.

In the second phase (named the experimentation phase), the nine different combinations (including the actual combination) are computed, to observe which one is more likely to have a greater effect on reducing the makespan and on overcoming the negative effect of the main bottleneck problem.

The results show that the third sequence used in this study (Highest Recipe ID First) is more likely to obtained minimum makespans than the other two, and a configuration of one additional hot sealing tank is optimum to give minimum makespans and reduce the negative effect of the main bottleneck problem, thus the combination that combines the third sequence with the configuration of one additional hot sealing tanks is considered the best combination.

As for the third, the objectives are to increase the number of jobs of two recipes and thus fully utilize the whole time of the two shifts (16 hours), hence the makespan is reduced. Two combinations are selected to compete with each other. Both of them using the actual configuration, but one uses the actual sequence, while the other uses the sequences that obtained the minimum makespan, these two combinations are referred to as the “actual combination” and “the minimum combination”, respectively.

The results show that the “minimum combination” utilizes the remaining time slightly more efficiently than the “actual combination”. However, the percentages of additional jobs for the “minimum combination” show higher values than the “actual combination” with an average of 21.83% for the “minimum combination” and an average of 18.79% for the “actual combination”

The final conclusion of this study is that a heuristic algorithm is developed, which reduces the makespan by an average of 18% for the first combination (the combination currently used in the plant). Also, the results of the nine combinations tests in the simulation model show that re-designing the plant by adding one additional hot sealing tank and prioritizing the jobs based on the third sequence (Highest Recipe ID First), forms the best combination to adopt to reduce the makespan and reduce the negative effect of the main bottleneck problem at the hot sealing stage. The average increment in the number of jobs of shortest recipes that the algorithm can achieve is around 20%.

## **8.2. Recommendations**

The proposed algorithm in this study can help in determining the best sequence to run the production for a day of two shifts (16 hours or more) by giving the suggested sequence along with jobs recipes. It will obtain estimated makespans for the real plant but without the consideration of breakdowns, the estimated makespans will determine which of the given sequences is the best to adopt.

In the study three types of sequences were tested, the first one is the actual sequence by which the jobs were entered to the anodizing stage, and the other two are obtained by sorting of the jobs based on their recipes ID, These two sequences are the Lowest Recipe ID First (the ascending order of the recipes) and the Highest Recipe ID First (the descending order of the recipes). The study shows the third sequence (HRIDF) is the most likely of the three to give the minimum makespans.

The planning department of Balexco can use the algorithm to test other sequences along with the proposed sequence to see which one of them is most likely to generate the minimum makespan. Thus, more jobs can be treated to increase production.

The study recommends adding one additional hot sealing tank in place of one outlet buffer position in order to reduce the negative effect of bottleneck problem.

The recommendations given in this study are not fully guaranteed to be applicable in the real plant, because of the relaxations applied in the algorithm (given in Table (3.13)), such as the replacing the actual durations for the empty hoists movements with an estimated duration and not considering the breakdown time, which affects the accuracy of the results.

### **8.3. Suggestions for Further Studies**

The possible future work for this thesis can be categories into two types, the first is by un-relax some of the relaxations given in Table (3.13). The other type is by enhancing the algorithm, to be able to do further experimentations. The list bellows summaries the suggestions for the future work.

1. Un-relax point no. 1, and 11 given in Table (3.13), to make the number of stages, namely: Loading stages (point 1); and Cleaning stages (Point 11) matching the procedure in the real plant.
2. Include more types of recipes by including the as many types of section profiles and their chemical treatment durations in the Etching, Anodizing and Electro-Coloring stages as well as the loading stage(s) durations
3. Including the feature of the breakdown durations into the algorithm for each day to be simulated. The breakdowns of the tanks will be included as input data, while breakdowns of hoist jamming are short (few seconds) and happen randomly, which might be coded in form of probabilities.
4. Construct a more accurate matrix for the loaded hoist travel durations, as well as constructing a new matrix for the empty hoist travel durations (un-relax point no. 7 in Table (3.13)).

5. Code the constraints regarding the empty hoist move, to enable the algorithm to track the last position that each hoist stopped at. Considering this constraint will make the hoist collision constraint more realistic (un-relax point no. 8 and 9 in Table (3.13)).
6. Improve the algorithm, so other parameters can be tested, such as the possible alternative hoists movements, this might be done if the heuristic algorithm is combined with Genetic Algorithm (or similar) to generate the makespans for the different scenarios.
7. Another possible parameter that can be tested easily is to study the effect of changing the hoists' ranges on the makespan.
8. Another objective that can be considered in this study is the feasibility of adding more tanks to overcome the bottleneck problem, where the complications of adding more tanks are studied. For example, the complications which are related of adding hot sealing tanks are: the distribution of water pipelines that deliver water to the hot sealing tanks; and the distribution of stream that heat the water inside those tanks.

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# Appendices

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**Appendix (1):** Hoist Collision Cases

**Appendix (2):** The Notations Used in Matlab Coding

**Appendix (3):** The Matlab Coding For the Further Experimentations  
(Phase 3)

**Appendix (4):** Estimated Duration after Anodizing Stage to Unloading per  
Recipe ID

**Appendix (5):** Gantt Charts for the Twelve (Combination no. 1)

**Appendix (6):** Job Flow Time at the Anodizing Stage for the Twelve Days  
by Combination 1

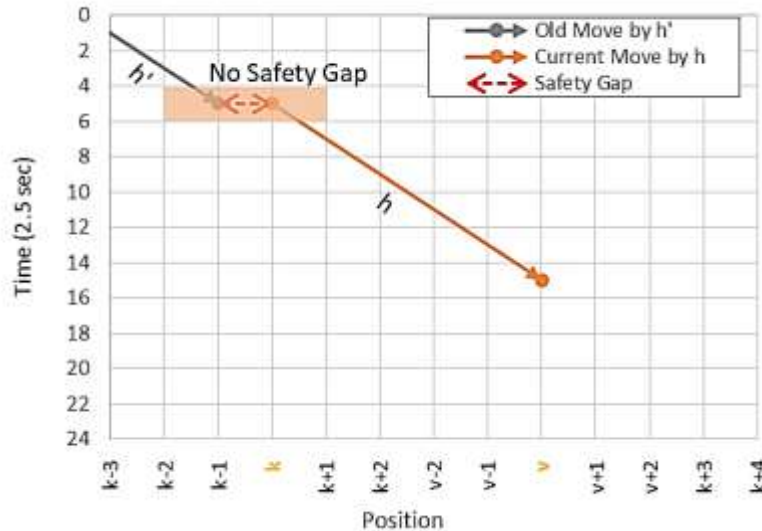
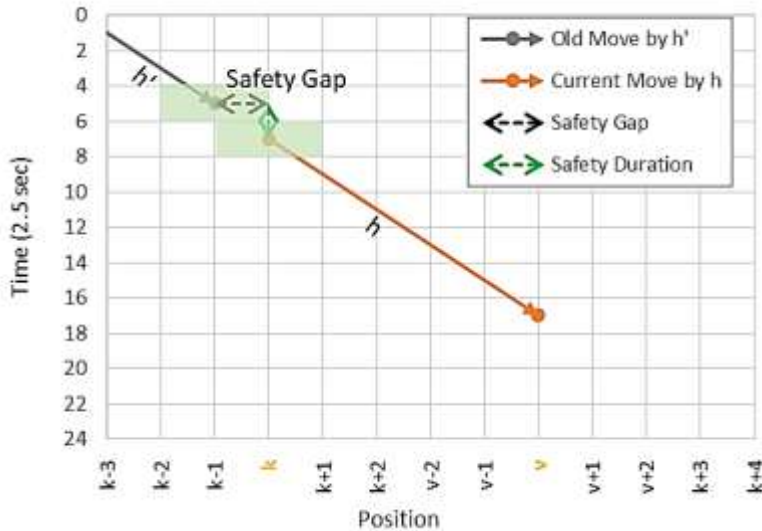
**Appendix (7):** Utilization of the Different Positions for the Twelve Days  
by Combination 1

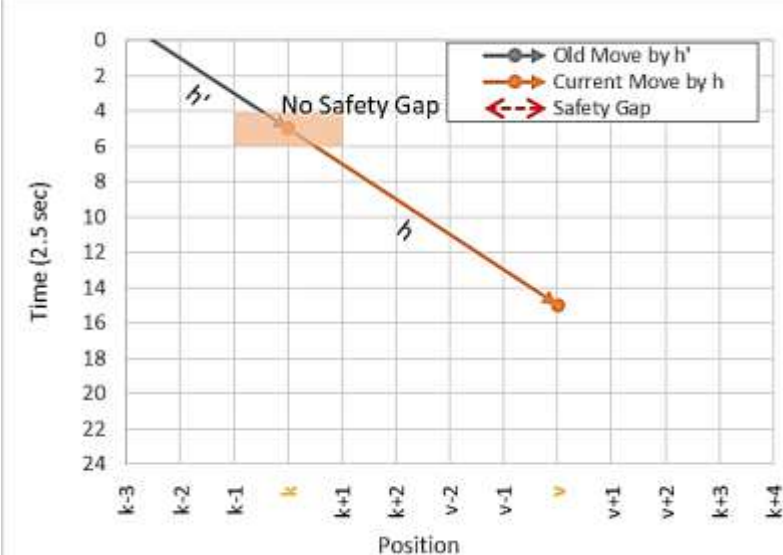
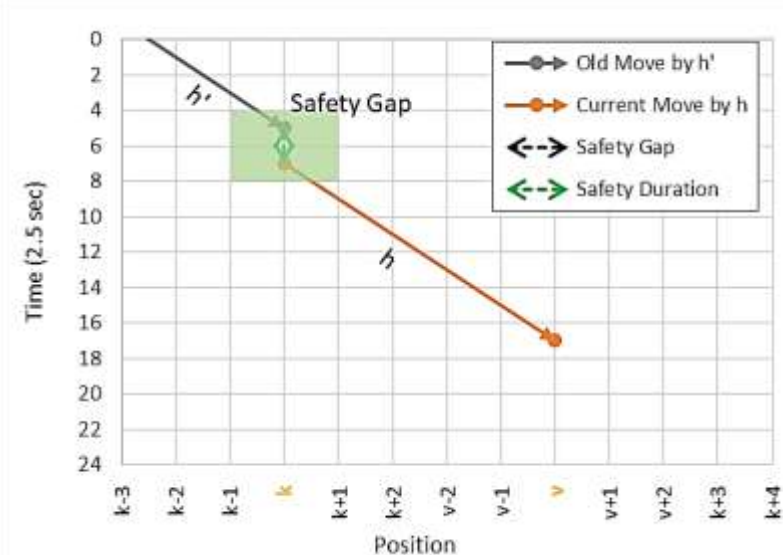
**Appendix (8):** Results of Combinations 2 to 9

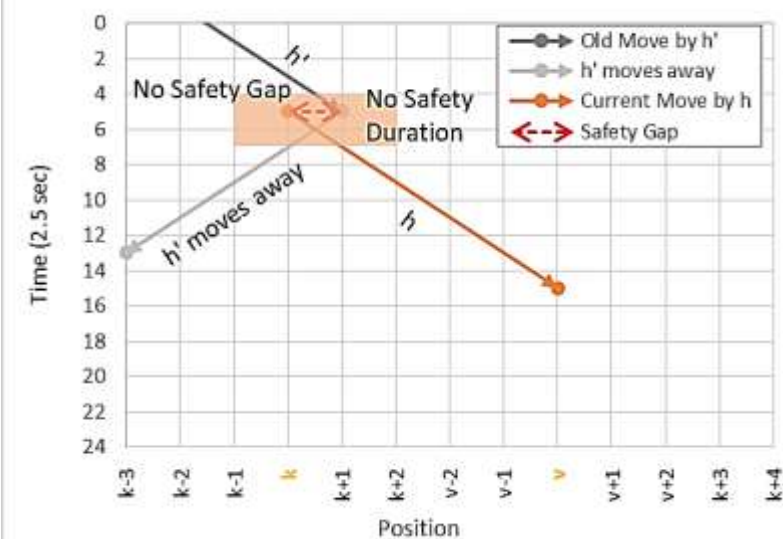
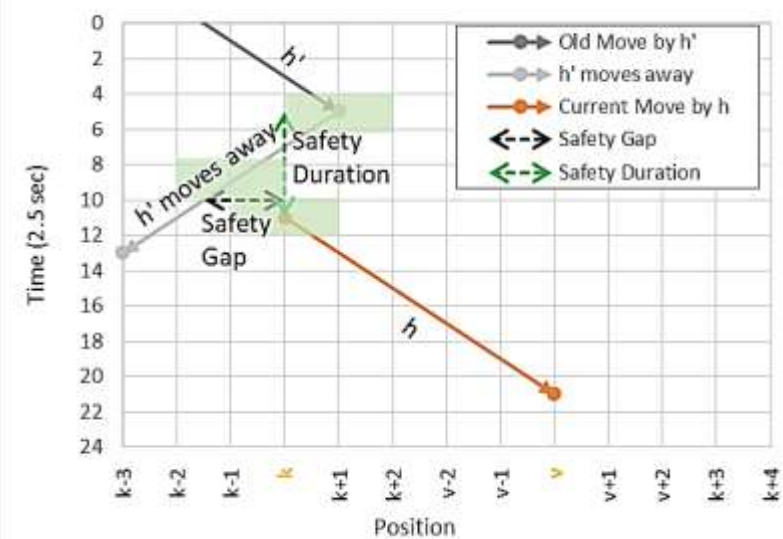
**Appendix (9):** Effect of Combinations on Overcoming the Bottleneck  
Problem

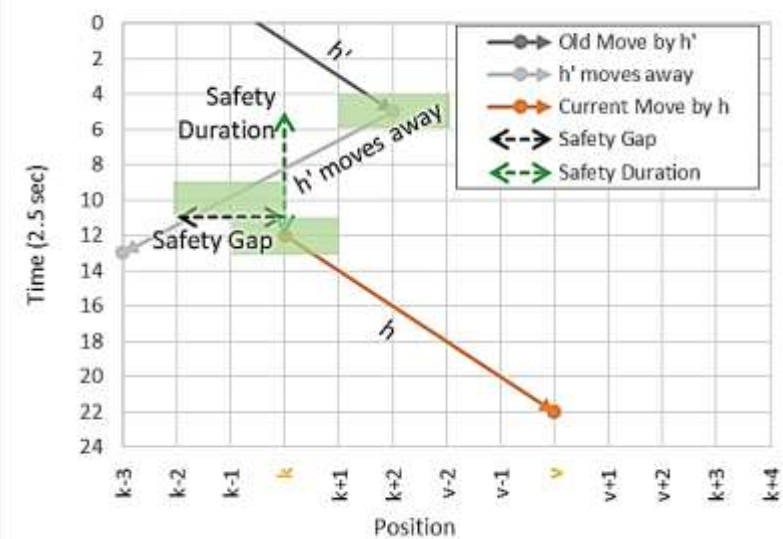
## Appendix (1): Hoist Collision Cases

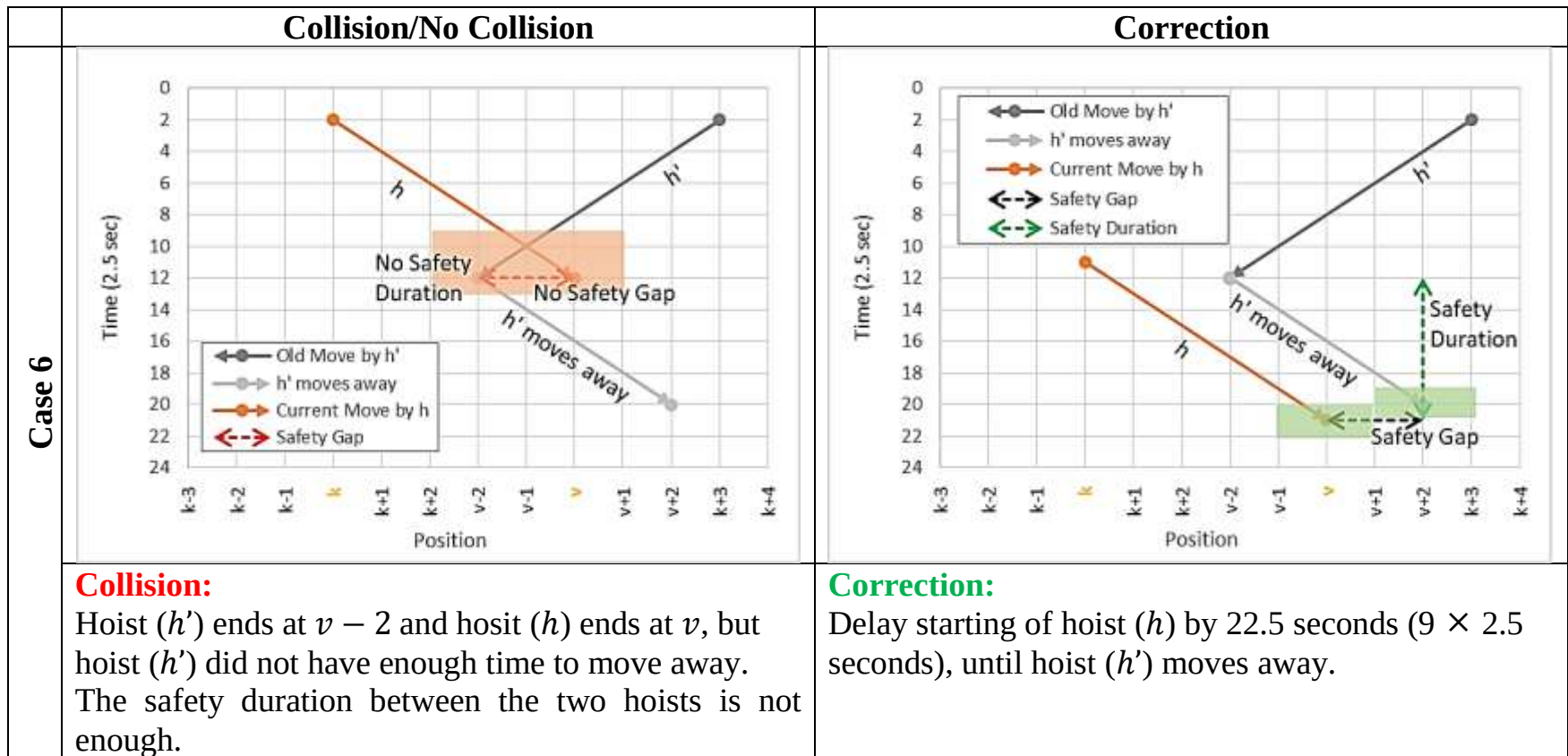
|        | Collision/No Collision                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Correction                             |
|--------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
| Case 1 | <p>The graph illustrates the movement of two hoists, <math>h'</math> and <math>h</math>, over time and position. The y-axis represents Time in units of 2.5 seconds, ranging from 0 to 24. The x-axis represents Position, ranging from <math>k-3</math> to <math>k+4</math>. Hoist <math>h'</math> (black line) starts at position <math>k-2</math> at time 0 and moves to position <math>k</math> at time 4. Hoist <math>h</math> (orange line) starts at position <math>k</math> at time 4 and moves to position <math>v</math> at time 16. A green shaded area labeled 'Safety Gap' is shown between the two hoists' paths from time 0 to 4, indicating no collision.</p> | -                                      |
|        | <p><b>No Collision:</b><br/> Hoist (<math>h'</math>) ends at <math>k - 2</math> and hoist (<math>h</math>) starts at <math>k</math> at the same time.<br/> The gap between the two hoists is safe.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | No correction needed for hoist ( $h$ ) |

|        |  | Collision/No Collision                                                                                                                                                                                  | Correction                                                                                                                |
|--------|--|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| Case 2 |  |                                                                                                                       |                                        |
|        |  | <p><b>Collision:</b><br/> Hoist (<math>h'</math>) ends at <math>k - 1</math> and hoist (<math>h</math>) starts at <math>k</math> at the same time.<br/> The gap between the two hoists is not safe.</p> | <p><b>Correction:</b><br/> Delay starting of hoist (<math>h</math>) by 5 seconds (<math>2 \times 2.5</math> seconds).</p> |

|        |  | Collision/No Collision                                                                                                                                                                               | Correction                                                                                                                                                                          |
|--------|--|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case 3 |  |                                                                                                                    |                                                                                                  |
|        |  | <p><b>Collision:</b></p> <p>Hoist (<math>h'</math>) ends at <math>k</math> and hoist (<math>h</math>) starts at <math>k</math>, at the same time.</p> <p>There is no gap between the two hoists.</p> | <p><b>Correction:</b></p> <p>Delay starting of hoist (<math>h</math>) by 5 seconds (<math>2 \times 2.5</math> seconds) in order to move <math>h</math> away from <math>k</math></p> |

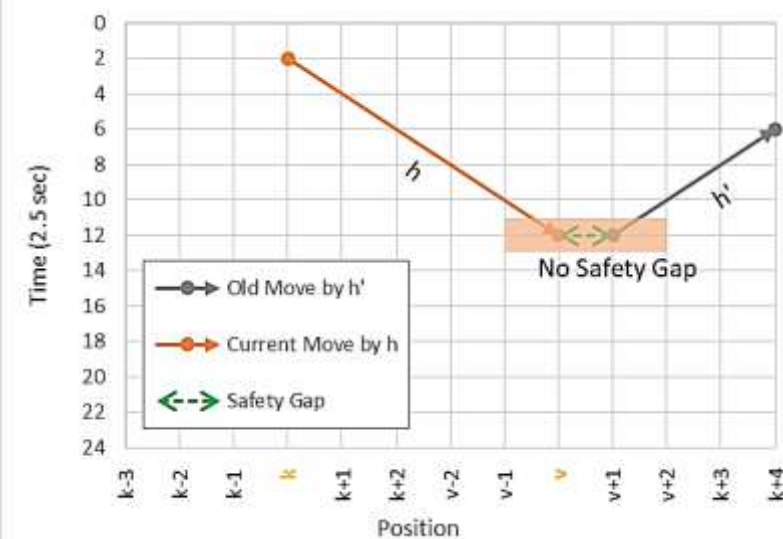
|        |  | Collision/No Collision                                                                                                                                                                                                                                               | Correction                                                                                                                                                             |
|--------|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case 4 |  |                                                                                                                                                                                    |                                                                                     |
|        |  | <p><b>Collision:</b></p> <p>Hoist (<math>h'</math>) ends at <math>k + 1</math> and hoist (<math>h</math>) starts at <math>k</math>, but hoist (<math>h'</math>) did not have enough time to move away. The safety duration between the two hoists is not enough.</p> | <p><b>Correction:</b></p> <p>Delay starting of hoist (<math>h</math>) by 15 seconds (<math>6 \times 2.5</math> seconds), until hoist (<math>h'</math>) moves away.</p> |

|        |  | Collision/No Collision                                                                                                                                                                                                                                               | Correction                                                                                                                                                               |
|--------|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case 5 |  |                                                                                                                                                                                    |                                                                                       |
|        |  | <p><b>Collision:</b></p> <p>Hoist (<math>h'</math>) ends at <math>k + 2</math> and hoist (<math>h</math>) starts at <math>k</math>, but hoist (<math>h'</math>) did not have enough time to move away. The safety duration between the two hoists is not enough.</p> | <p><b>Correction:</b></p> <p>Delay starting of hoist (<math>h</math>) by 17.5 seconds (<math>7 \times 2.5</math> seconds), until hoist (<math>h'</math>) moves away.</p> |



|        |  | Collision/No Collision                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Correction                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|--------|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case 7 |  |  <p>The graph plots Time (2.5 sec) on the y-axis (0 to 24) against Position on the x-axis (k-3 to k+4). Hoist <math>h</math> (orange line with dots) moves from position <math>k</math> to <math>v</math>. Hoist <math>h'</math> (black line with dots) moves from position <math>v</math> to <math>k</math>. A grey line shows <math>h'</math> moving away from <math>v</math> after the collision. A red dashed double-headed arrow at position <math>v-1</math> indicates the 'No Safety Duration' and 'No Safety Gap' period.</p> |  <p>The graph plots Time (2.5 sec) on the y-axis (0 to 24) against Position on the x-axis (k-3 to k+4). It shows the 'Old Move by <math>h'</math>' (black line), '<math>h'</math> moves away' (grey line), and 'Current Move by <math>h</math>' (orange line). The current move of <math>h</math> is delayed until <math>h'</math> has moved away. A green shaded area between <math>v-1</math> and <math>v+2</math> indicates the 'Safety Gap' and 'Safety Duration'.</p> |
|        |  | <p><b>Collision:</b></p> <p>Hoist (<math>h'</math>) ends at <math>v - 1</math> and hoist (<math>h</math>) ends at <math>v</math>, but hoist (<math>h'</math>) did not have enough time to move away. The safety duration between the two hoists is not enough.</p>                                                                                                                                                                                                                                                                                                                                                      | <p><b>Correction:</b></p> <p>Delay starting of hoist (<math>h</math>) starting by 17.5 seconds (<math>7 \times 2.5</math> seconds), until hoist (<math>h'</math>) moves away.</p>                                                                                                                                                                                                                                                                                                                                                                             |

|        |  | Collision/No Collision                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Correction                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------|--|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case 8 |  |  <p>The graph shows two hoists, <math>h</math> and <math>h'</math>, moving along a track. Hoist <math>h</math> starts at position <math>k</math> and moves towards position <math>v</math>. Hoist <math>h'</math> starts at position <math>v</math> and moves towards position <math>k+4</math>. They meet at position <math>v</math> at time 12. A red dashed line indicates 'No Safety Gap'.</p> |  <p>The graph shows the same scenario as the 'Collision/No Collision' graph, but with a correction. A green shaded area indicates 'Safety Gap'. The legend includes: Old Move by <math>h'</math> (black line with circle), Current Move by <math>h</math> (orange line with circle), and Safety Duration (green double-headed arrow).</p> |
|        |  | <p><b>Collision:</b></p> <p>Hoist (<math>h'</math>) started from <math>v</math> and hoist (<math>h</math>) ended at <math>v</math>, at the same time.</p> <p>There is no gap between the two hoists.</p>                                                                                                                                                                                                                                                                             | <p><b>Correction:</b></p> <p>Delay starting of hoist (<math>h</math>) starting by 5 seconds (<math>2 \times 2.5</math> seconds), until hoist (<math>h'</math>) moves away.</p>                                                                                                                                                                                                                                               |

|        |  | Collision/No Collision                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Correction                                                                                                                                                                                                                                                                                                                                          |
|--------|--|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Case 9 |  |  <p>The graph plots Time (2.5 sec) on the y-axis (0 to 24) against Position on the x-axis (k-3 to k+4). Hoist h (orange line with dots) moves from position k to v. Hoist h' (black line with dots) moves from position v+1 to k+4. A green dashed double-headed arrow labeled 'Safety Gap' is shown between positions v and v+1. An orange shaded area labeled 'No Safety Gap' is positioned between the two hoists' paths at the time they are at positions v and v+1 respectively.</p> |  <p>The graph is identical to the one in the 'Collision/No Collision' column, but with a green shaded area labeled 'Safety Gap' between positions v and v+1. This indicates that the collision has been avoided by delaying the start of hoist h's movement.</p> |
|        |  | <p><b>Collision:</b><br/> Hoist (<math>h'</math>) started from <math>v + 1</math> and hoist (<math>h</math>) ended at <math>v</math>, at the same time.<br/> The gap between the two hoists is safe.</p>                                                                                                                                                                                                                                                                                                                                                                    | <p><b>Correction:</b><br/> Delay starting hoist (<math>h</math>) starting by 5 seconds (<math>2 \times 2.5</math> seconds), until hoist (<math>h'</math>) moves away.</p>                                                                                                                                                                           |

|         |                                                                                                                                                                                         | Collision/No Collision                 | Correction |
|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|------------|
| Case 10 |                                                                                                                                                                                         |                                        | -          |
|         | <p><b>No Collision:</b><br/>Hoist (<math>h'</math>) started from <math>v + 2</math> and hoist (<math>h</math>) ended at <math>k</math>.<br/>The gap between the two hoists is safe.</p> | No correction needed for hoist ( $h$ ) |            |

## **Appendix (2): The Notations Used in Matlab Coding**

The notations used in the Matlab coding.

p: job priority.

JobID: the job identification number.

r: recipe identification number.

r\_type: the recipe type deification number.

s: the current stage.

ns: the next stage.

k: the current position.

v: the next position.

vc: selected next position (checking).

HoistRange: the hoist range number.

The hoists ranges are numbered with the co-responding hoists number (main hoist number).

h: hoist used to perform the loaded hoist move.

hc: selected hoist (checking).

h\_OL: the other hoist overlapping with the main hoist range.

In case (k & v) happens to be in an overlapping zone, then the other overlapping hoist is the first which to be checked. And in case the other hoist was not valid to be used, the main hoist is checked.

ANOD: the actual anodizing duration.

$TPS(p, s)$  : is the processing starting time of the  $p^{th}$  priority job at the  $s^{th}$  stage.

$TPF(p, s)$  : is the processing finishing time of the  $p^{th}$  priority job at the  $s^{th}$  stage.

$TLS(p, s)$  : is the loaded hoist starting time of  $p^{th}$  priority job from the  $s^{th}$  stage.

$TLF(p, s)$  : is the loaded hoist finishing time of the  $p^{th}$  priority job from the  $s^{th}$  stage.

$TLF(p, s)$  : is the loaded hoist finishing time of the  $p^{th}$  priority job that belongs to the  $s^{th}$  stage.

$TES(p, s)$  : is the empty hoist starting time that is going for the  $p^{th}$  priority job at the  $s^{th}$  stage.

$DT(r, s)$  : is the processing duration for the  $s^{th}$  stage for recipe (r).

$MT(k, v)$  : is the loaded hoist duration from the position (k) to position (v).

$PP\{r\_type, s\}$  : is the cell that lists the possible positions to be used for the  $s^{th}$  stage for recipe type (r\_type).

## Appendix (3): The Matlab Coding For the Further Experimentations (Phase 3)

```
% ACTUAL_PLANT_ADD_JOBS_CASES
% With Modified Start time for Deleting Hoists History
% APMODC=Actual_Prob_Modi_Cases;
% function Actual_Prob_Modi_Cases
% Main Data
Main_Data_Table=readtable('Main_File_Add_Jobs_Cases.xlsx');
Main_Data=table2struct(Main_Data_Table);
% Run_Timer_End=0;
for RUN=1:23
%     TIME_START=timeit(Actual_Prob_Modi_Cases);
    CPU_TIME_START=cputime;

    Day=Main_Data(RUN).Day;
    Seq=Main_Data(RUN).Seq;
    Num_of_Jobs=Main_Data(RUN).Num_Jobs;
    InputDatafile=Main_Data(RUN).Input_File;
    Results_File=Main_Data(RUN).Output_File;
    Real_Anodizing_MakeSpan=Main_Data(RUN).R_A_M;
    Sealing_Case=Main_Data(RUN).Seal_Case;
    Configuration=Main_Data(RUN).Conf;

% Selecting the Day and Configuration to be Scheduled
% User Input Data
% prompt = 'What is Number of Jobs in the Selected Day?      ';
% Num_of_Jobs=input(prompt);          %53; %height(InputDataTable);
% prompt='What is the Input Data File? e.g. File_Name.xlsx:  ';
% InputDatafile=input(prompt,'s');     %'Day 1_ Conf 1_ (08-04-15).xlsx';
% prompt='What is the Results File? e.g. File_Name.xlsx:    ';
% Results_File=input(prompt,'s');      %'Actual Plant Try1.xlsx';
% prompt='What is the Real time in which the last job finished the Anodizing
Stage?, please enter in seconds:  ';
% Real_Anodizing_MakeSpan=input(prompt);

% Tunning Variables:
% Tunning related to time
TI=100000; %TI:Time Interval
Delay=20; %Step value for the amount of Delay
E_or_W=20; %Estimated Average duration for an Empty Hoist Move or Waiting Hoist
(Hold on Hoist)
Any_W=0; %Estimated Intial Duration of Waiting for Every Job at Any of the
Waiting Positions
% Tunning related to Hoist Ranges:
R1S1=2; R1E1=8; R1S2=47; R1E2=60; % Hoist 1 Range
R2S=9; R2E=27; % Hoist 2 Range
R3S=23; R3E=30; % Hoist 3 Range
R4S=28; R4E=37; % Hoist 4 Range % Changed R4S from 29 to 28
R5S=38; R5E=57; % Hoist 5 Range
%Main Stages Numbering:
Max_Stage=27;
%Waiting Stages:
OS=1; %The Out-side Stage
```

```

L=2;      %The Loading Stage
InB1=3; %The Input Buffers (1) Stage
InB2=5; %The Input Buffers (2) Stage
OutB=26;%The Output Buffers Stage
UL=27;   %UnLoading Stage
%Transferor Stages:
Transf1=4; Transf2=20; %Transferors 1 & 2, recpevitly
Transf1_P=8; Transf2_P=37; %Starig Positions for Transferors 1 & 2, recpevitly
%Skipped Stages:
Etch=8; Etch_R1=9; Etch_R2=10; Etch_R3=11; Etch_R4=12; Etch_R5=13;
Des=14; Des_R1=15; Des_R2=16;           %Desumuting Stange and the following 2
Rinsing
E_Color=21; E_Color_R1=22; E_Color_R2=23; %Electro-Coloring and the following 2
Rinsings
AN_S=17; AN_R1=18; AN_R2=19;           %Anodizing Stage and the following 2
Rinsings
D_R=24;  %Dime-Rinsing

%Number of Position
Num_of_Positions=60;
%Num_of_Hoist +1
NH=6;

%Constructing Input Data in form of Structures
InputDataTable=readtable(InputDatafile);
j=table2struct(InputDataTable);
% Num_of_Jobs=height(InputDataTable);

%Intial Values and Intial Matricies
%Initial Value for Points in Time
AccTime=E_or_W+1; %AccTime: a point in time between waiting positions, like
between inlet and out let buffers
TimeStartLoading=E_or_W+1; %TimeStartLoading: the point in time in which a job
started/reached the Loading stage
TimeStartInBuffer1=E_or_W+1; %TimeStartInBuffer1: the point in time a job
started/reached the Inlet Buffer 1
TimeStartInBuffer2=E_or_W+1; %TimeStartInBuffer2: the point in time a job
started/reached the Inlet Buffer 2
TimeStartOutBuffer=E_or_W+1; %TimeStartOutBuffer: the point in time a job
started/reached the Outlet Buffer
% Waiting Durations
% Any_W=15;
WO=Any_W; %WO: Waiting at Out-side the process line
WL=Any_W; %WL: Waiting at the Loading Station
WIB1=Any_W; %WIB1: Waiting at the Input Buffer 1
WIB2=Any_W; %WIB2: Waiting at the Input Buffer 2
WOB=Any_W; %WOB: Waiting at the Output Buffer
Waiting_Matrix=zeros(5,Num_of_Jobs);

%MAIN EVENTS MATRICIES INTIALS
TPS=zeros(Num_of_Jobs,Max_Stage);
TPF=zeros(Num_of_Jobs,Max_Stage);
TLS=zeros(Num_of_Jobs,Max_Stage);
TLF=zeros(Num_of_Jobs,Max_Stage);
TPS_K=zeros(Num_of_Positions,Num_of_Jobs);
TPF_K=zeros(Num_of_Positions,Num_of_Jobs);

```

```

% Initila Position and Hoist Matricies
BlockPosition=zeros(Num_of_Positions,TI);
BlockHoist=zeros(NH,TI);
BH=BlockHoist;
HoistCarryJob=zeros(NH,TI);
HCJ=HoistCarryJob;
%Used Position/Hoist
Treatment_Loc=zeros(Num_of_Jobs,Max_Stage);
Used_Hoist=zeros(Num_of_Jobs,Max_Stage);

% Fixed Durations Treatments and Transportation
% Duration Treatment per recipe per stage
% at the begging of the While loop

% Estimated Remaining Duration from the end of the Anodizing stage to the
% end of Unloading
% E_R_D Matrix
E_R_D=xlsread('Est_Remaining_Dur.xlsx','ERD','B3:C32');
%MT info
%MT: Moving time(duration) for the Hoist (From-To Matrix)
MT=xlsread('From-To Matrix Actual Problem.xlsx',1,'B2:BI61');
PickUp_OS=15; Dipp_OS=15; %Pickup and Dipping for transportation from outside
PickUp_Not_Tank=15; PickUp_Tank=20; Dipp_Any=15; %Picking and Dipping inside the
plant

%PP_Possible Positions per recipe per stage (Cell Array)
switch Configuration
case 1 % Original Tanks Configuration
PP={1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,23,25,25,26, 00,00 ,00,[30 31 33 34],[32 35],[35
36],37,00,00,00,42,[43 44 45 46],[47 48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,28 ,29,[30 31 33 34],[32 35],[35
36],37,00,00,00,42,[43 44 45 46],[47 48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,[28 29],00,[30 31 33 34],[32 35],[35
36],37,00,00,00,42,[43 44 45 46],[47 48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,23,25,25,26, 00,00 ,00,[30 31 33 34],[32 35 36],00,
37,39,40,41,42,[43 44 45 46],[47 48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,28 ,29,[30 31 33 34],[32 35 36],00,
37,39,40,41,42,[43 44 45 46],[47 48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,[28 29],00,[30 31 33 34],[32 35 36],00,
37,39,40,41,42,[43 44 45 46],[47 48 49 50 51 52 53 54 55 56 57 58],[59 60]};
case 2 % +1 Anodizing & + 1 Hot Sealing
PP={1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,23,25,25,26, 00,00 ,00,[30 31 33 34 36],[32 35],[32
35],37,00,00,00,42,[43 44 45 46 47],[48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,28 ,29,[30 31 33 34 36],[32 35],[32
35],37,00,00,00,42,[43 44 45 46 47],[48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,[28 29],00,[30 31 33 34 36],[32 35],[32
35],37,00,00,00,42,[43 44 45 46 47],[48 49 50 51 52 53 54 55 56 57 58],[59 60];

```

```

1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,23,25,25,26, 00,00 ,00,[30 31 33 34 36],[32 35],00 ,
37,39,40,41,42,[43 44 45 46 47],[48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,28 ,29,[30 31 33 34 36],[32 35],00 ,
37,39,40,41,42,[43 44 45 46 47],[48 49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,[28 29],00,[30 31 33 34 36],[32 35],00 ,
37,39,40,41,42,[43 44 45 46 47],[48 49 50 51 52 53 54 55 56 57 58],[59 60]};
case 3 % +1 Anodizing & + 2 Hot Sealing
PP={1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,23,25,25,26, 00,00 ,00,[30 31 33 34 36],[32 35],[32
35],37,00,00,00,42,[43 44 45 46 47 48],[49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,28 ,29,[30 31 33 34 36],[32 35],[32
35],37,00,00,00,42,[43 44 45 46 47 48],[49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,[28 29],00,[30 31 33 34 36],[32 35],[32
35],37,00,00,00,42,[43 44 45 46 47 48],[49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,23,25,25,26, 00,00 ,00,[30 31 33 34 36],[32 35],00 ,
37,39,40,41,42,[43 44 45 46 47 48],[49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,28 ,29,[30 31 33 34 36],[32 35],00 ,
37,39,40,41,42,[43 44 45 46 47 48],[49 50 51 52 53 54 55 56 57 58],[59 60];
1,[2 3 4],[5 6 7],8,[10 11 12 13 14 15 16 17],[18 20],[19 21],[22
24],23,25,26,00,00, 27,[28 29],00,[30 31 33 34 36],[32 35],00 ,
37,39,40,41,42,[43 44 45 46 47 48],[49 50 51 52 53 54 55 56 57 58],[59 60]};
end

%Main Loops
p=1;
Add_Job=1;
Max_Jobs=Num_of_Jobs;
New_Num_of_Jobs=Num_of_Jobs+Add_Job;
while p<=New_Num_of_Jobs

    if p<=Num_of_Jobs
        JobID=j(p).JobID; % 1) JobID: Identify the Current
Job ID
        s=j(p).StartingStage; % 2) Starting Stage: Intial Identification
for the Starting Stage of the Current Job
        SL=j(p).StartingLoc; % 3) Starting Position: Identify the Starting
Location of the Current Job
        r=j(p).RecipeID; % 4) Recipe: Identify the Recipe
ID of the Current Job
    end

    if p>Num_of_Jobs
        JobID=p;
        SS=1;
        s=1;
        SL=1;
        ANOD=30*60; % Average Anodizing Treatment
        if mod(Add_Job,3)==1
            r=6;
        else

```

```

        r=3;
    end
end

% 5) Recipe_Type: Determine the Type of the Recipe of the Current Job
if r==1
    r_type=1; % 5 Rinsings after Etching, NoDesumuting, Anodizing+2R & No
Electro-Coloring
elseif r==2
    r_type=2; % 3 Rinsings after Etching Desumuting+2R, Anodizing+2R & No
Electro-Coloring
elseif r==3
    r_type=3; % 3 Rinsings after Etching Desumuting+1R, Anodizing+2R & No
Electro-Coloring
elseif r==4 | r==7 | r==10 | r==13 | r==16 | r==19 | r==22 | r==25 | r==28
    r_type=4; % 5 Rinsings after Etching, No Desumuting, Anodizing+1R &
Electro-Coloring+2R
elseif r==5 | r==8 | r==11 | r==14 | r==17 | r==20 | r==23 | r==26 | r==29 |
r==30
    r_type=5; % 3 Rinsings after Etching, Desumuting+2R, Anodizing+1R &
Electro-Coloring+2R
else
    r_type=6; % 3 Rinsings after Etching, Desumuting+1R, Anodizing+1R &
Electro-Coloring+2R
end
% 6) Identify the co-responding Andizing Treatment duration for the Current
Job
if p<=Num_of_Jobs
    ANOD=j(p).Anodizing;
end

while s<=Max_Stage %27
    % 7) SS:Starting Stage (repaeted)
    if p<=Num_of_Jobs
        SS=j(p).StartingStage;
    end

    % 8) DT Matrix was put here to increase the waiting duration if happened
    % Waiting Durations are (WO, WL, WIB1, WIB2, WOB)
    %OS   L       InB1   Tr1 InB2   Ak   R   Etc   R1 R2 R3 R4 R5 Ds R1 R2
Anod R1 R2 Tr2 Col R1 R2 DR Seal OutB   UL
    DT=[%Matt       Finish (recipes 1-3)
        0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 60 60 0000 00 00 60 2700 600+WOB 600;
        0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 60 60 0000 00 00 60 2700 600+WOB 600;
        0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 60 60 0000 00 00 60 2700 600+WOB 600;
        %Col 16       Finish (recipes 4-6)
        0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0060 60 60 60 2700 600+WOB 600;
        0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 0060 60 60 60 2700 600+WOB 600;
        0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0060 60 60 60 2700 600+WOB 600;
        %Col 15       Finish (recipes 7-9)

```

```

0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0120 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 60 60 60
ANOD 60 00 60 0120 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0120 60 60 60 2700 600+WOB 600;
%Col 10 Finish (recipes 10-12)
0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0210 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 0210 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0210 60 60 60 2700 600+WOB 600;
%Col 11 Finish (recipes 13-15)
0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0270 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 0270 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0270 60 60 60 2700 600+WOB 600;
%Col 17 Finish (recipes 16-18)
0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0360 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 0360 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0360 60 60 60 2700 600+WOB 600;
%Col 21 Finish (recipes 19-21)
0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0540 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 0540 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0540 60 60 60 2700 600+WOB 600;
%Col 30 Finish (recipes 22-24)
0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0660 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 0660 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0660 60 60 60 2700 600+WOB 600;
%Col 40 Finish (recipes 25-27)
0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 0870 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 0870 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 0870 60 60 60 2700 600+WOB 600;
%Black Finish (recipes 28-30)
0+WO 1800+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 60 60 00 00 00
ANOD 60 00 60 1440 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 60
ANOD 60 00 60 1440 60 60 60 2700 600+WOB 600;
0+WO 0600+WL 0+WIB1 60 0+WIB2 360 60 1080 60 60 60 00 00 60 60 00
ANOD 60 00 60 1440 60 60 60 2700 600+WOB 600];

```

% 9)TPS: Time in which a Process (Treatments) Starts

% 10)value of (k):Current Position

```

% The reason for making these "if statements" is to save the
% starting time at a waiting stage and the position that was
% assigned for the current job, in case of violation(s) i.e Deleting and
Delay
if SS==1 & s==OS
    TPS(p,s)=E_or_W+1; %1
    if p<=Num_of_Jobs
        k=j(p).StartingLoc;
    else
        k=1;
    end

elseif SS==1 & s==L
    TPS(p,s)=TimeStartLoading;
    k=k1_L;
elseif SS==1 & s==InB1
    TPS(p,s)=TimeStartInBuffer1;
    k=k1_IB1;
elseif SS==1 & s>InB1 & s<InB2
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==1 & s==InB2
    TPS(p,s)=TimeStartInBuffer2;
    k=k1_IB2;
elseif SS==1 & s>InB2 & s<OutB
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==1 & s==OutB
    TPS(p,s)=TimeStartOutBuffer;
    k=k1_OB;
elseif SS==1 & s==UL
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==2 & s==L
    TPS(p,s)=E_or_W+1; %1
    k=j(p).StartingLoc;
elseif SS==2 & s==InB1
    TPS(p,s)=TimeStartInBuffer1;
    k=k2_IB1;
elseif SS==2 & s>InB1 & s<InB2
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==2 & s==InB2
    TPS(p,s)=TimeStartInBuffer2;
    k=k2_IB2;
elseif SS==2 & s>InB2 & s<OutB
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==2 & s==OutB
    TPS(p,s)=TimeStartOutBuffer;
    k=k2_OB;
elseif SS==2 & s==UL
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==3 & s==InB1
    TPS(p,s)=E_or_W+1; %1
    k=j(p).StartingLoc;
elseif SS==3 & s>InB1 & s<InB2

```

```

        TPS(p,s)=AccTime;
        k=k_Now;
elseif SS==3 & s==InB2
    TPS(p,s)=TimeStartInBuffer2;
    k=k3_IB2;
elseif SS==3 & s>InB2 & s<OutB
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==3 & s==OutB
    TPS(p,s)=TimeStartOutBuffer;
    k=k3_OB;
elseif SS==3 & s==UL
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==5 & s==InB2
    TPS(p,s)=E_or_W+1; %1
    k=j(p).StartingLoc;
elseif SS==5 & s>InB2 & s<OutB
    TPS(p,s)=AccTime;
    k=k_Now;
elseif SS==5 & s==OutB
    TPS(p,s)=TimeStartOutBuffer;
    k=k5_OB;
elseif SS==5 & s==UL
    TPS(p,s)=AccTime;
    k=k_Now;
end
% 11) TPSsf (for sub-function if needed) for TPS(p,s)
TPSsf=TPS(p,s);

% 12) TPF: Time in which the Process (Treatment) Finishes
DT_Now=DT(r,s);
if s==25 %Sealing Stage
switch Sealing_Case
    case 1 % For the days in 2015
        if Configuration==1 % Original Tanks Configuration
            DT_Now=45*60;
        end
        if Configuration==2 % +1 Anodizing & +1 Hot Sealing
            if k==43 | k==44 | k==45 | k==46
                DT_Now=45*60;
            elseif k==47
                DT_Now=20*60;
            end
        end
        if Configuration==3 % +1 Anodizing & +2 Hot Sealing
            if k==43 | k==44 | k==45 | k==46
                DT_Now=45*60;
            elseif k==47 | k==48
                DT_Now=20*60;
            end
        end
    case 2 % For the days in 2017
        if Configuration==1 % Original Tanks Configuration
            if k==43
                DT_Now=20*60;
            elseif k==44 | k==45 | k==46
                DT_Now=60*60;
            end
        end
    end
end

```

```

        end
    end
    if Configuration==2 % +1 Anodizing & +1 Hot Sealing
        if k==43 | k==47
            DT_Now=20*60;
        elseif k==44 | k==45 | k==46
            DT_Now=60*60;
        end
    end
    if Configuration==3 % +1 Anodizing & +2 Hot Sealing
        if k==43 | k==47 | k==48
            DT_Now=20*60;
        elseif k==44 | k==45 | k==46
            DT_Now=60*60;
        end
    end
end
end

% Adjust Loading Duration
if s==27 & (r==1 | r==4 | r==7 | r==10 | r==13 | r==16 | r==19 | r==22 |
r==25 | r==28)
    DT_Now=3*60;
end

TPF(p,s)=TPS(p,s)+DT_Now;
% 13) TPFsf (for sub-function if needed) for TPF(p,s)
TPFsf=TPF(p,s);
disp(['Now Working with Run: ',num2str(RUN),', [Day: ',num2str(Day),
'/Seq.',num2str(Seq),'/Conf.',num2str(Configuration),']; Current
Job no. ',num2str(p),'; Now TPF = ',num2str(TPFsf)])

% 14) Used Position (Location) for the Process (Treatment) Matrix
% 15) Changingable TPS_K(k,p) & TPF_K(k,p)
% The Two Matrices (TPS_K & TPF_K are the same as TPS & TPF, but in state
of taking s:stage as index it take k:current position as the index, and they are
transposed)
Treatment_Loc(p,s)=k;
%     TPS_K(k,p)=TPS(p,s);
%     TPF_K(k,p)=TPF(p,s);

% 16) TLS: Time in which a Loaded Hoist Starts
TLS(p,s)=TPF(p,s);
% 17) TLSsf (for sub-function if needed) for TLS(p,s)
TLSsf=TLS(p,s);

% 18) Dipping Value
% 19) PickingUp Value
if s==1
    Pickup=PickUp_OS; %Because no hoist used to move a job from outside
to a Loading Station
    Dipp=Dipp_OS;      %Because no hoist used to move a job from outside
to a Loading Station
elseif s>1
    Dipp=Dipp_Any;
end

```

```

    %PickUp=2; % In Case we try with one PickUp value
    %PickUp from Loading,Buffer, or UnLoading
    if (s>=L & s<=InB2) | (s>=OutB & s<=UL)
        PickUp=PickUp_Not_Tank;
        %PickUp from a Tank (Position with Liquid)
    elseif (s>=InB2+1 & s<=OutB-1)
        PickUp=PickUp_Tank;
    end
end

% To Obtain TLF: Time in which the Loaded Hoist Finishes
% The Next Position of the Next Stage (v) Must be Determined
% To Determine (v), Intail v is selected (vc)
% vc (the selected Position) is Checked if it was Ready (Free) Or Not
% This Done in the Cell Array and "if-else statement" below
% Also in the "if-else" statement, A Decision Variable Called
"No_More_Stages" is
% determined, which is used to decide to get of the while loop or
% Not later on
% the job finished at the Last Stage (UnLoading)

% 20) No_More_Stages is obtained (1=true, 0=false)
% 21) Determining the Next Stage (ns), depending on the recipe type and the
stage
% 22) Possible Position are selected as vector
% 23) Closet vc if selected first
% 24) vc is checked if it is Free Or Not (1=true (free), 0=false (busy))
% 25) if it was busy, 2nd close vc is selected, and checked, and so on

% Sub-function for Steps (20 to 25), if needed

%[Next_Position_Is_Ready,v,No_More_Stages]=CheckPosition(p,s,r,k,TLSSf,PickUp,Dip
p,BlockPosition,MT,DT,PP)

    if s+1>Max_Stage %27
        No_More_Stages=1;
    else
        ns=s+1;
        if (r_type==1 | r_type==4) & ns==Des % Stages 12 & 13 (Desmuting and
Rinising) for recipe_type 1|2 are skipped
            ns=AN_S; % ==>so next stage (ns) is to
jume to Stage 14 (Anodizing)
        end
        if (r_type==1 | r_type==2 | r_type==3) & ns==E_Color % Stages 18 to
20 (Electro-Coloring and 2 Rinising) for recipe_type 1|3 are skipped
            ns=D_R; % ==>so next stage (ns)
is jume to Stage 21 (Demi-Rinsing)
        end
        if (r_type==2 | r_type==3 | r_type==5 | r_type==6) & ns==Etch_R4
            ns=Des;
        end
        if (r_type==3 | r_type==6) & ns==Des_R2
            ns=AN_S;
        end
        if (r_type==4 | r_type==5 | r_type==6) & ns==AN_R2
            ns=Transf2;
        end
    end

```

```

%           else           % Otherwise if none of the above
%           ns=s+1; % Next Stage (ns)=current stage + 1
%       end
% SV_First the Required Vector is Selected from the Cell Array
% PP {per recipe type, per next stage}
SV=PP{r_type,ns};
for i=1:length(SV)
    vc=SV(i);

    % IF r_type==1 or 4, stage no. must not use the position 35
    % twice
    if ns==19 & Configuration==1
        if vc==k %vc=k=35
            vc=36;
        end
    end
    if ns==19 & (Configuration==2 | Configuration==3)
        if vc==k %vc=k=32
            vc=35;
        end
    end
    end

    %k-->v for Transferors
    if s==Transf1
        k=k+1;
    end
    if s==Transf2
        k=k+1;
    end
    end

    TPS_Next_Stage=TLSSf+PickUp+MT(k,vc)+Dipp;
    DT_Next=DT(r,ns);

    % Giving Extra Duration for Buffers (just for checking, Not for
Calculation Nor Blocking)
    if ns==3 | ns==5
        DT_Next=5*60; % An Average estimated duration
    end

    % Adjusting the Duration of Hot Sealing
    if ns==25
        switch Sealing_Case
            case 1
                if Configuration==1
                    DT_Next=45*60;
                end
                if Configuration==2 % +1 Anodizing & +1 Hot Sealing
                    if vc==43 | vc==44 | vc==45 | vc==46
                        DT_Next=45*60;
                    elseif vc==47
                        DT_Next=20*60;
                    end
                end
            case 3
                if Configuration==3 % +1 Anodizing & +2 Hot Sealing
                    if vc==43 | vc==44 | vc==45 | vc==46
                        DT_Next=45*60;
                    elseif vc==47 | vc==48

```

```

        DT_Next=45*60;
    end
end
case 2
    if Configuration==1 % Original Configuration
        if vc==43
            DT_Next=20*60;
        elseif vc==44 | vc==45 | vc==46
            DT_Next=60*60;
        end
    end
    if Configuration==2 % +1 Anodizing & +1 Hot Sealing
        if vc==43 | vc==47 | vc==48
            DT_Next=20*60;
        elseif vc==44 | vc==45 | vc==46
            DT_Next=60*60;
        end
    end
    if Configuration==3 % +1 Anodizing & +2 Hot Sealing
        if vc==43 | vc==47 | vc==48
            DT_Next=20*60;
        elseif vc==44 | vc==45 | vc==46
            DT_Next=60*60;
        end
    end
end
end

% Adjust UnLoading Duration
% if ns==27
%     DT_Next=12*60;
% end
if ns==27 & (r==1 | r==4 | r==7 | r==10 | r==13 | r==16 | r==19 |
r==22 | r==25 | r==28)
    DT_Next=3*60;
end

TPF_Next_Stage=TLSSf+PickUp+MT(k,vc)+Dipp+DT_Next+(0*60);
% if (r_type==1 | r_type==4) %& vc>=k
% if BlockPosition(vc,TPS_Next_Stage:TPF_Next_Stage)==0
%     Next_Position_Is_Ready=1;
%     v=vc;
%     No_More_Stages=0;
%     break
% else
%     Next_Position_Is_Ready=0;
%     v=vc; %Temperaturly
%     No_More_Stages=0;
% end
end
end

% Now the time of TLF can be calculated, only If there are More Stages
% Last TLF is like a Dummy (not calculated)
% 26) Are There More Stages? No_More_Stages?
% 27) TLF: Time in which the Loaded Hoist Finishes

```

```

% 28) TLFsf (for sub-function if needed) for TLF(p,s)
if No_More_Stages==1
    break
else
    TLF(p,s)=TLS(p,s)+PickUp+MT(k,v)+Dipp;
    TLFsf=TLF(p,s);
end

% Until Now the Position for the Next Stage is Planned
% What is Reaming is the Planning for the Loaded Hoist Move
% First the case is selected based on the Full (Org) Range of the most
trivial hoist to be selected
% Then from the Org range selected the overlap zone is checked
% If the next position (v) was within the Overlap zone
% ==> The other hoist is checked/selected
% If the next position was not within the Overlap zone
% ==> The Org. (main) hoist is checked/selected
% IF both hoists were not okay to selected
% ==> Delay the new job entrance was applied as a solution for the
% hoist un-availability

% 29) Selecting the main Hoist Range
% 30) Checking the hoist the overlap with the main rage
% 30.1) Checking the Overlap Range
% 30.2) Checking the Availability
% 30.3) Checking No Collision possible
% 31) Do the same for org hoist

% 29) Selecting a Range Case
if (k>=R1S1 & k<=R1E1 & v>=R1S1 & v<=R1E1) | (k>=R1S2 & k<=R1E2 & v>=R1S2
& v<=R1E2) % Hoist 1 Full Range of Hoist 1
    HoistRange=1;
elseif (k>=R2S & k<=R2E & v>=R2S & v<=R2E)
    HoistRange=2;
elseif (k>=R3S & k<=R3E & v>=R3S & v<=R3E)
    HoistRange=3;
elseif (k>=R4S & k<=R4E & v>=R4S & v<=R4E)
    HoistRange=4;
elseif (k>=R5S & k<=R5E & v>=R5S & v<=R5E)
    HoistRange=5;
else
    HoistRange=6;
end

% 30 & 31) Checking the Hoists
switch HoistRange
case 1
    hc=5;
    h_OL=1;
    if (k>=R1S2 & k<=R5E & v>=R1S2 & v<=R5E) & HCJ(hc,TLSSsf-
E_or_W:TLSSsf)==0 & HCJ(hc,TLFsf)==0 & BH(h_OL,TLSSsf)~=k-1 & BH(h_OL,TLSSsf)~=k &
BH(h_OL,TLSSsf)~=k+1 & BH(h_OL,TLFsf)~=v-1 & BH(h_OL,TLFsf)~=v &
BH(h_OL,TLFsf)~=v+1
        Hoist_Is_Okay=1;
        h=hc;
    else

```

```

        hc=1;
        if HCJ(hc, TLSsf-E_or_W:TLSsf)==0 & HCJ(hc, TLFsf)==0
            Hoist_Is_Okay=1;
            h=hc;
        else
            Hoist_Is_Okay=0;
        end
    end
case 2
    hc=3;
    h_OL=2;
    if (k>=R3S & k<=R2E & v>=R3S & v<=R2E) & HCJ(hc, TLSsf-
E_or_W:TLSsf)==0 & HCJ(hc, TLFsf)==0 & BH(h_OL, TLSsf)~=k-1 & BH(h_OL, TLSsf)~=k &
BH(h_OL, TLSsf)~=k+1 & BH(h_OL, TLFsf)~=v-1 & BH(h_OL, TLFsf)~=v &
BH(h_OL, TLFsf)~=v+1
        Hoist_Is_Okay=1;
        h=hc;
    else
        hc=2;
        if HCJ(hc, TLSsf-E_or_W:TLSsf)==0 & HCJ(hc, TLFsf)==0
            Hoist_Is_Okay=1;
            h=hc;
        else
            Hoist_Is_Okay=0;
        end
    end
case 3
    hc=4;
    h_OL=3;
    if (k>=R4S & k<=R3E & v>=R4S & v<=R3E) & HCJ(hc, TLSsf-
E_or_W:TLSsf)==0 & HCJ(hc, TLFsf)==0 & BH(h_OL, TLSsf)~=k-1 & BH(h_OL, TLSsf)~=k &
BH(h_OL, TLSsf)~=k+1 & BH(h_OL, TLFsf)~=v-1 & BH(h_OL, TLFsf)~=v &
BH(h_OL, TLFsf)~=v+1
        Hoist_Is_Okay=1;
        h=hc;
    else
        hc=2;
        h_OL=3;
        if (k>=R3S & k<=R2E & v>=R3S & v<=R2E) & HCJ(hc, TLSsf-
E_or_W:TLSsf)==0 & HCJ(hc, TLFsf)==0 & BH(h_OL, TLSsf)~=k-1 & BH(h_OL, TLSsf)~=k &
BH(h_OL, TLSsf)~=k+1 & BH(h_OL, TLFsf)~=v-1 & BH(h_OL, TLFsf)~=v &
BH(h_OL, TLFsf)~=v+1
            Hoist_Is_Okay=1;
            h=hc;
        else
            hc=3;
            if HCJ(hc, TLSsf-E_or_W:TLSsf)==0 & HCJ(hc, TLFsf)==0
                Hoist_Is_Okay=1;
                h=hc;
            else
                Hoist_Is_Okay=0;
            end
        end
    end
case 4
    hc=3;
    h_OL=4;

```

```

        if (k>=R4S & k<=R3E & v>=R4S & v<=R3E) & HCJ(hc,TLSSsf-
E_or_W:TLSSsf)==0 & HCJ(hc,TLFsf)==0 & BH(h_OL,TLSSsf)~=k-1 & BH(h_OL,TLSSsf)~=k &
BH(h_OL,TLSSsf)~=k+1 & BH(h_OL,TLFsf)~=v-1 & BH(h_OL,TLFsf)~=v &
BH(h_OL,TLFsf)~=v+1
            Hoist_Is_Okay=1;
            h=hc;
        else
            hc=4;
            if HCJ(hc,TLSSsf-E_or_W:TLSSsf)==0 & HCJ(hc,TLFsf)==0
                Hoist_Is_Okay=1;
                h=hc;
            else
                Hoist_Is_Okay=0;
            end
        end
    case 5
        hc=1;
        h_OL=5;
        if (k>=R1S2 & k<=R5E & v>=R1S2 & v<=R5E) & HCJ(hc,TLSSsf-
E_or_W:TLSSsf)==0 & HCJ(hc,TLFsf)==0 & BH(h_OL,TLSSsf)~=k-1 & BH(h_OL,TLSSsf)~=k &
BH(h_OL,TLSSsf)~=k+1 & BH(h_OL,TLFsf)~=v-1 & BH(h_OL,TLFsf)~=v &
BH(h_OL,TLFsf)~=v+1
            Hoist_Is_Okay=1;
            h=hc;
        else
            hc=5;
            if HCJ(hc,TLSSsf-E_or_W:TLSSsf)==0 & HCJ(hc,TLFsf)==0
                Hoist_Is_Okay=1;
                h=hc;
            else
                Hoist_Is_Okay=0;
            end
        end
    case 6
        h=6;
end

% Used Hoist Matrix, to show which hoist was used to per job per
% stage
Used_Hoist(p,s)=h;
UH=Used_Hoist;

```

```

% 32.1) Block & Update
% or 32.2) Delete and Delay
% The Section is Divided into Two Sections
% Section 1: When there was Successful Planning for the next
% position and Hoist
% Section 2: When there was Un-Successful Planning from either Next
% Position or/and Hoist

```

```

% In Section 1: the following Main Steps are appllied
% 1) Block the time of duration of the Current Stage:
% @ BlockPosition(k,TPS:TPF)=JobID.
% 2) Reserve the time of duration of the Next Stage to be blocked:
% @ BlockPosition(v,TPS_next:TPF:next).

```

```

% 3) Block the Hoist for the Loaded Move, with JobID:
%   @ HCJ(h,TLS:TLF)=JobID
% 4) Block the starting and finishing positions of the Loaded Hoist
% Move:
%   @ BH(h,TLS)=k & BH(h,TLF)=v
% 5) Update the stage for the next stage number.
% 6) Update the current position (k) to the next position (v)
%   k=v
% 7) Update the time to the latest recored time at the (TLF) Matrix

% If the Nexttt stage is a Transferor
% ==> Step 2 add time of Pickup and catrage return for both of the
% transferor poisitions
% & ==> k=v+1, to take the finishing position of the trasferor as
% the next current position
if Next_Position_Is_Ready==1 & Hoist_Is_Okay==1
    if s==Transf1 % Transferor 1 %k==8-->9
        BH(h,TLSSf)=k;
        BH(h,TLFsf)=v;
        HCJ(h,TLSSf-E_or_W:TLSSf-1)=300+JobID; %For the Empty Hoist Move

Blocking
        HCJ(h,TLSSf:TLFsf)=JobID;
        BlockPosition(k-1:k,TPSSf:TPFsf)=JobID;
        BlockPosition(k-1:k,TPFsf:TPFsf+PickUp)=100+JobID;
        BlockPosition(k-1:k,TPFsf+PickUp:TPFsf+PickUp+DT(r,s))=200+JobID;
        % Up-date stage, position k, and time
        s=s+1;
        if SS==1
            k1_IB2=v;
        end
        if SS==2
            k2_IB2=v;
        end
        if SS==3
            k3_IB2=v;
        end
        k_Now=v;
        TimeStartInBuffer2=TLFsf;
    elseif s==Transf2 % Transferor 2 %k==37-->38
        BH(h,TLSSf)=k;
        BH(h,TLFsf)=v;
        HCJ(h,TLSSf-E_or_W:TLSSf-1)=300+JobID; %For the Empty Hoist Move

Blocking
        HCJ(h,TLSSf:TLFsf)=JobID;
        BlockPosition(k-1:k,TPSSf:TPFsf)=JobID;
        BlockPosition(k-1:k,TPFsf:TPFsf+PickUp)=100+JobID;
        BlockPosition(k-1:k,TPFsf+PickUp:TPFsf+PickUp+DT(r,s))=200+JobID;
        % Up-date the stage, position k, and time
        s=s+1;
        if (r_type==1 | r_type==2 | r_type==3) & s==E_Color
            s=D_R;
        end
        v=k+1;
        k_Now=v;
        AccTime=TLFsf;
    else %s~=Transf1 & s~=Transf2 %OTHER STAGES
        TLFsf=TLF(p,s);
        BH(h,TLSSf)=k;

```

## Blocking

```

BH(h,TLFsf)=v;
HCJ(h,TLSSf-E_or_W:TLSSf-1)=300+JobID; %For the Empty Hoist Move

HCJ(h,TLSSf:TLFsf)=JobID;
BlockPosition(k,TPSsf:TPFsf)=JobID;
if ns==Max_Stage
BlockPosition(v,TLFsf:TLFsf+DT(r,ns))=JobID;
end
% Up-date stage, position k, and time
s=s+1;
if (r_type==1 | r_type==4) & s==Des % Stages 12 & 13 (Desumuting
and Rinising) for recipe_type 1|2 are skipped
s=AN_S; % ==>so next stage (ns) is
to jumpe to Stage 14 (Anodizing)
end
if (r_type==1 | r_type==2 | r_type==3) & s==E_Color % Stages 18
to 20 (Electro-Coloring and 2 Rinising) for recipe_type 1|3 are skipped
s=D_R; % ==>so next stage
(ns) is jumpe to Stage 21 (Demi-Rinsing)
end
if (r_type==2 | r_type==3 | r_type==5 | r_type==6) & s==Etch_R4
s=Des;
end
if (r_type==3 | r_type==6) & s==Des_R2
s=AN_S;
end
if (r_type==4 | r_type==5 | r_type==6) & s==AN_R2
s=Transf2;
end
%Up-Dating the Current Position by Next Position
%Up-Dating the Time;
if SS==1 & s==L
k1_L=v;
TimeStartLoading=TLFsf;
elseif SS==1 & s==InB1
k1_IB1=v;
TimeStartInBuffer1=TLFsf;
elseif SS==1 & s>InB1 & s<InB2
k_Now=v;
AccTime=TLFsf;
elseif SS==1 & s==InB2
k1_IB2=v;
TimeStartInBuffer2=TLFsf;
elseif SS==1 & s>InB2 & s<OutB
k_Now=v;
AccTime=TLFsf;
elseif SS==1 & s==OutB
k1_OB=v;
TimeStartOutBuffer=TLFsf;
elseif SS==1 & s==UL
k_Now=v;
AccTime=TLFsf;
elseif SS==2 & s==InB1
k2_IB1=v;
TimeStartInBuffer1=TLFsf;
elseif SS==2 & s>InB1 & s<InB2
k_Now=v;
AccTime=TLFsf;

```

```

elseif SS==2 & s==InB2
    k2_IB2=v;
    TimeStartInBuffer2=TLFsf;
elseif SS==2 & s>InB2 & s<OutB
    k_Now=v;
    AccTime=TLFsf;
elseif SS==2 & s==OutB
    k2_OB=v;
    TimeStartOutBuffer=TLFsf;
elseif SS==2 & s==UL
    k_Now=v;
    AccTime=TLFsf;
elseif SS==3 & s>InB1 & s<InB2
    k_Now=v;
    AccTime=TLFsf;
elseif SS==3 & s==InB2
    k3_IB2=v;
    TimeStartInBuffer2=TLFsf;
elseif SS==3 & s>InB2 & s<OutB
    k_Now=v;
    AccTime=TLFsf;
elseif SS==3 & s==OutB
    k3_OB=v;
    TimeStartOutBuffer=TLFsf;
elseif SS==3 & s==UL
    k_Now=v;
    AccTime=TLFsf;
elseif SS==5 & s>InB2 & s<OutB
    k_Now=v;
    AccTime=TLFsf;
elseif SS==5 & s==OutB
    k5_OB=v;
    TimeStartOutBuffer=TLFsf;
elseif SS==5 & s==UL
    k_Now=v;
    AccTime=TLFsf;
end % End of Successful Commands for Other Stages
end %End of ALL Successful Commands for ALL Stages

% Commands of Un-Successful Planning
% In Section 2, the following Main Steps are applied
% 1) Delete the History of the Current Job in the 3 Matrices
% (BlockPosition, HCJ, and BH), from the Starting time of the
% latest Waiting Stage to the time of the Latest Stage that this
% job reached.
% Since the elements inside the BH Matrix are only values of
% Positions, the HCJ Matrix was used to detect (find) the
% location of the elements in BH Matrix that need to be Deleted.
% 2) State Which Waiting Stage to return to.
% 3) Increase the Waiting duration to the returned stage (i.e. More
Delay)
% As for which Position the job will return to is already known
% (saved) from the command of the "if statements" in Section 1
% (Step 32.1) and the TPS (Steps 9 & 10).
else
    Max_Stop=TLSSf; %+DT(r,ns); %+5000; %TI
    if SS==1 & s+1==L
        BH(find(HCJ==JobID))==0;

```

```

%           HCJ(find(HCJ==JobID))==0;
%           BlockPosition(find(BlockPosition==JobID))==0;
%           HCJ_Delet1_OtoL=HCJ(:,1:Max_Stop);
%           BH_Delet1_OtoL=BH(:,1:Max_Stop);
%           BP_Delet1_OtoL=BlockPosition(:,1:Max_Stop);
%           BH_Delet1_OtoL(find(HCJ_Delet1_OtoL==JobID))==0;
%           HCJ_Delet1_OtoL(HCJ_Delet1_OtoL==JobID)=0;
%           BP_Delet1_OtoL(BP_Delet1_OtoL==JobID)=0;
%           BH(:,1:Max_Stop)=BH_Delet1_OtoL;
%           HCJ(:,1:Max_Stop)=HCJ_Delet1_OtoL;
%           BlockPosition(:,1:Max_Stop)=BP_Delet1_OtoL;
s=OS;
WO=WO+Delay;
continue
elseif SS==1 & s+1==InB1
    HCJ_Delet1_LtoIB1=HCJ(:,TLS(p,L)-E_or_W:Max_Stop); %Max_Stop);
    BH_Delet1_LtoIB1=BH(:,TLS(p,L)-E_or_W:Max_Stop); %Max_Stop);
    BP_Delet1_LtoIB1=BlockPosition(:,TimeStartLoading:Max_Stop);
%Max_Stop);

    BH_Delet1_LtoIB1(find(HCJ_Delet1_LtoIB1==JobID))==0;

    HCJ_Delet1_LtoIB1(HCJ_Delet1_LtoIB1==300+JobID)=0; %For Deleting
History of Empty Hoist Move
    HCJ_Delet1_LtoIB1(HCJ_Delet1_LtoIB1==JobID)=0;

%           BP_Delet1_LtoIB1(BP_Delet1_LtoIB1==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
%           BP_Delet1_LtoIB1(BP_Delet1_LtoIB1==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
    BP_Delet1_LtoIB1(BP_Delet1_LtoIB1==JobID)=0;

    BH(:,TLS(p,L)-E_or_W:Max_Stop)=BH_Delet1_LtoIB1;
    HCJ(:,TLS(p,L)-E_or_W:Max_Stop)=HCJ_Delet1_LtoIB1;
    BlockPosition(:,TimeStartLoading:Max_Stop)=BP_Delet1_LtoIB1;
s=L;
WL=WL+Delay;
continue
elseif SS==1 & s+1>InB1 & s+1<=InB2
    if s==Transf1
        Max_Stop_BP=TLSSf+PickUp+DT(r,s);
    else
        Max_Stop_BP=TLSSf; %Max_Stop);
    end
    HCJ_Delet1_IB1toIB2=HCJ(:,TLS(p,InB1)-E_or_W:Max_Stop);
%Max_Stop);
    BH_Delet1_IB1toIB2=BH(:,TLS(p,InB1)-E_or_W:Max_Stop); %Max_Stop);

    BP_Delet1_IB1toIB2=BlockPosition(:,TimeStartInBuffer1+1:Max_Stop_BP);
%Max_Stop_BP);

    BH_Delet1_IB1toIB2(find(HCJ_Delet1_IB1toIB2==JobID))==0;

    HCJ_Delet1_IB1toIB2(HCJ_Delet1_IB1toIB2==300+JobID)=0; %For
Deleting History of Empty Hoist Move
    HCJ_Delet1_IB1toIB2(HCJ_Delet1_IB1toIB2==JobID)=0;

```

```

        BP_Delet1_IB1toIB2(BP_Delet1_IB1toIB2==100+JobID)=0; %For
Deleting the Picking Up event from Transferor
        BP_Delet1_IB1toIB2(BP_Delet1_IB1toIB2==200+JobID)=0; %For
Deleting the Catrage return event at the Transferor
        BP_Delet1_IB1toIB2(BP_Delet1_IB1toIB2==JobID)=0;

        BH(:,TLS(p,InB1)-E_or_W:Max_Stop)=BH_Delet1_IB1toIB2;
        HCJ(:,TLS(p,InB1)-E_or_W:Max_Stop)=HCJ_Delet1_IB1toIB2;

BlockPosition(:,TimeStartInBuffer1+1:Max_Stop_BP)=BP_Delet1_IB1toIB2;
        s=InB1;
        WIB1=WIB1+Delay;
        continue
    elseif SS==1 & s+1>InB2 & s+1<=OutB
        HCJ_Delet1_IB2toOB=HCJ(:,TLS(p,InB2)-E_or_W:Max_Stop);
%Max_Stop);

        BH_Delet1_IB2toOB=BH(:,TLS(p,InB2)-E_or_W:Max_Stop); %Max_Stop);
        BP_Delet1_IB2toOB=BlockPosition(:,TimeStartInBuffer2:Max_Stop);
%Max_Stop);

        BH_Delet1_IB2toOB(find(HCJ_Delet1_IB2toOB==JobID))=0;

        HCJ_Delet1_IB2toOB(HCJ_Delet1_IB2toOB==300+JobID)=0; %For
Deleting History of Empty Hoist Move
        HCJ_Delet1_IB2toOB(HCJ_Delet1_IB2toOB==JobID)=0;

        BP_Delet1_IB2toOB(BP_Delet1_IB2toOB==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
        BP_Delet1_IB2toOB(BP_Delet1_IB2toOB==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
        BP_Delet1_IB2toOB(BP_Delet1_IB2toOB==JobID)=0;

        BH(:,TLS(p,InB2)-E_or_W:Max_Stop)=BH_Delet1_IB2toOB;
        HCJ(:,TLS(p,InB2)-E_or_W:Max_Stop)=HCJ_Delet1_IB2toOB;
        BlockPosition(:,TimeStartInBuffer2:Max_Stop)=BP_Delet1_IB2toOB;
        s=InB2;
        WIB2=WIB2+Delay;
        continue
    elseif SS==1 & s+1==UL
        HCJ_Delet1_OBtoUL=HCJ(:,TLS(p,OutB)-E_or_W:Max_Stop);
        BH_Delet1_OBtoUL=BH(:,TLS(p,OutB)-E_or_W:Max_Stop);
        BP_Delet1_OBtoUL=BlockPosition(:,TimeStartOutBuffer:Max_Stop);

        BH_Delet1_OBtoUL(find(HCJ_Delet1_OBtoUL==JobID))=0;

        HCJ_Delet1_OBtoUL(HCJ_Delet1_OBtoUL==300+JobID)=0; %For Deleting
History of Empty Hoist Move
        HCJ_Delet1_OBtoUL(HCJ_Delet1_OBtoUL==JobID)=0;

%           BP_Delet1_OBtoUL(BP_Delet1_OBtoUL==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
%           BP_Delet1_OBtoUL(BP_Delet1_OBtoUL==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
        BP_Delet1_OBtoUL(BP_Delet1_OBtoUL==JobID)=0;

        BH(:,TLS(p,OutB)-E_or_W:Max_Stop)=BH_Delet1_OBtoUL;

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        HCJ(:, TLS(p, OutB) - E_or_W:Max_Stop) = HCJ_Delet1_OBtoUL;
        BlockPosition(:, TimeStartOutBuffer:Max_Stop) = BP_Delet1_OBtoUL;
        s = OutB;
        WOB = WOB + Delay;
        continue
elseif SS == 2 & s + 1 == InB1
    HCJ_Delet2_LtoIB1 = HCJ(:, TLS(p, L) - E_or_W:Max_Stop); %Max_Stop);
    BH_Delet2_LtoIB1 = BH(:, TLS(p, L) - E_or_W:Max_Stop); %Max_Stop);
    BP_Delet2_LtoIB1 = BlockPosition(:, TimeStartLoading:Max_Stop);
    %Max_Stop);

    BH_Delet2_LtoIB1(find(HCJ_Delet2_LtoIB1 == JobID)) = 0;

    HCJ_Delet2_LtoIB1(HCJ_Delet2_LtoIB1 == 300 + JobID) = 0; %For Deleting
History of Empty Hoist Move
    HCJ_Delet2_LtoIB1(HCJ_Delet2_LtoIB1 == JobID) = 0;

%           BP_Delet2_LtoIB1(BP_Delet2_LtoIB1 == 100 + JobID) = 0; %For Deleting
the Picking Up event from Transferor
%           BP_Delet2_LtoIB1(BP_Delet2_LtoIB1 == 200 + JobID) = 0; %For Deleting
the Catrage return event at the Transferor
    BP_Delet2_LtoIB1(BP_Delet2_LtoIB1 == JobID) = 0;

    BH(:, TLS(p, L) - E_or_W:Max_Stop) = BH_Delet2_LtoIB1;
    HCJ(:, TLS(p, L) - E_or_W:Max_Stop) = HCJ_Delet2_LtoIB1;
    BlockPosition(:, TimeStartLoading:Max_Stop) = BP_Delet2_LtoIB1;
    s = L;
    WL = WL + Delay;
    continue
elseif SS == 2 & s + 1 > InB1 & s + 1 <= InB2
    if s == Transf1
        Max_Stop_BP = TLSsf + Pickup + DT(r, s);
    else
        Max_Stop_BP = TLSsf; %Max_Stop);
    end
    HCJ_Delet2_IB1toIB2 = HCJ(:, TLS(p, InB1) - E_or_W:Max_Stop);
    BH_Delet2_IB1toIB2 = BH(:, TLS(p, InB1) - E_or_W:Max_Stop); %Max_Stop);

    BP_Delet2_IB1toIB2 = BlockPosition(:, TimeStartInBuffer1:Max_Stop_BP);
    %Max_Stop_BP);

    BH_Delet2_IB1toIB2(find(HCJ_Delet2_IB1toIB2 == JobID)) = 0;

    HCJ_Delet2_IB1toIB2(HCJ_Delet2_IB1toIB2 == 300 + JobID) = 0; %For
Deleting History of Empty Hoist Move
    HCJ_Delet2_IB1toIB2(HCJ_Delet2_IB1toIB2 == JobID) = 0;

    BP_Delet2_IB1toIB2(BP_Delet2_IB1toIB2 == 100 + JobID) = 0; %For
Deleting the Picking Up event from Transferor
    BP_Delet2_IB1toIB2(BP_Delet2_IB1toIB2 == 200 + JobID) = 0; %For
Deleting the Catrage return event at the Transferor
    BP_Delet2_IB1toIB2(BP_Delet2_IB1toIB2 == JobID) = 0;

    BH(:, TLS(p, InB1) - E_or_W:Max_Stop) = BH_Delet2_IB1toIB2;
    HCJ(:, TLS(p, InB1) - E_or_W:Max_Stop) = HCJ_Delet2_IB1toIB2;

    BlockPosition(:, TimeStartInBuffer1:Max_Stop_BP) = BP_Delet2_IB1toIB2;
    s = InB1;

```

```

        WIB1=WIB1+Delay;
        continue
    elseif SS==2 & s+1>InB2 & s+1<=OutB
        HCJ_Delet2_IB2toOB=HCJ(:,TLS(p,InB2)-E_or_W:Max_Stop);
%Max_Stop);

        BH_Delet2_IB2toOB=BH(:,TLS(p,InB2)-E_or_W:Max_Stop); %Max_Stop);
        BP_Delet2_IB2toOB=BlockPosition(:,TimeStartInBuffer2:Max_Stop);
%Max_Stop);

        BH_Delet2_IB2toOB(find(HCJ_Delet2_IB2toOB==JobID))=0;

        HCJ_Delet2_IB2toOB(HCJ_Delet2_IB2toOB==300+JobID)=0; %For
Deleting History of Empty Hoist Move
        HCJ_Delet2_IB2toOB(HCJ_Delet2_IB2toOB==JobID)=0;

        BP_Delet2_IB2toOB(BP_Delet2_IB2toOB==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
        BP_Delet2_IB2toOB(BP_Delet2_IB2toOB==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
        BP_Delet2_IB2toOB(BP_Delet2_IB2toOB==JobID)=0;

        BH(:,TLS(p,InB2)-E_or_W:Max_Stop)=BH_Delet2_IB2toOB;
        HCJ(:,TLS(p,InB2)-E_or_W:Max_Stop)=HCJ_Delet2_IB2toOB;
        BlockPosition(:,TimeStartInBuffer2:Max_Stop)=BP_Delet2_IB2toOB;
        s=InB2;
        WIB2=WIB2+Delay;
        continue
    elseif SS==2 & s+1==UL
        HCJ_Delet2_OBtoUL=HCJ(:,TLS(p,OutB)-E_or_W:Max_Stop); %Max_Stop);
        BH_Delet2_OBtoUL=BH(:,TLS(p,OutB)-E_or_W:Max_Stop); %Max_Stop);
        BP_Delet2_OBtoUL=BlockPosition(:,TimeStartOutBuffer:Max_Stop);
%Max_Stop);

        BH_Delet2_OBtoUL(find(HCJ_Delet2_OBtoUL==JobID))=0;

        HCJ_Delet2_OBtoUL(HCJ_Delet2_OBtoUL==300+JobID)=0; %For Deleting
History of Empty Hoist Move
        HCJ_Delet2_OBtoUL(HCJ_Delet2_OBtoUL==JobID)=0;

        %           BP_Delet2_OBtoUL(BP_Delet2_OBtoUL==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
        %           BP_Delet2_OBtoUL(BP_Delet2_OBtoUL==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
        BP_Delet2_OBtoUL(BP_Delet2_OBtoUL==JobID)=0;

        BH(:,TLS(p,OutB)-E_or_W:Max_Stop)=BH_Delet2_OBtoUL;
        HCJ(:,TLS(p,OutB)-E_or_W:Max_Stop)=HCJ_Delet2_OBtoUL;
        BlockPosition(:,TimeStartOutBuffer:Max_Stop)=BP_Delet2_OBtoUL;
        s=OutB;
        WOB=WOB+Delay;
        continue
    elseif SS==3 & s+1>InB1 & s+1<=InB2
        if s==Transf1
            Max_Stop_BP=TLSSsf+PickUp+DT(r,s);
        else
            Max_Stop_BP=TLSSsf; %Max_Stop);

```

```

end
HCJ_Delet3_IB1toIB2=HCJ(:, TLS(p, InB1)-E_or_W:Max_Stop);
%Max_Stop);
BH_Delet3_IB1toIB2=BH(:, TLS(p, InB1)-E_or_W:Max_Stop); %Max_Stop);

BP_Delet3_IB1toIB2=BlockPosition(:, TimeStartInBuffer1:Max_Stop_BP);
%Max_Stop_BP);
BH_Delet3_IB1toIB2(find(HCJ_Delet3_IB1toIB2==JobID))=0;

HCJ_Delet3_IB1toIB2(HCJ_Delet3_IB1toIB2==300+JobID)=0; %For
Deleting History of Empty Hoist Move
HCJ_Delet3_IB1toIB2(HCJ_Delet3_IB1toIB2==JobID)=0;

BP_Delet3_IB1toIB2(BP_Delet3_IB1toIB2==100+JobID)=0; %For
Deleting the Catrage Picking up event from Transferor
BP_Delet3_IB1toIB2(BP_Delet3_IB1toIB2==200+JobID)=0; %For
Deleting the Catrage return event at the Transferor
BP_Delet3_IB1toIB2(BP_Delet3_IB1toIB2==JobID)=0;

BH(:, TLS(p, InB1)-E_or_W:Max_Stop)=BH_Delet3_IB1toIB2;
HCJ(:, TLS(p, InB1)-E_or_W:Max_Stop)=HCJ_Delet3_IB1toIB2;

BlockPosition(:, TimeStartInBuffer1:Max_Stop_BP)=BP_Delet3_IB1toIB2;
s=InB1;
WIB1=WIB1+Delay;
continue
elseif SS==3 & s+1>InB2 & s+1<=OutB
HCJ_Delet3_IB2toOB=HCJ(:, TLS(p, InB2)-E_or_W:Max_Stop);
%Max_Stop);
BH_Delet3_IB2toOB=BH(:, TLS(p, InB2)-E_or_W:Max_Stop); %Max_Stop);
BP_Delet3_IB2toOB=BlockPosition(:, TimeStartInBuffer2:Max_Stop);
%Max_Stop);
BH_Delet3_IB2toOB(find(HCJ_Delet3_IB2toOB==JobID))=0;

HCJ_Delet3_IB2toOB(HCJ_Delet3_IB2toOB==300+JobID)=0; %For
Deleting History of Empty Hoist Move
HCJ_Delet3_IB2toOB(HCJ_Delet3_IB2toOB==JobID)=0;

BP_Delet3_IB2toOB(BP_Delet3_IB2toOB==100+JobID)=0; %For Deleting
the Picking up event from Transferor
BP_Delet3_IB2toOB(BP_Delet3_IB2toOB==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
BP_Delet3_IB2toOB(BP_Delet3_IB2toOB==JobID)=0;

BH(:, TLS(p, InB2)-E_or_W:Max_Stop)=BH_Delet3_IB2toOB;
HCJ(:, TLS(p, InB2)-E_or_W:Max_Stop)=HCJ_Delet3_IB2toOB;
BlockPosition(:, TimeStartInBuffer2:Max_Stop)=BP_Delet3_IB2toOB;
s=InB2;
WIB2=WIB2+Delay;
continue
elseif SS==3 & s+1==UL
HCJ_Delet3_OBtoUL=HCJ(:, TLS(p, OutB)-E_or_W:Max_Stop); %Max_Stop);
BH_Delet3_OBtoUL=BH(:, TLS(p, OutB)-E_or_W:Max_Stop); %Max_Stop);
BP_Delet3_OBtoUL=BlockPosition(:, TimeStartOutBuffer:Max_Stop);
%Max_Stop);
BH_Delet3_OBtoUL(find(HCJ_Delet3_OBtoUL==JobID))=0;

```

```

        HCJ_Delet3_OBtoUL(HCJ_Delet3_OBtoUL==300+JobID)=0; %For Deleting
History of Empty Hoist Move
        HCJ_Delet3_OBtoUL(HCJ_Delet3_OBtoUL==JobID)=0;

%           BP_Delet3_OBtoUL(BP_Delet3_OBtoUL==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
%           BP_Delet3_OBtoUL(BP_Delet3_OBtoUL==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
        BP_Delet3_OBtoUL(BP_Delet3_OBtoUL==JobID)=0;

        BH(:,TLS(p,OutB)-E_or_W:Max_Stop)=BH_Delet3_OBtoUL;
        HCJ(:,TLS(p,OutB)-E_or_W:Max_Stop)=HCJ_Delet3_OBtoUL;
        BlockPosition(:,TimeStartOutBuffer:Max_Stop)=BP_Delet3_OBtoUL;
        s=OutB;
        WOB=WOB+Delay;
        continue
elseif SS==5 & s+1>InB2 & s+1<=OutB
        HCJ_Delet5_IB2toOB=HCJ(:,TLS(p,InB2)-E_or_W:Max_Stop);
%Max_Stop);

        BH_Delet5_IB2toOB=BH(:,TLS(p,InB2)-E_or_W:Max_Stop); %Max_Stop);
        BP_Delet5_IB2toOB=BlockPosition(:,TimeStartInBuffer2:Max_Stop);
%Max_Stop);

        BH_Delet5_IB2toOB(find(HCJ_Delet5_IB2toOB==JobID))=0;

        HCJ_Delet5_IB2toOB(HCJ_Delet5_IB2toOB==300+JobID)=0; %For
Deleting History of Empty Hoist Move
        HCJ_Delet5_IB2toOB(HCJ_Delet5_IB2toOB==JobID)=0;

        BP_Delet5_IB2toOB(BP_Delet5_IB2toOB==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
        BP_Delet5_IB2toOB(BP_Delet5_IB2toOB==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor
        BP_Delet5_IB2toOB(BP_Delet5_IB2toOB==JobID)=0;

        BH(:,TLS(p,InB2)-E_or_W:Max_Stop)=BH_Delet5_IB2toOB;
        HCJ(:,TLS(p,InB2)-E_or_W:Max_Stop)=HCJ_Delet5_IB2toOB;
        BlockPosition(:,TimeStartInBuffer2:Max_Stop)=BP_Delet5_IB2toOB;
        s=InB2;
        WIB2=WIB2+Delay;
        continue
elseif SS==5 & s+1==UL
        HCJ_Delet5_OBtoUL=HCJ(:,TLS(p,OutB)-E_or_W:Max_Stop);
        BH_Delet5_OBtoUL=BH(:,TLS(p,OutB)-E_or_W:Max_Stop); %Max_Stop);
        BP_Delet5_OBtoUL=BlockPosition(:,TimeStartOutBuffer:Max_Stop);
%Max_Stop);

        BH_Delet5_OBtoUL(find(HCJ_Delet5_OBtoUL==JobID))=0;

        HCJ_Delet5_OBtoUL(HCJ_Delet5_OBtoUL==300+JobID)=0; %For Deleting
History of Empty Hoist Move
        HCJ_Delet5_OBtoUL(HCJ_Delet5_OBtoUL==JobID)=0;

%           BP_Delet5_OBtoUL(BP_Delet5_OBtoUL==100+JobID)=0; %For Deleting
the Picking Up event from Transferor
%           BP_Delet5_OBtoUL(BP_Delet5_OBtoUL==200+JobID)=0; %For Deleting
the Catrage return event at the Transferor

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        BP_Delet5_OBtoUL(BP_Delet5_OBtoUL==JobID)=0;

        BH(:,TLS(p,OutB)-E_or_W:Max_Stop)=BH_Delet5_OBtoUL;
        HCJ(:,TLS(p,OutB)-E_or_W:Max_Stop)=HCJ_Delet5_OBtoUL;
        BlockPosition(:,TimeStartOutBuffer:Max_Stop)=BP_Delet5_OBtoUL;
        s=OutB;
        WOB=WOB+Delay;
        continue
    end % END Of ALL Un-Sucessfull Planning Re-solution Commands
end % END of Sucessfull Or Un-Sucessfull
Waiting_Matrix(1,p)=WO;      % For Total Waiting OutSide;
Waiting_Matrix(2,p)=WL;      % For Total Waiting at Loading;
Waiting_Matrix(3,p)=WIB1;    % For Total Waiting at Input Buffer 1;
Waiting_Matrix(4,p)=WIB2;    % For Total Waiting at Input Buffer 2;
Waiting_Matrix(5,p)=WOB;     % For Total Waiting at Output Buffer;
end % End of While Loop

% 33) Restart some variables (Starting Times, Waiting Durations) for New Job
%     AccTime=1;
%     TimeStartLoading=1; TimeStartInBuffer1=1; TimeStartInBuffer2=1;
%     TimeStartOutBuff=1;
AccTime=E_or_W+1;
TimeStartLoading=E_or_W+1; TimeStartInBuffer1=E_or_W+1;
TimeStartInBuffer2=E_or_W+1;
TimeStartOutBuff=E_or_W+1; %ALL WERE =1
WO=Any_W; WL=Any_W; WIB1=Any_W; WIB2=Any_W; WOB=Any_W; %Any_W;
k_Now=1;

% Adding More Jobs Update
%     if p>Num_of_Jobs
%         if TPF(p,Max_Stage)>16*60*60
%             Add_Job=Add_Job-Num_of_Jobs-1;
%             disp(['The Maximum Number of Jobs that can be added are:
',num2str(Add_Job), ' Job(s)'])
%             Max_Jobs=p-1;
%             break
%         else
%             Add_Job=Add_Job+1;
%             p=p+1;
%             New_Num_of_Jobs=Num_of_Jobs+Add_Job;
%             continue
%         end
%     end

end % End of For Loop

% 34) RESULTS:
% 1] Obtaining the values of Make Span

%Up Date number of jobs to Max number of Jobs For the Gantt Chart(s) and
%Exportations to Excel
disp('=====')
disp(['These Results for Run no.: ',num2str(RUN), ' [Day: ',num2str(Day), ', Seq.
',num2str(Seq), ', Conf. ',num2str(Configuration), ' ]'])
disp('-----')
Num_of_Jobs=Max_Jobs;
disp(['The Maximum number of Jobs are: ',num2str(Max_Jobs), ' Jobs'])

```

```

Added_Colored_Jobs=ceil(Add_Job/3);
Added_Matt_Jobs=Add_Job-Added_Colored_Jobs;
disp([num2str(Added_Colored_Jobs+Added_Matt_Jobs),' of them are additional
job(s)'])
disp([num2str(Added_Matt_Jobs),' of them are matt finsh job(s)'])
disp([num2str(Added_Colored_Jobs),' of them are colored job(s)'])

Last_Job_Recipe=j(Max_Jobs-(Added_Colored_Jobs+Added_Matt_Jobs)).RecipeID;

disp(['The Real      Makespan at Anodizing = ',num2str(Real_Anodizing_MakeSpan)])
Algo_Anodizing_MakeSpan=max(TPF(:,AN_S));
disp(['The Algorithm Makespan at Anodizing = ',num2str(Algo_Anodizing_MakeSpan)])
Real_MakeSpan=Real_Anodizing_MakeSpan+E_R_D(Last_Job_Recipe,Sealing_Case);%Estima
ted
disp(['The Esitimated Real Makespan = ',num2str(Real_MakeSpan)])
Algo_MakeSpan=max(TPF(:,Max_Stage));
disp(['The Algorithm      Makespan = ',num2str(Algo_MakeSpan)])
disp('-----')
Differnce_Anodizing=Real_Anodizing_MakeSpan-Algo_Anodizing_MakeSpan;
Differnce_MakeSpan=Real_MakeSpan-Algo_MakeSpan;
if Add_Job>0
if Differnce_Anodizing>0
    disp('At the Anodizing Stage')
    disp(['The ',num2str(Add_Job),' added job(s) has still not exceeded the
original makespan by: ',num2str(Differnce_Anodizing),' second(s)'])
elseif Differnce_Anodizing==0
    disp('At the Anodizing Stage')
    disp(['The ',num2str(Add_Job),' added job(s) are done at the same time of
the original makespan'])
elseif Differnce_Anodizing<0
    disp('At the Anodizing Stage')
    disp(['The ',num2str(Add_Job),' added job(s) has exceeded the original
makespan by: ',num2str(abs(Differnce_Anodizing)),' second(s)'])
end
if Differnce_MakeSpan>0
    disp('At the Last Stage')
    disp(['The ',num2str(Add_Job),' added job(s) has still not exceeded the
original makespan by: ',num2str(Differnce_MakeSpan),' second(s)'])
elseif Differnce_Anodizing==0
    disp('At the Last Stage')
    disp(['The ',num2str(Add_Job),' added job(s) are done at the same time of
the original makespan'])
elseif Differnce_Anodizing<0
    disp('At the Last Stage')
    disp(['The ',num2str(Add_Job),' added job(s) has exceeded the original
makespan by: ',num2str(abs(Differnce_MakeSpan)),' second(s)'])
end
elseif Add_Job==0
    disp('No More Jobs can be Added')
end

% Run_Timer=timeit(Actual_Prob_Modi_Cases)-TIME_START
Run_Timer=round(cputime-CPU_TIME_START) %Run_Timer_End

% 2] Postions Gantt Chart;
% 2.1] Re-creating the Matricies TPS_K & TPF_K

```

```

% TPS_K ==> TPS_Gantt
% TPF_K ==> TPF_Gantt
% The reason for re-creating these matrices is to remove any position(s)
% that were changed during the Simulation, due to violation(s)
TPS_Gantt=zeros(Num_of_Positions,Num_of_Jobs);
TPF_Gantt=zeros(Num_of_Positions,Num_of_Jobs);
for p=1:Num_of_Jobs
    for s=1:Max_Stage
        K=Treatment_Loc(p,s);
        if K==0
            continue
        else

            TPS_Gantt(K,p)=TPS(p,s);
            TPF_Gantt(K,p)=TPF(p,s);
            if K==Transf1_P | K==Transf2_P
                TPS_Gantt(K+1,p)=TPS(p,s);
                TPF_Gantt(K+1,p)=TPF(p,s);
            end

        end
    end
end

% Re-sorting TPS & TPF
for row=1:size(TPS_Gantt,1)
    TPS_Gantt_row=TPS_Gantt(row,:);
    TPS_Gantt_row(TPS_Gantt_row~=0)=sort(TPS_Gantt_row(TPS_Gantt_row~=0));
    TPS_Gantt(row,:)=TPS_Gantt_row;
end
TPS_Gantt;
for row=1:size(TPF_Gantt,1)
    TPF_Gantt_row=TPF_Gantt(row,:);
    TPF_Gantt_row(TPF_Gantt_row~=0)=sort(TPF_Gantt_row(TPF_Gantt_row~=0));
    TPF_Gantt(row,:)=TPF_Gantt_row;
end
TPF_Gantt;

% 2.2] Creating the Main Gantt Matrix for the Positions
% This Matrix size is (Num_of_Position , 2*Num_of_Jobs)
% Rows for ==> Position number
% Each Two column ==> a job Gap that left the position empty and a Duration of
% that job in a Stage
GAP_DT_Matrix=zeros(Num_of_Positions,Num_of_Jobs*2);
for K=1:Num_of_Positions
    cj=1;
    TPS_next_take=0;
    TPF_now_saved=0;
    while cj<=Num_of_Jobs
        % for GAP calculation we need:
        % 1) Saved TPF when ever GAP<0
        % 2) Look for TPS>0
        % 3) Modifiy GAP and cj
        if cj==1
            GAP_Gantt=TPS_Gantt(K,cj)-0;
        elseif cj>1
            GAP_Gantt=TPS_Gantt(K,cj)-TPF_Gantt(K,cj-1);
        end
    end
end

```

```

        % This the Initail GAP calculated to if it is +,0,-
    end

    if GAP_Gantt<0 %-
        %GAP_Gantt=0
        % Step 1) Save TPF
        TPF_now_saved=TPF_Gantt(K,cj-1);
        % Step 2) Look for the next TPS>0 +
        for i=cj+1:Num_of_Jobs
            if TPS_Gantt(K,i)>0 % Must be +
                TPS_next_take=TPS_Gantt(K,i);
                break
            else
                TPS_next_take=TPF_now_saved;
                %GAP_Gantt=0;
                %GAP_DT_Matrix(K,2*cj-1)=GAP_Gantt;
                continue
            end
        end
        % Step 3) Up date or Modify TPF and cj
        cj=i;
        GAP_Gantt=TPS_next_take-TPF_now_saved;
        % the place on the new GAP in GAP_DT_Matrix
        GAP_DT_Matrix(K,2*cj-1)=GAP_Gantt;

    elseif GAP_Gantt>=0 % GAP is + or 0
        GAP_Gantt=GAP_Gantt; % Unchanged from the Initail GAP
        % Nromal place in the matrix
        GAP_DT_Matrix(K,2*cj-1)=GAP_Gantt;
    end

    % Now for DT
    DT_Gantt=TPF_Gantt(K,cj)-TPS_Gantt(K,cj);
    GAP_DT_Matrix(K,2*cj)=DT_Gantt;

    % Normal Update for cj
    cj=cj+1;
end
end

% The Final Results of the Gantt_Matrix for the Positions
GAP_DT_Matrix;

% Searching for the First Gap
First_GAP=zeros(Num_of_Positions,1);
for K=1:Num_of_Positions
    for first_gap_search=1:Num_of_Jobs
        if GAP_DT_Matrix(K,first_gap_search)>0
            First_GAP(K,1)=GAP_DT_Matrix(K,first_gap_search);
            break
        else
            continue
        end
    end
end
end

% 3] Usage Percentage

```

```

% In this section a Matrix called (Usage_Percentage) was calculated
% It uses the previous matrix (GAP_DT_Matix) to sum all the Gap duration
% and the treatment duration per position
% To Calculate the GAPs
for K=1:Num_of_Positions
    Total_GAPs=0;
    for UseCol=1:2:Num_of_Jobs*2-1
        GAPs(K)=GAP_DT_Matrix(K,UseCol);
        Total_GAPs=Total_GAPs+GAPs(K);
        Total_GAPs_Matrix(K,1)=Total_GAPs;
    end
end
% To Calculate the DTs (the treatments)
for K=1:Num_of_Positions
    Total_DTs=0;
    for UseCol=2:2:Num_of_Jobs*2
        DTs(K)=GAP_DT_Matrix(K,UseCol);
        Total_DTs=Total_DTs+DTs(K);
        Total_DTs_Matrix(K,1)=Total_DTs;
    end
end
% The Final Result for the Usage Percentage Matrix
Usage_Percentage=[Total_GAPs_Matrix Total_DTs_Matrix];

% 4] Hoists Gantt Chart
% The Idea to create the Hoists Gantt Matrix is different from the idea that was
applied to
% create the Position Gantt Matrix
% The Idea for the Hoists was:
% 1. to like the Matrix (Used_Hoist) with the TLS at one time and with TLF
% at another time
% 2. this link tells us how many times each hoist was used
% Thus creating a vector that shows the times in which the hoist was used for
both TLS & TLF
% 3. However these time series may not be sorted in ascending order,
% Thus they have to sort in ascending order.
% First Creating TLS_Sort & TLF_Sort Matrices
for h=1:NH-1
    TLS_Select=TLS(find(Used_Hoist==h));
    TLS_Sort=sort(TLS_Select);
    TLS_Gantt(h,1:length(TLS_Sort))=TLS_Sort;
    TLF_Select=TLF(find(Used_Hoist==h));
    TLF_Sort=sort(TLF_Select);
    TLF_Gantt(h,1:length(TLF_Sort))=TLF_Sort;
end
% Secondly Creating the Main Hoist Gantt Matrix
for H=1:NH-1
    [m,n]=size(TLF_Gantt);
    col=1;
    while col<=n
        if col==1
            GAP_Hoist=TLS_Gantt(H,col)-0;
        else
            GAP_Hoist=TLS_Gantt(H,col)-TLF_Gantt(H,col-1);
        end
    end
end

```

```

        if GAP_Hoist<0
            GAP_Hoist=0;
        end

        DT_Hoist=TLF_Gantt(H,col)-TLS_Gantt(H,col);

        Hoist_Gantt_Matrix(H,2*col-1)=GAP_Hoist;
        Hoist_Gantt_Matrix(H,2*col)=DT_Hoist;

        col=col+1;
    end
end
% Final Results of the Hoists Gantt Matrix:
Hoist_Gantt_Matrix;

% 5] Exporting all the Result to Excel
% Results_File='Actual_Plant_Try1.xlsx';
% Main Four Event per job per stage
TPS_Final=TPS;
TPF_Final=TPF;
TLS_Final=TLS;
TLF_Final=TLF;
disp('Exporting TPS, TPF, TLS, and TLF to Excel.....')
xlswrite(Results_File,TPS_Final,'TPS','C3:AC82');
xlswrite(Results_File,TPF_Final,'TPF','C3:AC82');
xlswrite(Results_File,TLS_Final,'TLS','C3:AC82');
xlswrite(Results_File,TLF_Final,'TLF','C3:AC82');
xlswrite(Results_File,TPS_Gantt,'TPS_K','C3:CD62');
xlswrite(Results_File,TPF_Gantt,'TPF_K','C3:CD62');
% disp('TPS, TPF, TLS, TLF Matricies were Exported!')
% Used Position/Hoist
disp('Exporting Treatment_Loc and Used Hoist to Excel.....')
xlswrite(Results_File,Treatment_Loc,'Used Position','C3:AC82');
xlswrite(Results_File,Used_Hoist,'Used Hoist','C3:AC82');
% disp('Treatment_Loc and Used_Hoist were Exported!')

% Charts for Postions/Hoists
% Slight modification to the Matricies
% BlockPosition(find(BlockPosition>=100 & BlockPosition<=199))=100;
% BlockPosition(find(BlockPosition>=200 & BlockPosition<=299))=200;
% HCJ(find(HCJ>=300 & HCJ<=399))=300;
Position_Chart=BlockPosition';
Hoist_Job=HCJ';
Hoist_Loc=BH';
% BlockPosition=num2cell(BlockPosition);
% BlockPosition(BlockPosition==0)=' ';
% disp('Exporting Charts Data to Excel.....')
% xlswrite(Results_File,Position_Chart,'Charts','C3:BJ100005');
% xlswrite(Results_File,Hoist_Job,'Charts','BL3:BQ100005');
% xlswrite(Results_File,Hoist_Loc,'Charts','BS3:BX100005');
% disp('BlockPosition, HCJ & BH were Exported!')
% Exporting Positions Gantt Matrix to Excel
disp('Exporting Positions Gantt Matrix to Excel...')
xlswrite(Results_File,GAP_DT_Matrix,'Positions Gantt Matrix','B70:FE130')
% disp('Positions Gantt Matrix was Exported!')
% Exporting Hoists Gantt Matrix to Excel

```

```

disp('Exporting Hoists Gantt Matrix to Excel...')
xlswrite(Results_File,Hoist_Gantt_Matrix,'Hoists Gantt Matrix')
% disp('Hoists Gantt Matrix was Exported!')

% Exporting Used Percentage Matrix to Excel
disp('Exporting Usage Percentage Matrix to Excel...')
xlswrite(Results_File,Usage_Percentage,'Usage Percentage','B2:C61')
xlswrite(Results_File,First_GAP,'Usage Percentage','D2:D61')
% disp('Usage Percentage Matrix was Exported!')
% Exporting Waiting Matrix to Excel
% disp('Exporting Waiting Matrix to Excel...')
xlswrite(Results_File, Waiting_Matrix',' Waiting Matrix','C3:G82')

% 6] Constructing Gantt Charts in MATLAB (Still Under Development.....)
% FOR Hoists
%
PositionS=[1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60];
% PositionS=flipr(PositionS);
% Gantt=barh(PositionS,GAP_DT_Matrix,'stacked')
% HoistS=[1,2,3,4,5];
% Hoist_Gantt_Chart=barh(HoistS,Hoist_Gantt_Matrix,'stacked')
% for BAR_Col=1:NH-1
%     BAR_n=BAR_Col;
%     if mod(BAR_n,2)==1
%         BAR_n=(BAR_n+1)/2;
%     end
%     Gantt(BAR_n).FaceColor=[0 1 1]; %'c'; %color
%     else
%         Gantt(BAR_n).FaceColor=[1 1 1];
%     end
% end
% disp('Done!')
% For Validation
% Real_Timing=zeros(55,2);
% for p=1:Num_of_Jobs
%     Real_Timing(p,1)=j(p).Real_TPS;
%     Real_Timing(p,2)=j(p).Real_TPF;
% end
% disp('Exporting Validation Real Timing..')
% xlswrite(Results_File,Real_Timing,'Validation','B4:C58')
% Exporting Final Results
FINAL_RESULTS=[Real_Anodizing_MakeSpan;Algo_Anodizing_MakeSpan;Real_MakeSpan;Algo_MakeSpan;Difference_Anodizing;Difference_MakeSpan;Add_Job;Added_Matt_Jobs;Added_Colored_Jobs;Max_Jobs;Run_Timer];
disp('Exporting Final Results to Excel...')
xlswrite(Results_File,FINAL_RESULTS,'Final Results','B2:B12');
% Exporting the Results to the Main Results File
% RUN_Results=[Algo_Anodizing_MakeSpan Difference_Anodizing]
%
xlswrite('Main_Results_File.xlsx',RUN_Results,'Runs_Results','B',num2str(RUN):'B8',num2str(RUN));
% Run_Timer_End=cputime;
disp(['Run no. ',num2str(RUN),' is completed!'])
end
disp('All Done!')
% end

```

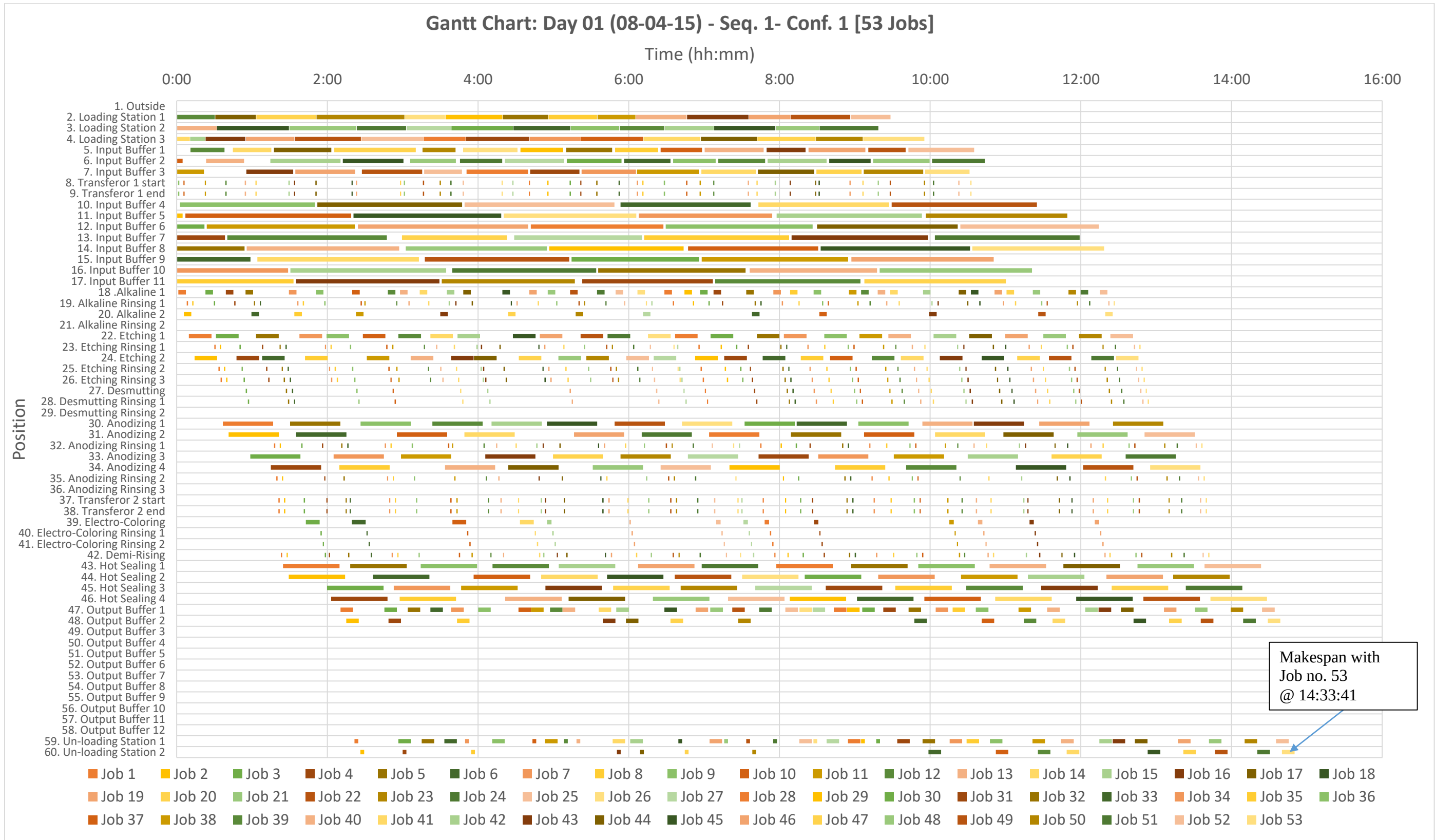
## **Appendix (4): Estimated Duration after Anodizing Stage to Unloading per Recipe ID**

This Appendix shows the estimated durations used to calculate the estimated time for the actual makespan, from the time the last job finishes the anodizing stage to the time it finishes at the unloading stage.

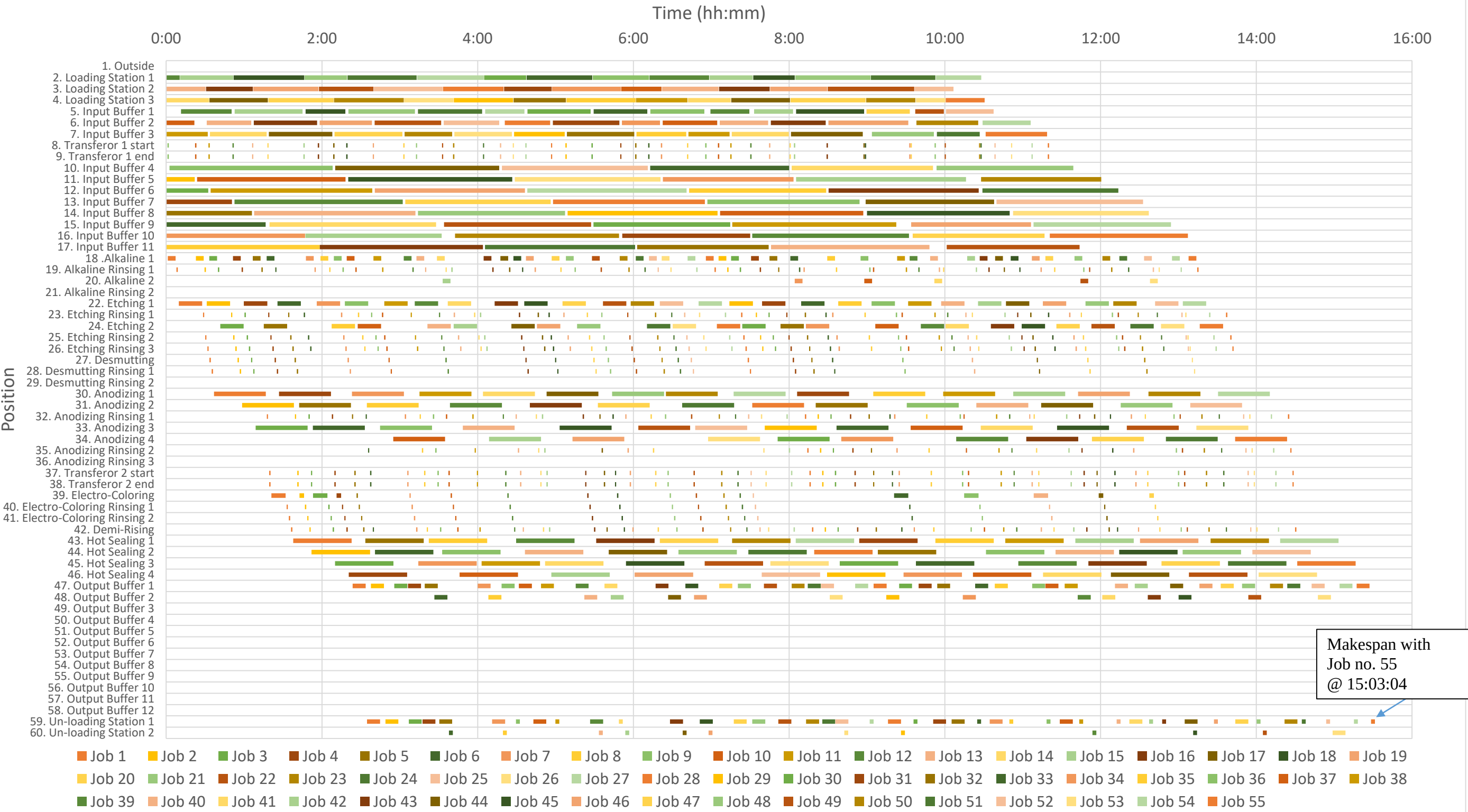
There are two types of these durations, one is when the Hot sealing duration is 45 minutes (HS=45) and the other is when the Hot Sealing duration is 60 minutes (HS=60). The durations are in seconds.

| Recipe ID | Estimated duration<br>(seconds) |        | Recipe ID | Estimated duration<br>(seconds) |        |
|-----------|---------------------------------|--------|-----------|---------------------------------|--------|
|           | HS = 45                         | HS =60 |           | HS = 45                         | HS =60 |
| <b>1</b>  | 3836                            | 4736   | <b>16</b> | 4192                            | 5092   |
| <b>2</b>  | 4256                            | 5156   | <b>17</b> | 4612                            | 5512   |
| <b>3</b>  | 4256                            | 5156   | <b>18</b> | 4612                            | 5512   |
| <b>4</b>  | 3892                            | 4792   | <b>19</b> | 4372                            | 5272   |
| <b>5</b>  | 4312                            | 5212   | <b>20</b> | 4792                            | 5692   |
| <b>6</b>  | 4312                            | 5212   | <b>21</b> | 4792                            | 5692   |
| <b>7</b>  | 3952                            | 4852   | <b>22</b> | 4492                            | 5392   |
| <b>8</b>  | 4372                            | 5272   | <b>23</b> | 4912                            | 5812   |
| <b>9</b>  | 4372                            | 5272   | <b>24</b> | 4912                            | 5812   |
| <b>10</b> | 4042                            | 4942   | <b>25</b> | 4702                            | 5602   |
| <b>11</b> | 4462                            | 5362   | <b>26</b> | 5122                            | 6022   |
| <b>12</b> | 4462                            | 5362   | <b>27</b> | 5122                            | 6022   |
| <b>13</b> | 4102                            | 5002   | <b>28</b> | 5272                            | 6172   |
| <b>14</b> | 4522                            | 5422   | <b>29</b> | 5692                            | 6592   |
| <b>15</b> | 4522                            | 5422   | <b>30</b> | 5692                            | 6592   |

# Appendix (5): Gantt Charts for the Twelve (Combination no. 1)



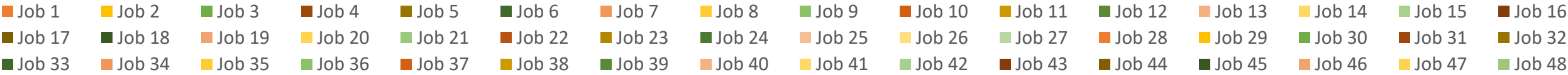
Gantt Chart: Day 02 (13-04-15) - Seq. 1 - Conf. 1 [55 Jobs]



Gantt Chart: Day 03 (23-04-15) - Seq. 1 - Conf. 1 [48 Jobs]

Time (hh:mm)

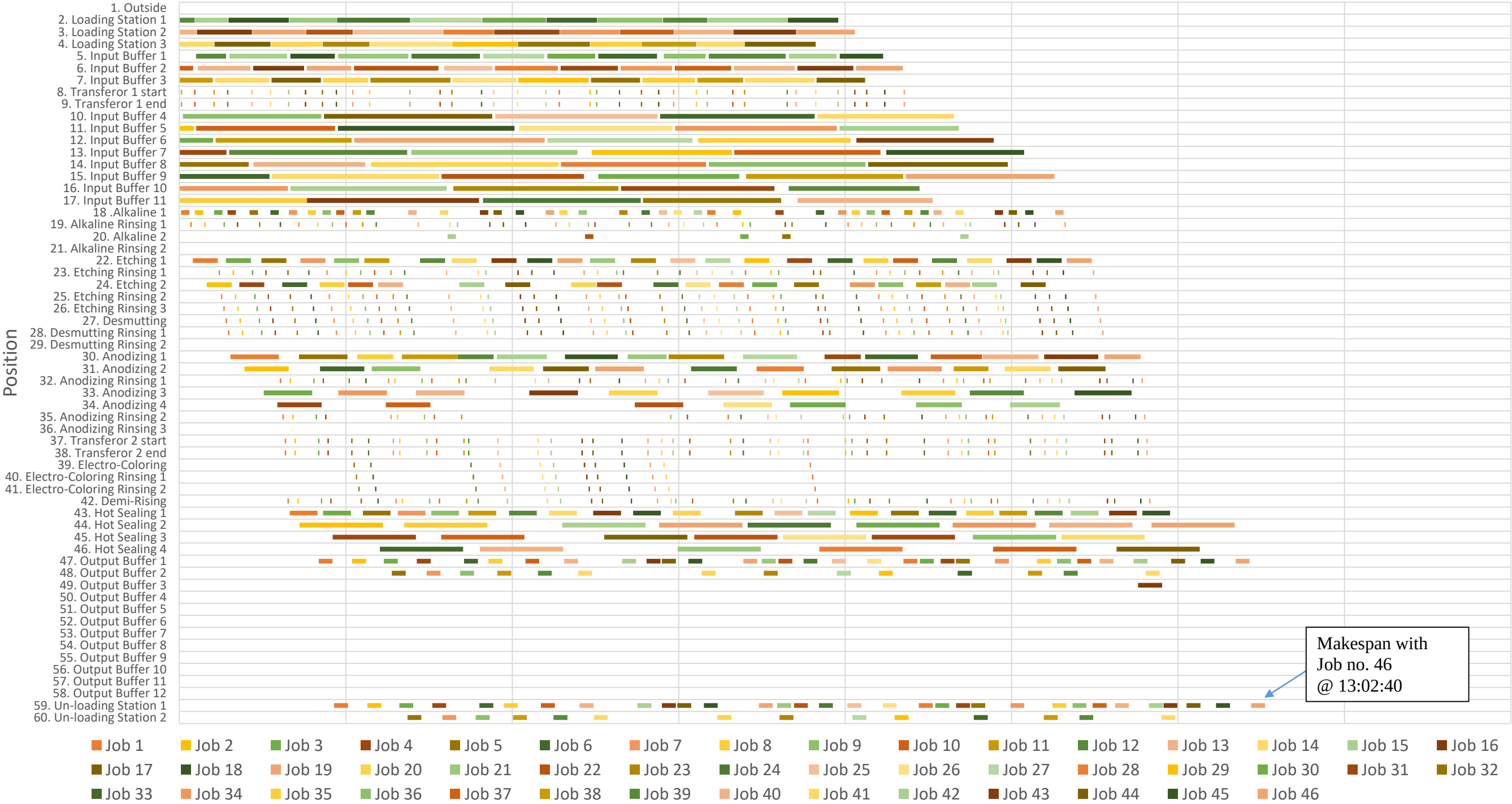
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 04 (01-06-17) - Seq. 1 - Conf. 1 [46 Jobs]

Time (hh:mm)

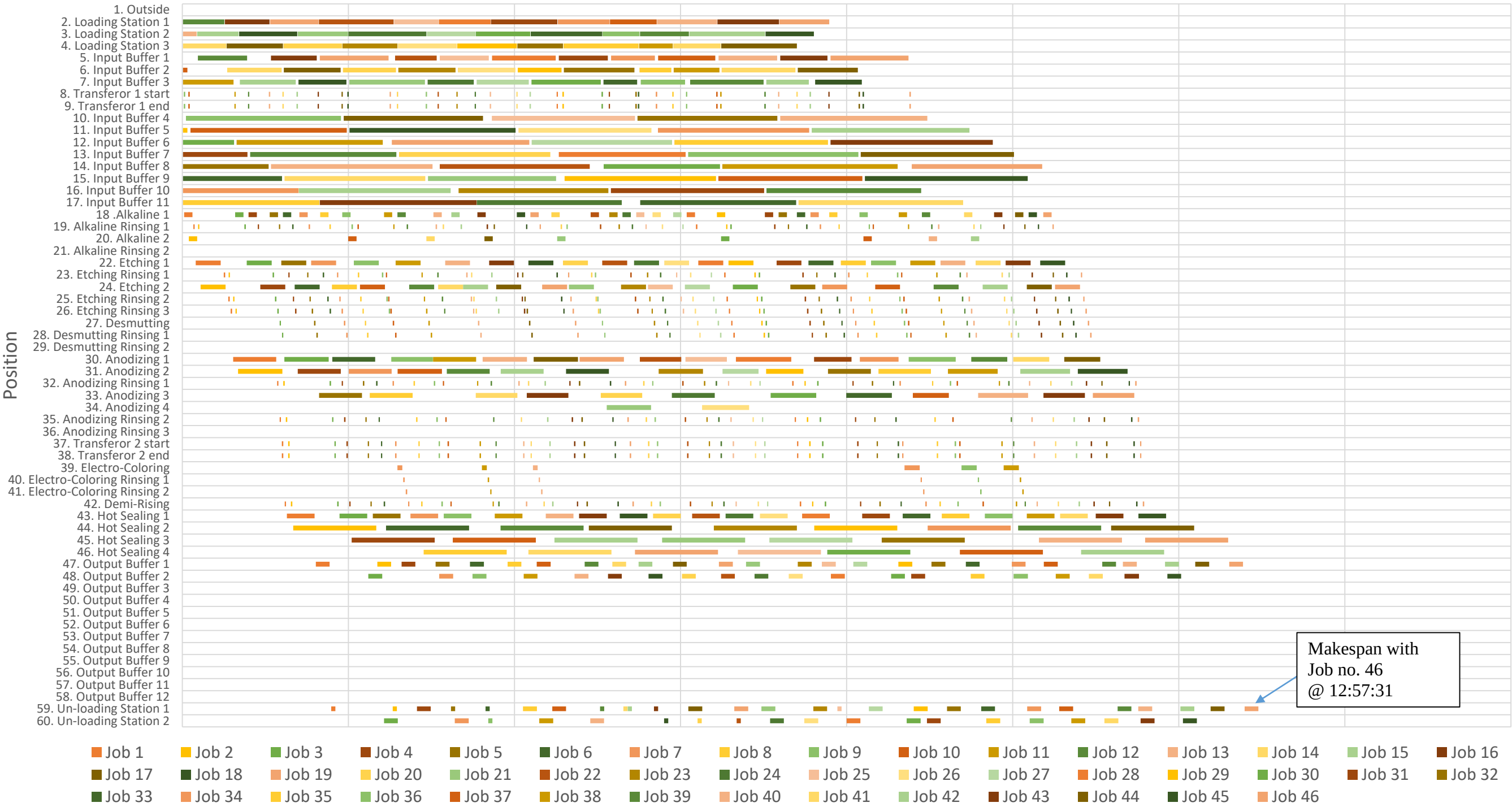
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 05 (02-06-17) - Seq. 1 - Conf. 1 [46 Jobs]

Time (hh:mm)

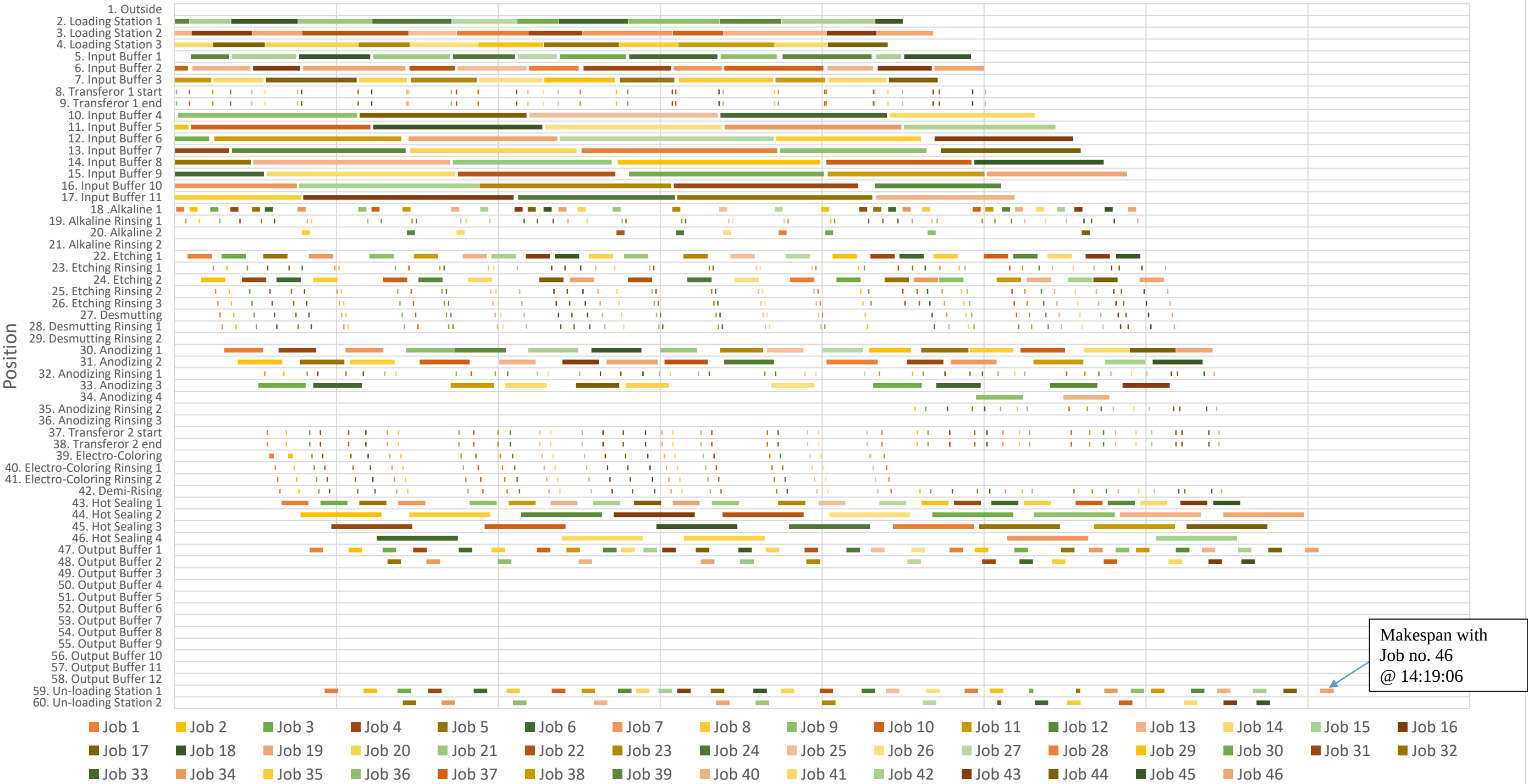
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 06 (09-06-17) - Seq. 1 - Conf. 1 [46 Jobs]

Time (hh:mm)

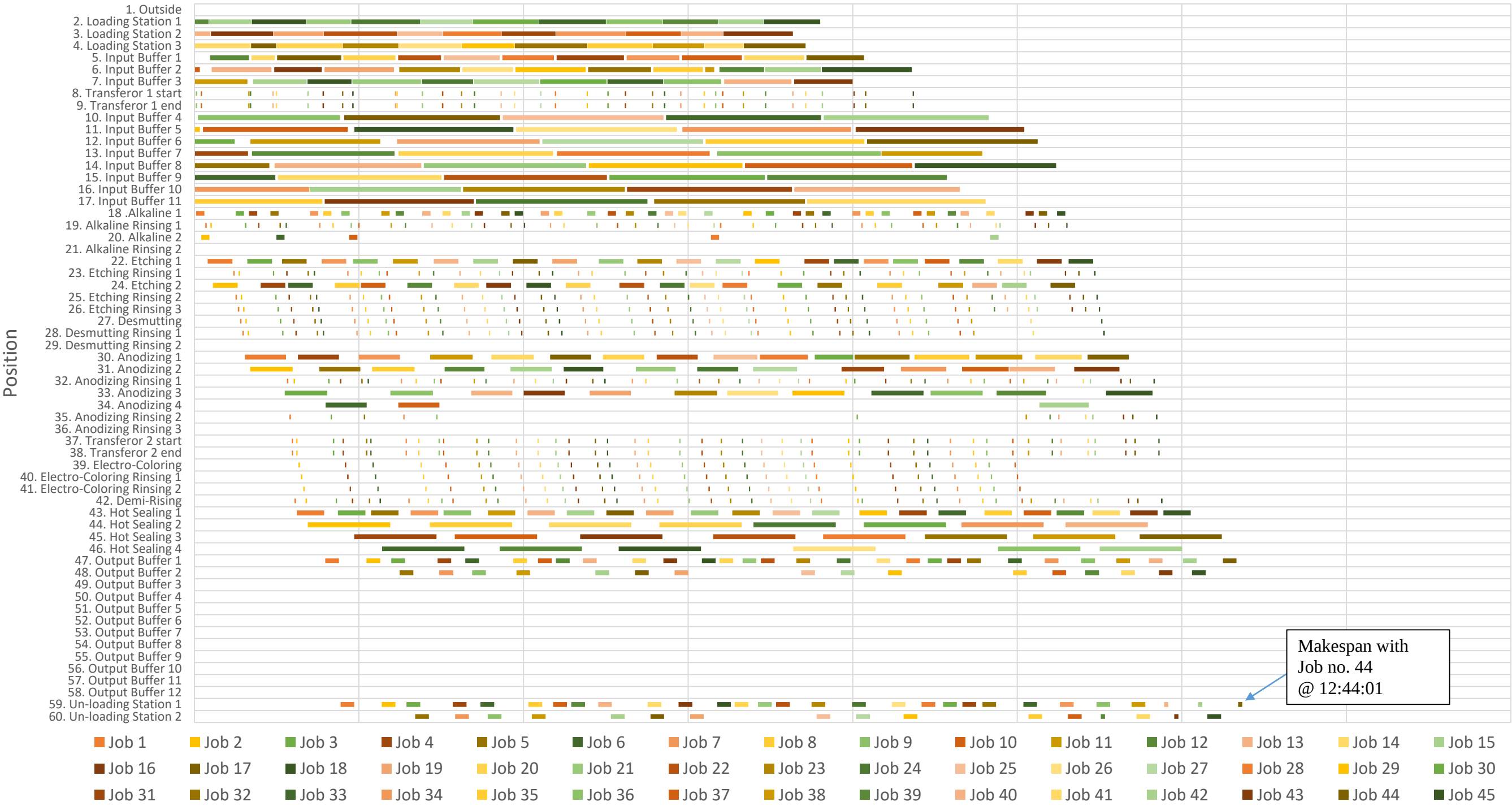
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 07 (11-06-17) - Seq. 1 - Conf. 1 [45 Jobs]

Time (hh:mm)

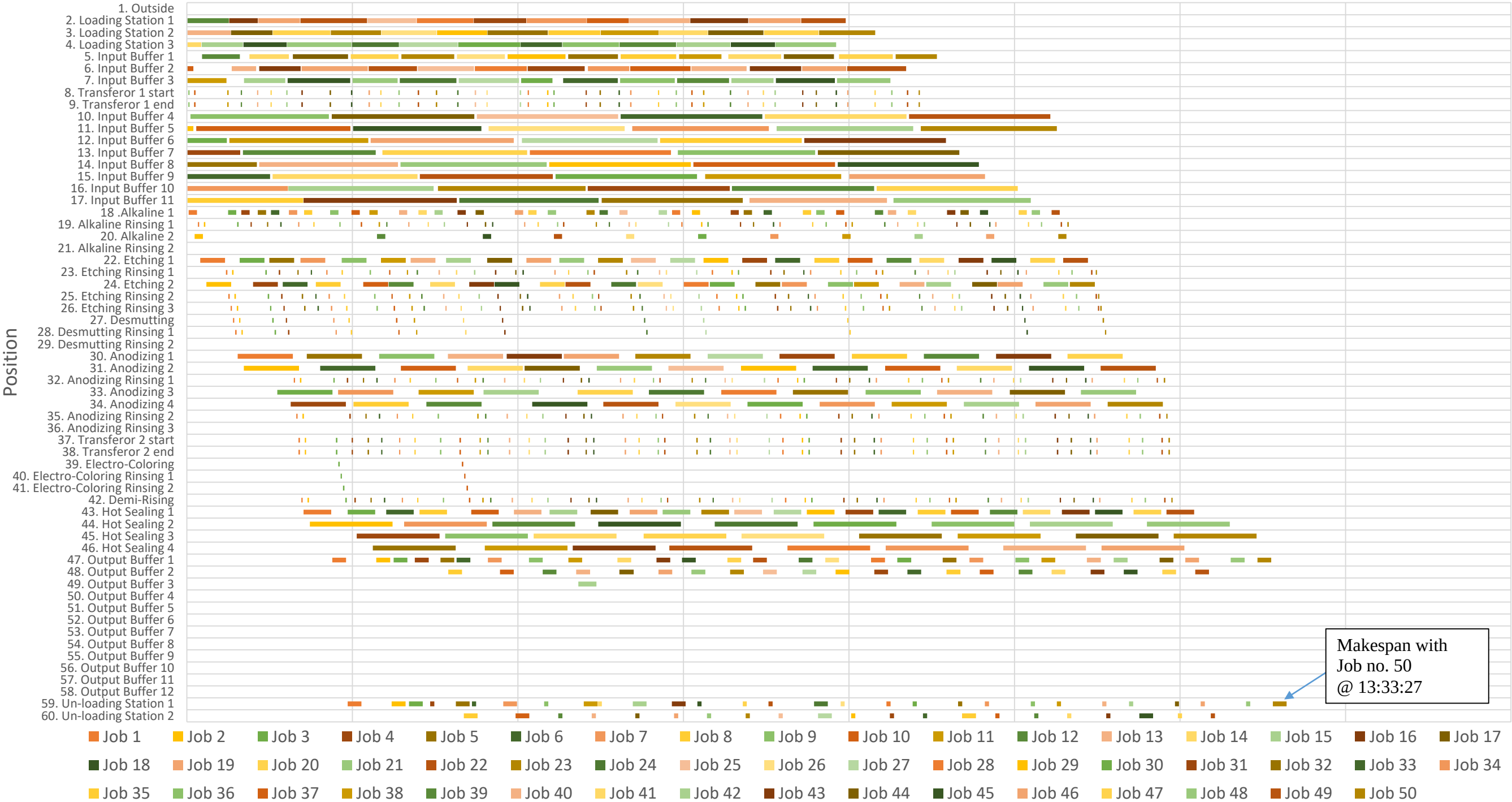
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 08 (17-06-17) - Seq. 1 - Conf. 1 [50 Jobs]

Time (hh:mm)

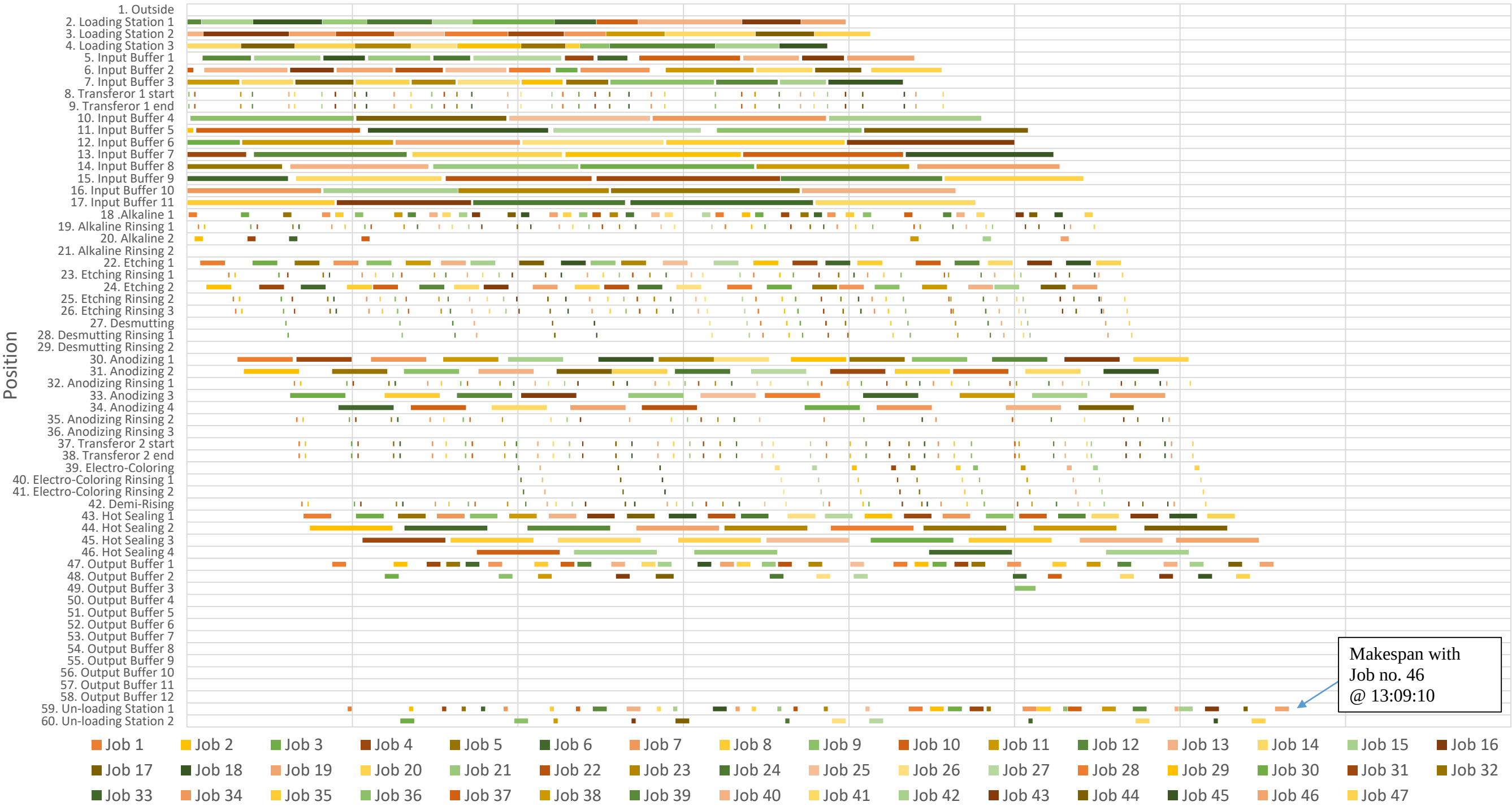
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 09 (19-06-17) - Seq. 1 - Conf. 1 [47 Jobs]

Time (hh:mm)

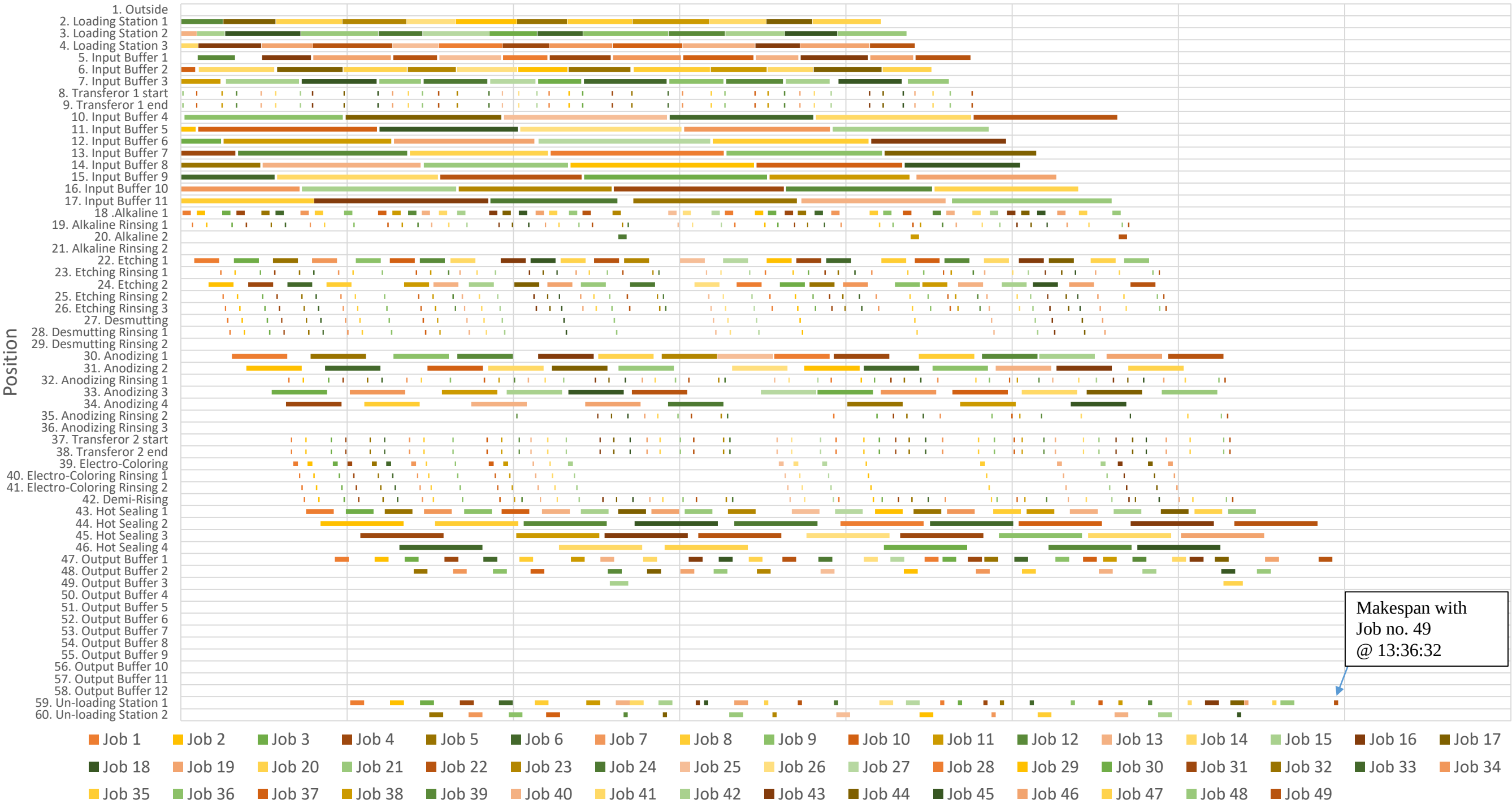
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 10 (24-06-17) - Seq. 1 - Conf. 1 [49 Jobs]

Time (hh:mm)

0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00



Gantt Chart: Day 11 (27-06-17) - Seq. 1 - Conf. 1 [52 Jobs]

Time (hh:mm)

0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00

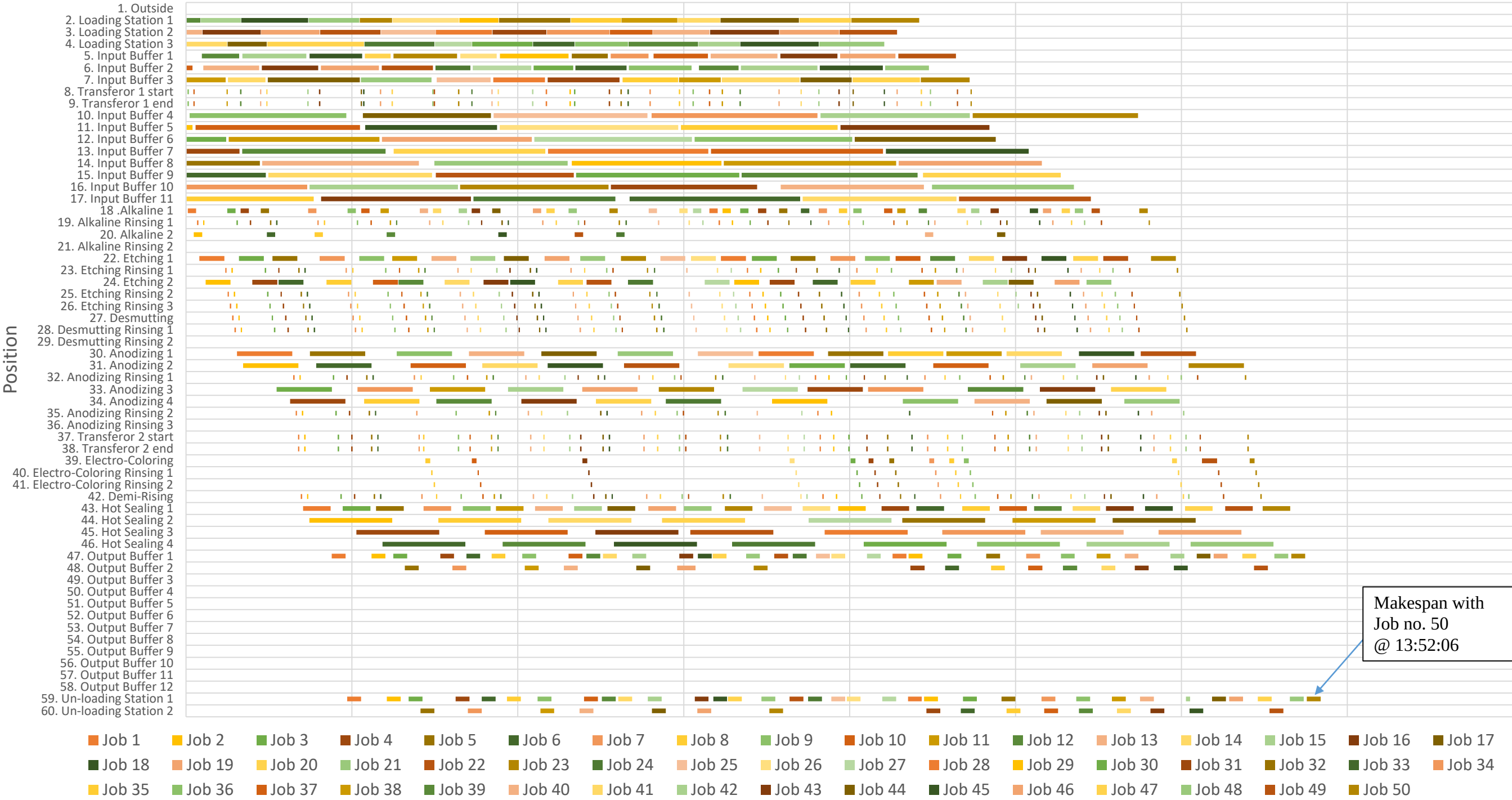


- Job 1 Job 2 Job 3 Job 4 Job 5 Job 6 Job 7 Job 8 Job 9 Job 10 Job 11 Job 12 Job 13 Job 14 Job 15 Job 16 Job 17 Job 18  
Job 19 Job 20 Job 21 Job 22 Job 23 Job 24 Job 25 Job 26 Job 27 Job 28 Job 29 Job 30 Job 31 Job 32 Job 33 Job 34 Job 35 Job 36  
Job 37 Job 38 Job 39 Job 40 Job 41 Job 42 Job 43 Job 44 Job 45 Job 46 Job 47 Job 48 Job 49 Job 50 Job 51 Job 52 Job 53

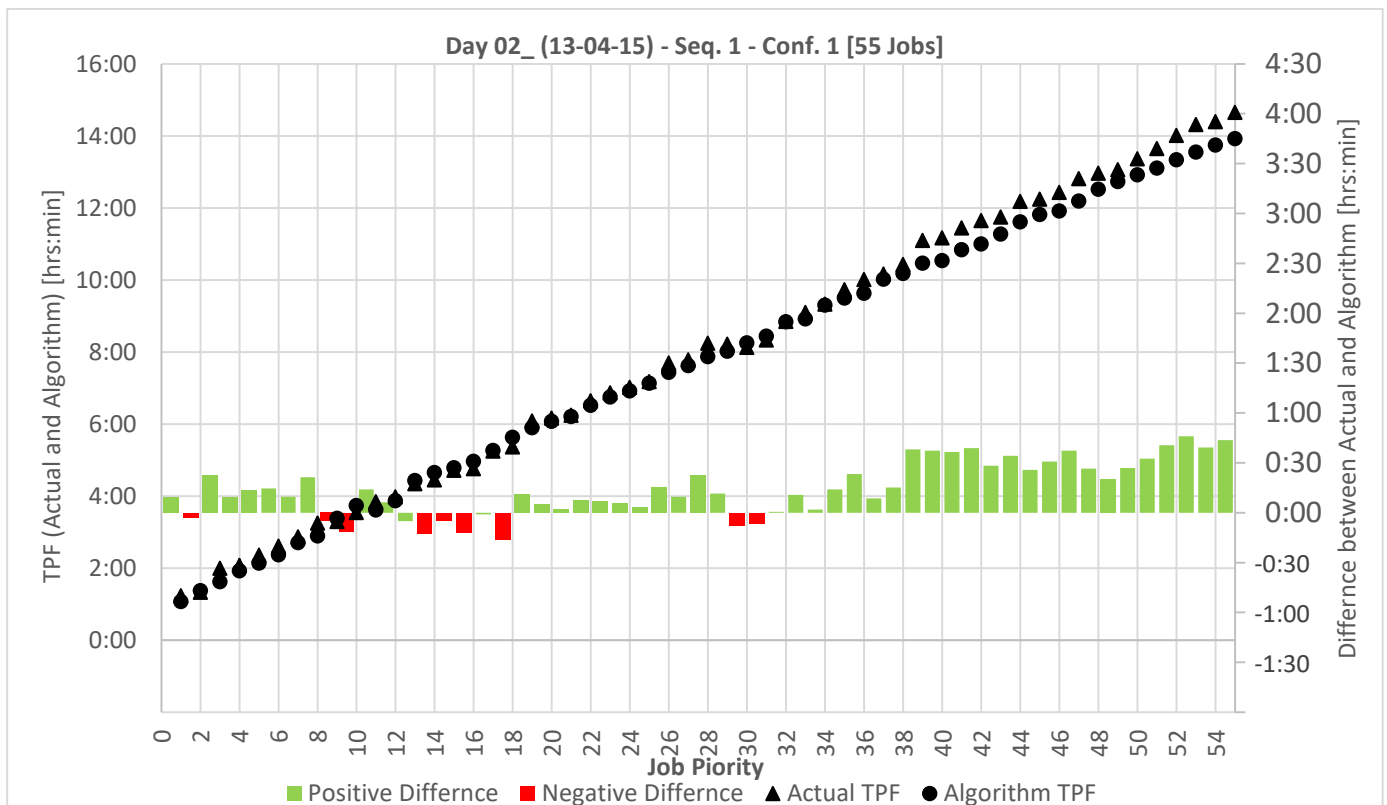
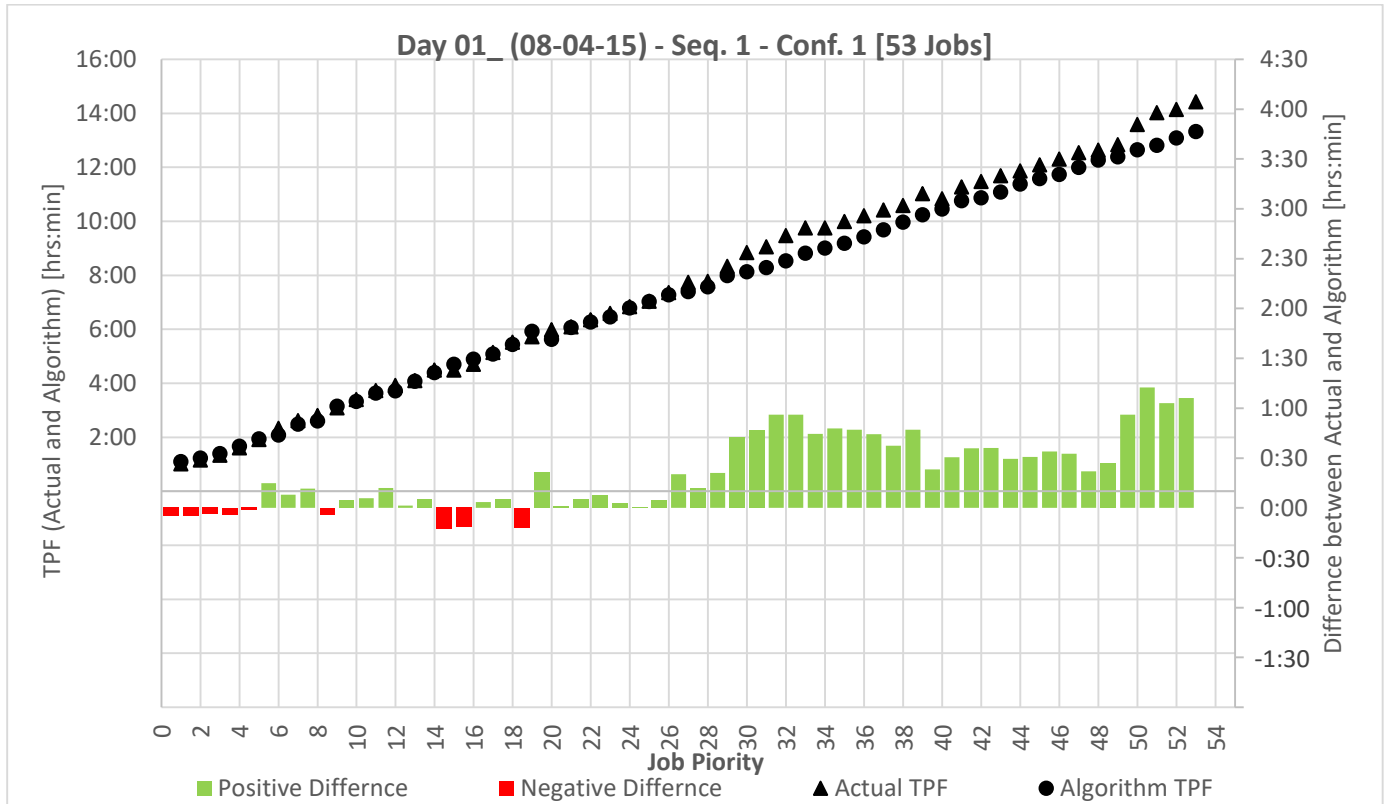
Gantt Chart: Day 12 (29-06-17) - Seq. 1 - Conf. 1 [50 Jobs]

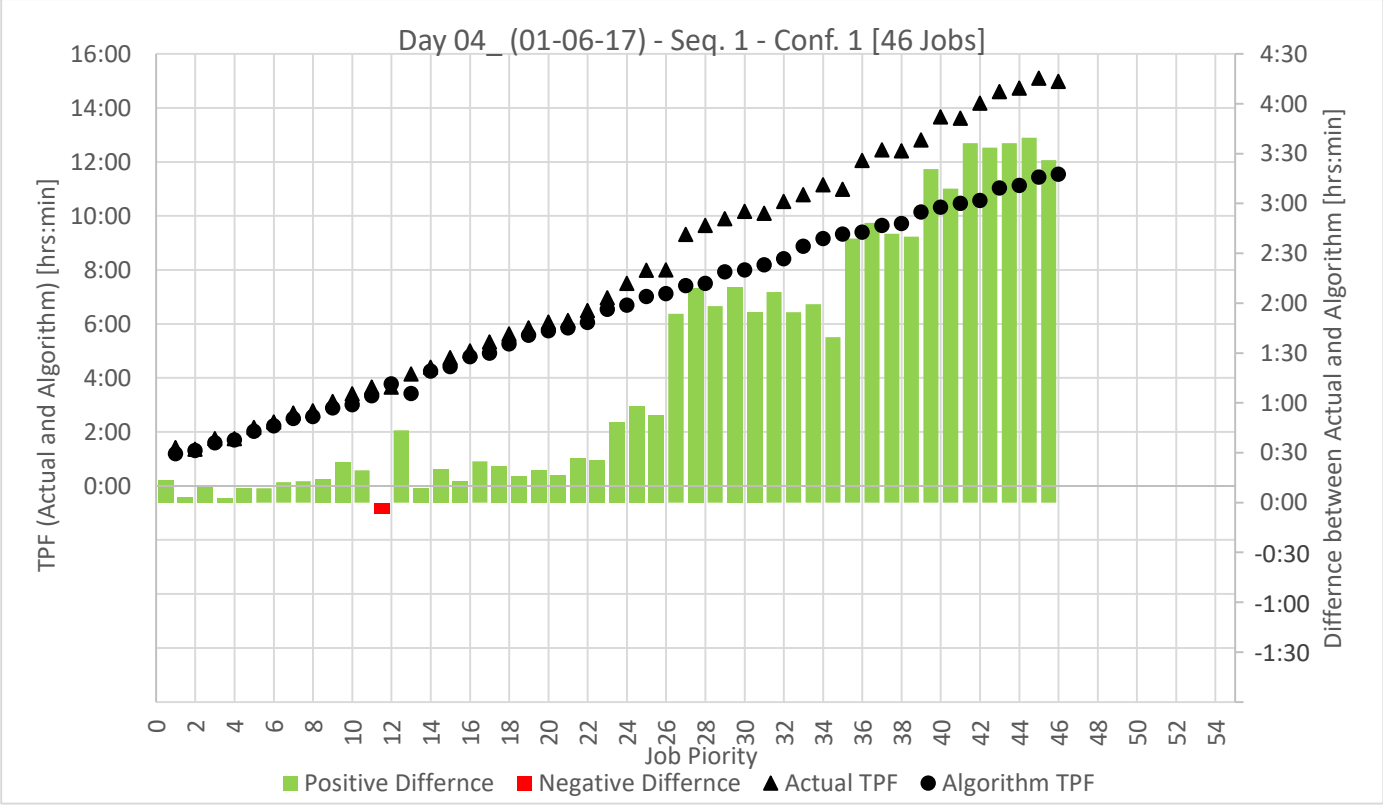
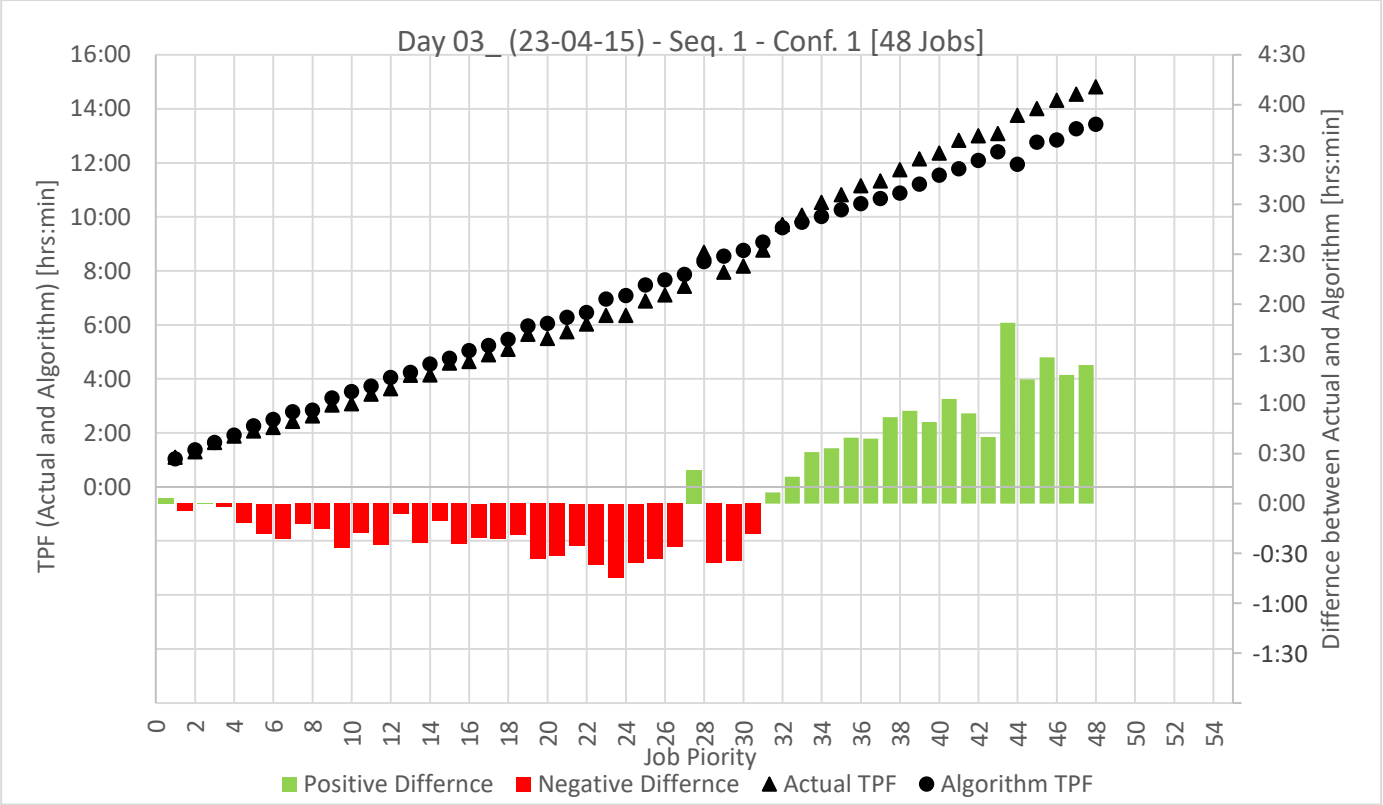
Time (hh:mm)

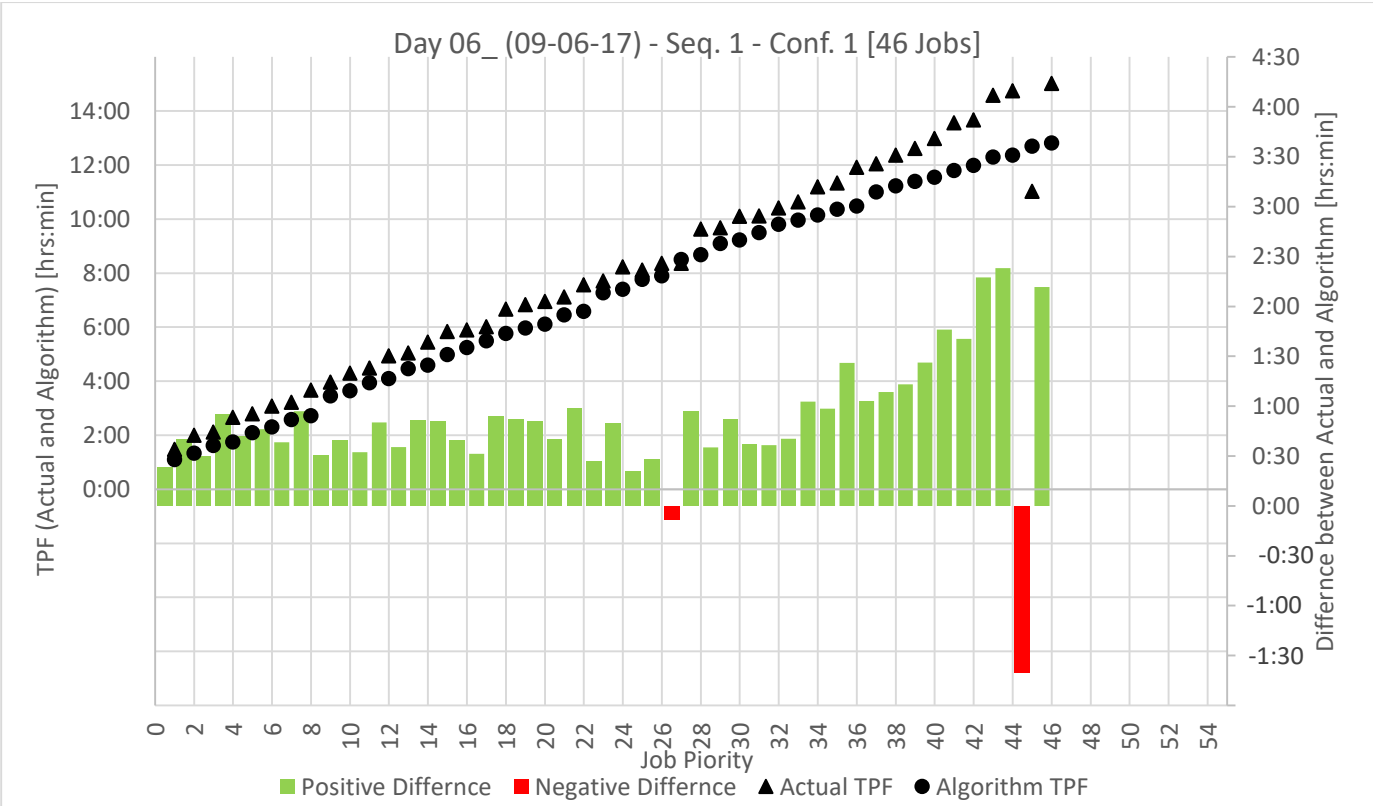
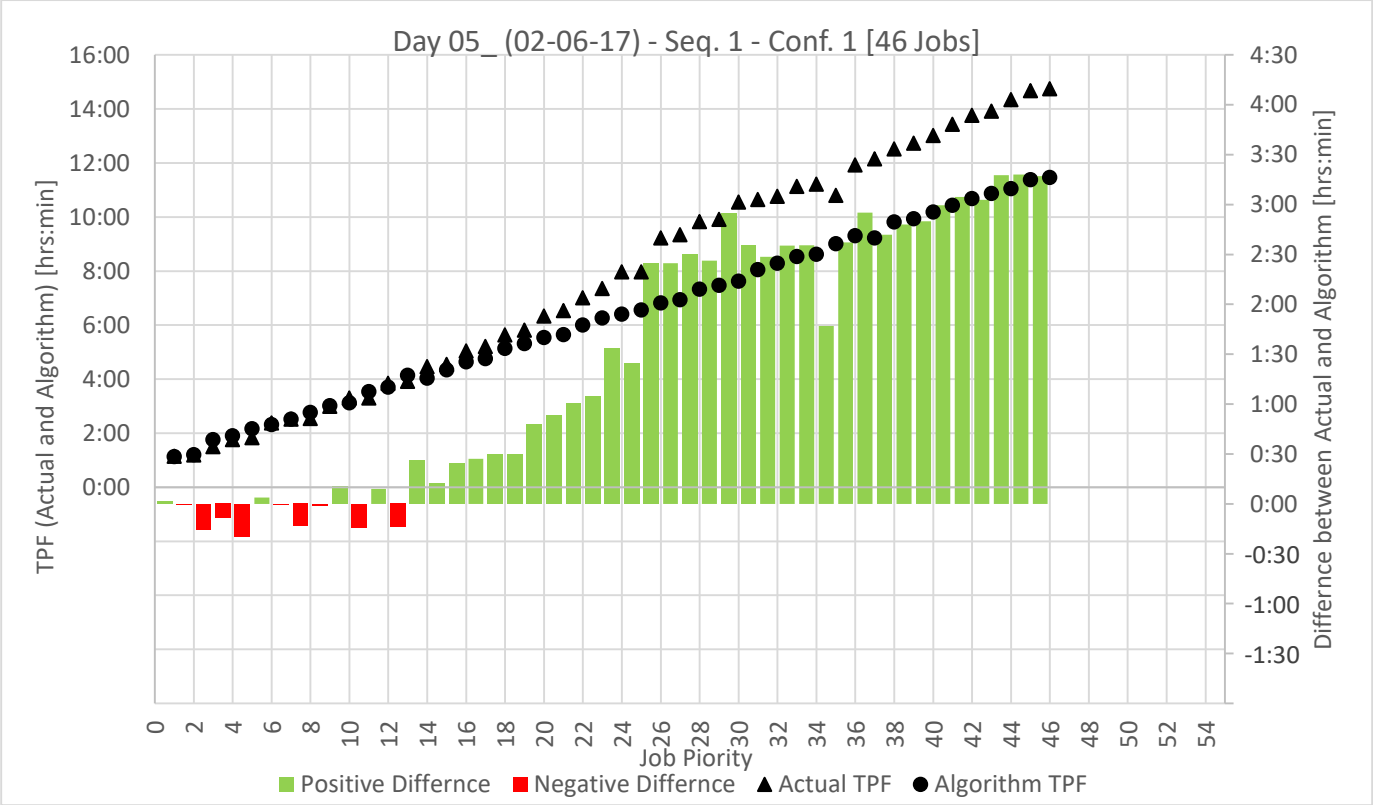
0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00

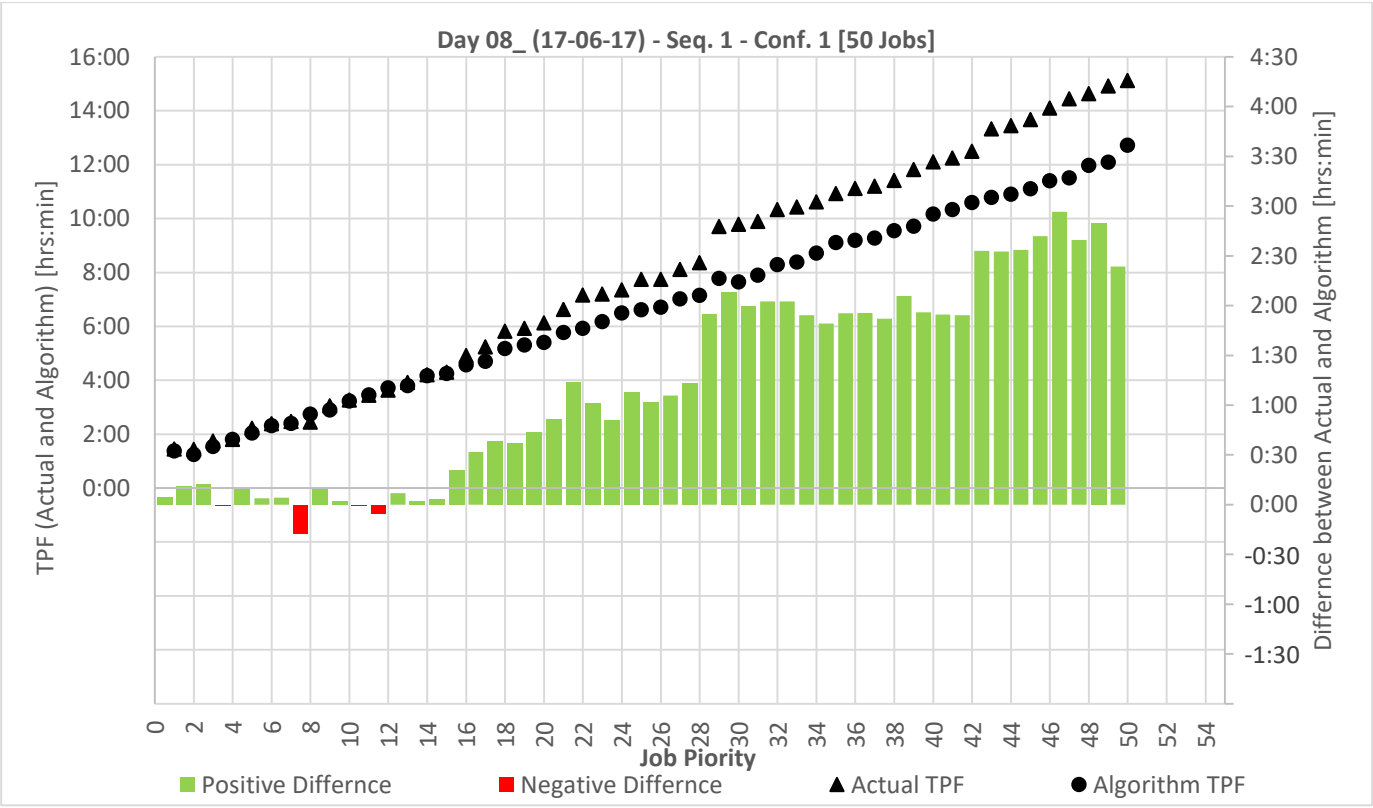
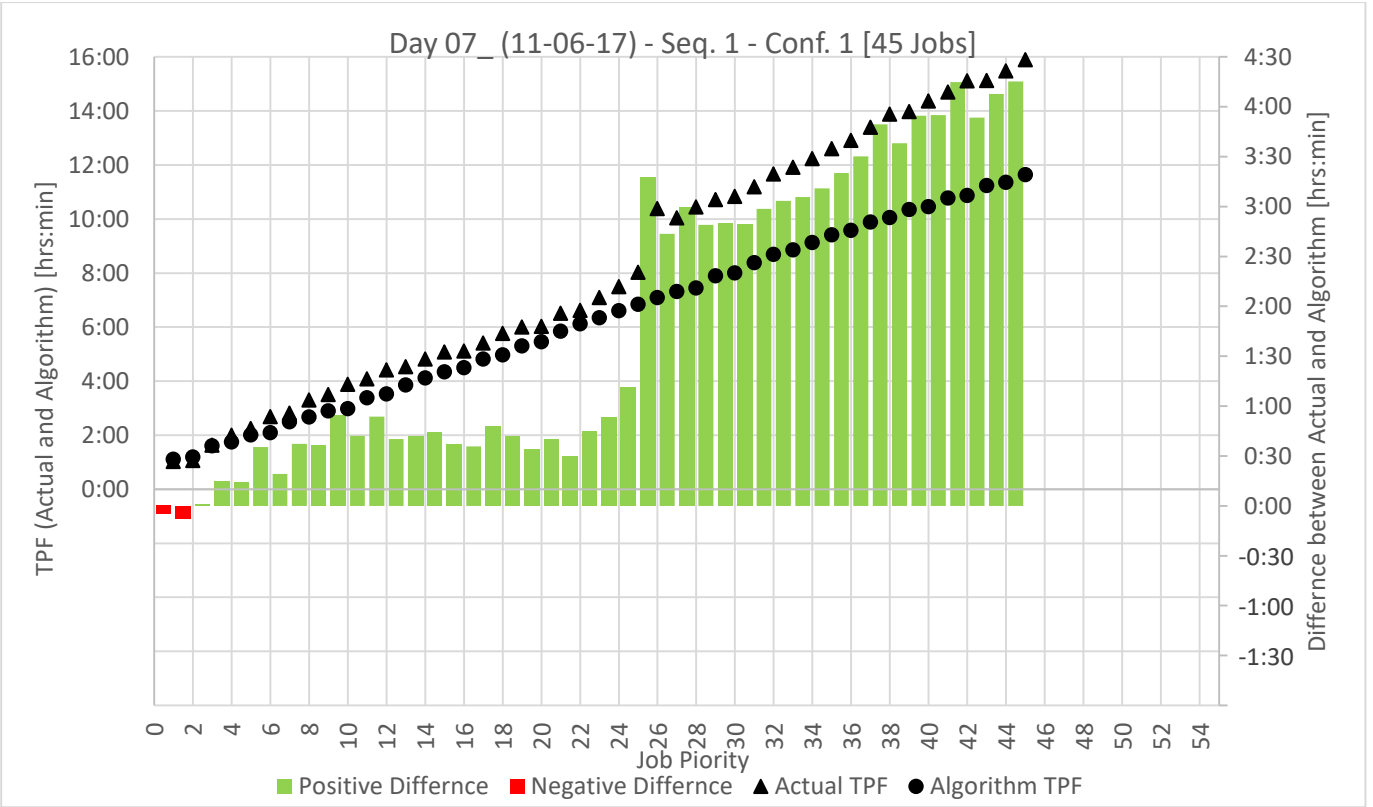


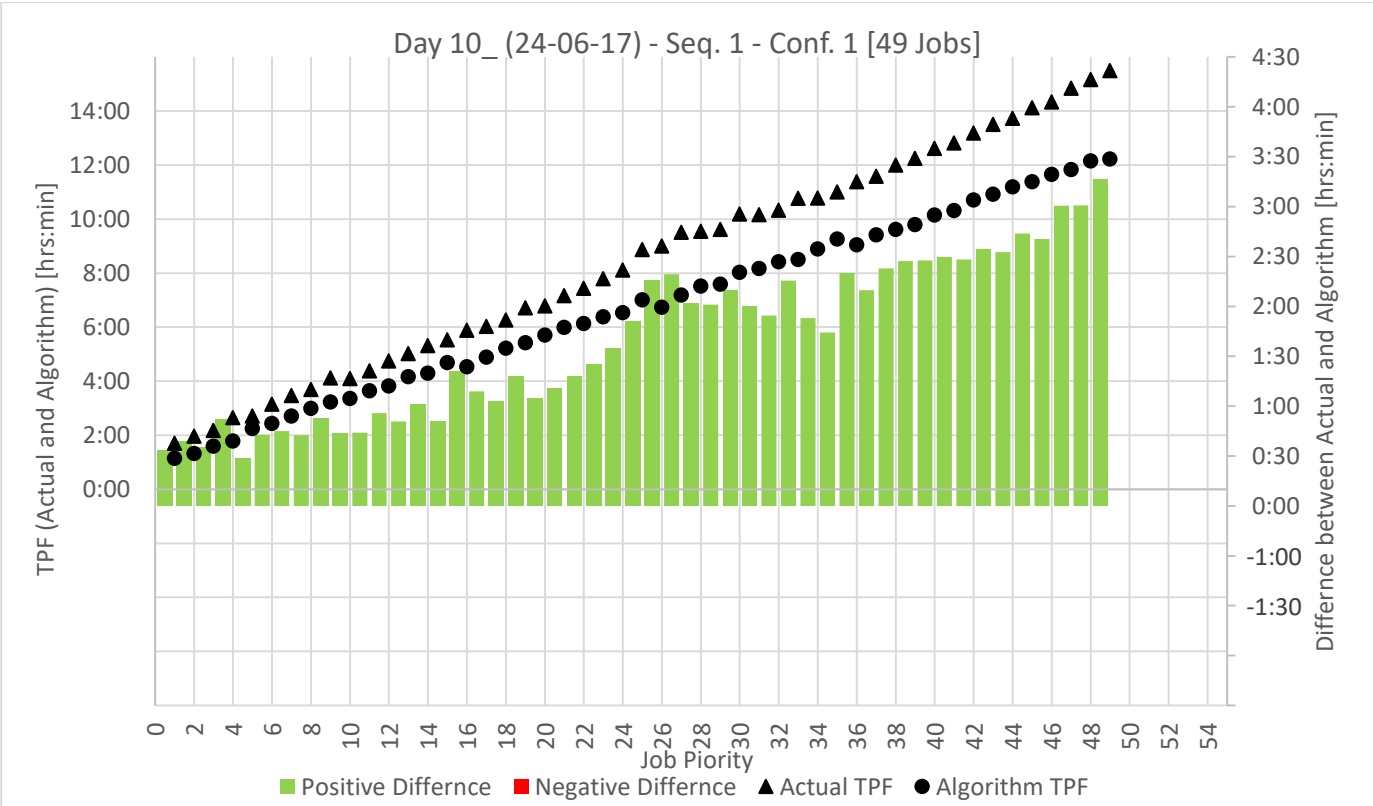
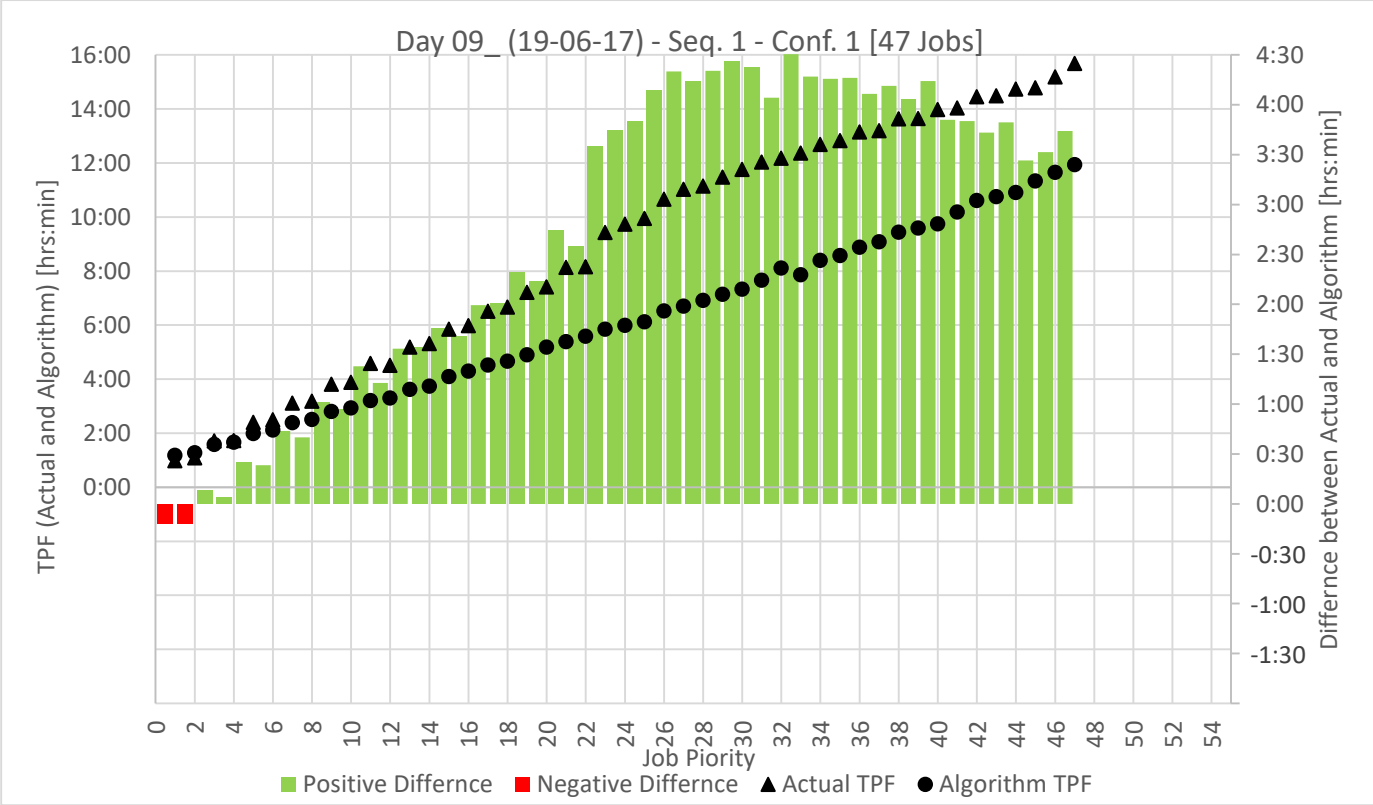
## Appendix (6): Job Flow Time at the Anodizing Stage for the Twelve Days by Combination 1

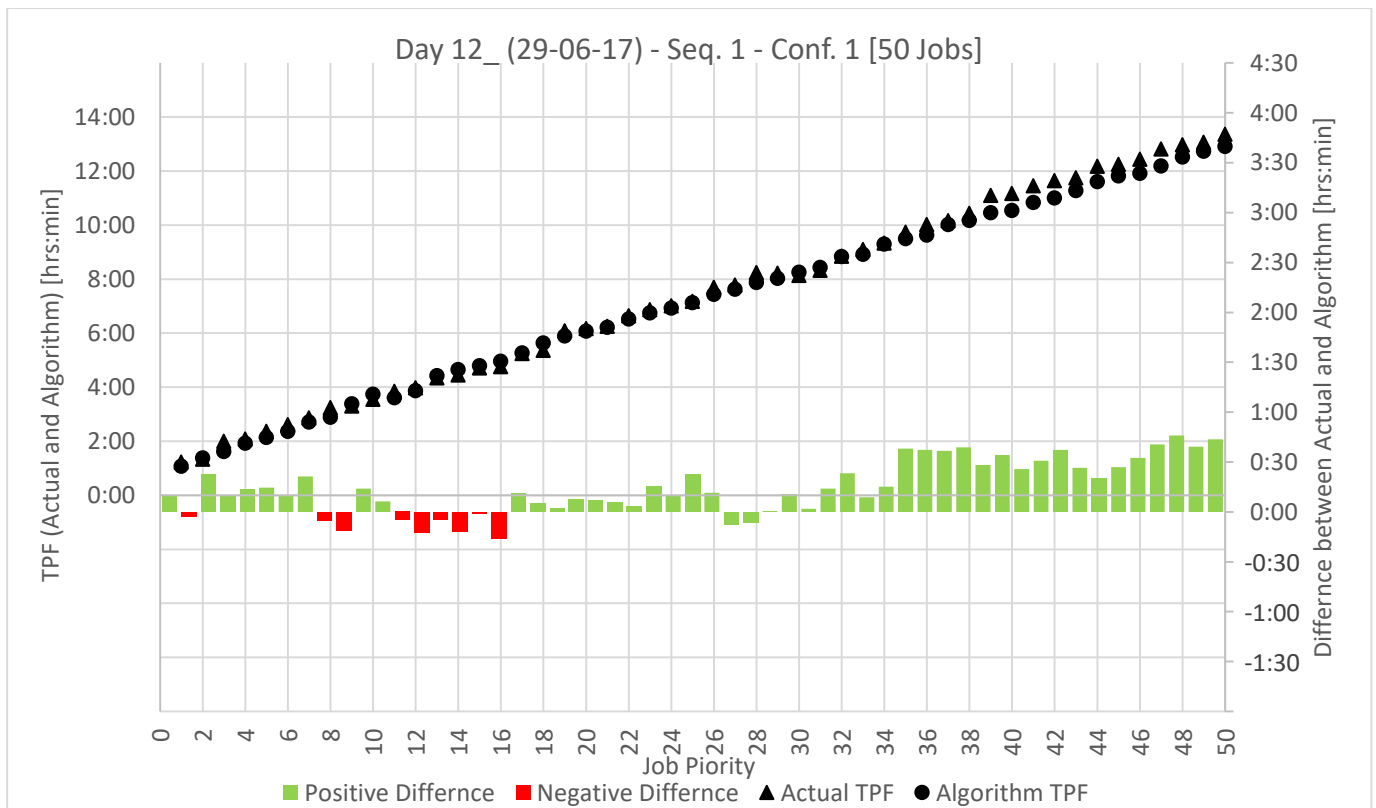
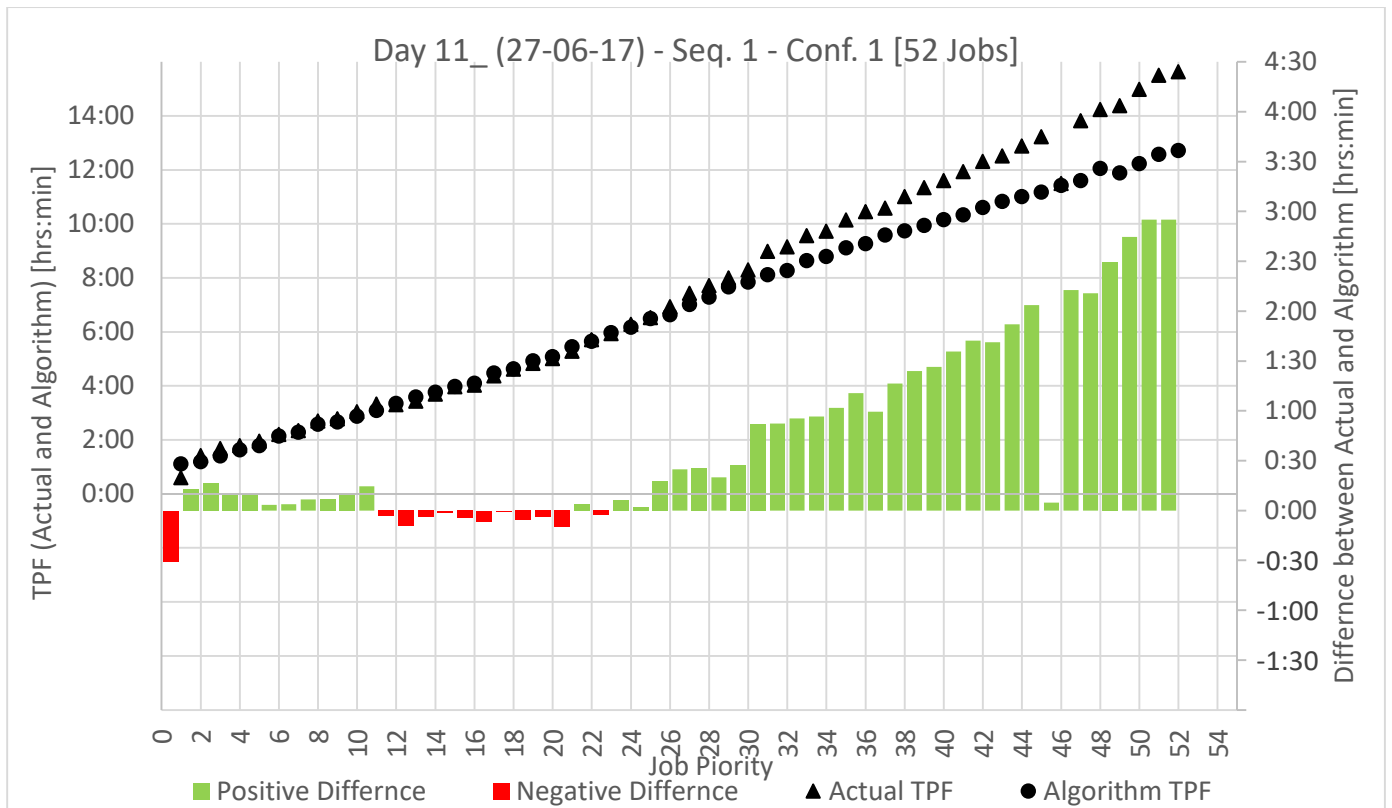












# Appendix (7): Utilization of the Different Positions for the Twelve Days by Combination 1

Results of Utilization of the Different Positions in Day no.1

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing                | 30           | 3.83%               | 18.88%                | 18.23%           | 59.06%               |
| Loading              | 02           | 0.04%               | 0.45%                 | 38.71%           | 60.80%               |                          | 31           | 4.88%               | 23.34%                | 16.78%           | 55.00%               |
|                      | 03           | 0.04%               | 0.42%                 | 40.76%           | 58.78%               |                          | 33           | 6.92%               | 70.95%                | 16.60%           | 5.52%                |
|                      | 04           | 0.04%               | 0.49%                 | 39.20%           | 60.28%               |                          | 34           | 6.09%               | 42.15%                | 22.59%           | 29.17%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 3.96%                 | 34.09%           | 61.91%               | Anodizing Rinsing        | 32           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 06           | 0.04%               | 2.24%                 | 36.92%           | 60.80%               |                          | 35           | 7.11%               | 72.41%                | 16.42%           | 4.06%                |
|                      | 07           | 0.04%               | 5.42%                 | 35.34%           | 59.20%               |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 61.29%                | 33.92%           | 4.69%                | Transferor 2             | 37 and 38    | 7.28%               | 70.95%                | 16.24%           | 5.52%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.27%                 | 29.00%           | 69.69%               | Electro-Coloring         | 39           | 0.00%               | 66.17%                | 25.86%           | 7.97%                |
|                      | 11           | 0.04%               | 1.18%                 | 27.57%           | 71.22%               | Electro-Coloring Rinsing | 40           | 0.00%               | 72.86%                | 25.68%           | 1.46%                |
|                      | 12           | 0.04%               | 1.41%                 | 24.73%           | 73.82%               |                          | 41           | 0.00%               | 73.05%                | 25.50%           | 1.46%                |
|                      | 13           | 0.04%               | 1.74%                 | 26.45%           | 71.77%               | Demi-Rinsing             | 42           | 7.49%               | 70.95%                | 16.03%           | 5.52%                |
|                      | 14           | 0.04%               | 1.14%                 | 23.16%           | 75.66%               | Hot Sealing              | 43           | 7.67%               | 12.25%                | 14.45%           | 65.63%               |
|                      | 15           | 0.04%               | 1.13%                 | 33.07%           | 65.76%               |                          | 44           | 8.51%               | 13.14%                | 12.72%           | 65.63%               |
|                      | 16           | 0.04%               | 1.38%                 | 31.43%           | 67.15%               |                          | 45           | 9.73%               | 13.89%                | 15.45%           | 60.94%               |
|                      | 17           | 0.04%               | 0.94%                 | 30.03%           | 68.99%               |                          | 46           | 10.52%              | 21.97%                | 11.26%           | 56.25%               |
| Alkaline             | 18           | 0.13%               | 46.15%                | 22.46%           | 31.25%               | Output Buffers Zone      | 47           | 12.44%              | 36.79%                | 10.15%           | 40.63%               |
|                      | 20           | 0.83%               | 71.36%                | 22.29%           | 5.52%                |                          | 48           | 13.28%              | 59.85%                | 13.32%           | 13.54%               |
| Alkaline Rinsing     | 19           | 24.16%              | 35.88%                | 38.09%           | 1.88%                |                          | 49           | 0.00%               | 28.81%                | 70.11%           | 1.08%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 26.15%                | 20.34%           | 52.50%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 71.20%                | 20.16%           | 5.52%                |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 29.18%                | 21.89%           | 46.88%               |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 71.03%                | 19.99%           | 5.52%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 71.03%                | 19.81%           | 5.52%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 49.31%                | 19.64%           | 3.54%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 49.31%                | 19.47%           | 3.54%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 43.77%                | 8.99%            | 33.65%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 65.69%                | 12.15%           | 7.71%                |

Results of Utilization of the Different Positions in Day no.2

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing                | 30           | 3.83%               | 20.63%                | 14.08%           | 61.46%               |
| Loading              | 02           | 0.04%               | 0.49%                 | 35.69%           | 63.78%               |                          | 31           | 4.88%               | 29.01%                | 12.99%           | 53.13%               |
|                      | 03           | 0.04%               | 0.49%                 | 33.82%           | 65.66%               |                          | 33           | 6.09%               | 48.71%                | 15.31%           | 29.90%               |
|                      | 04           | 0.04%               | 0.45%                 | 37.85%           | 61.67%               |                          | 34           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Input Buffers Zone 1 | 05           | 0.04%               | 4.80%                 | 31.63%           | 63.54%               | Anodizing Rinsing        | 32           | 6.92%               | 74.53%                | 12.81%           | 5.73%                |
|                      | 06           | 0.04%               | 4.01%                 | 30.57%           | 65.38%               |                          | 35           | 7.11%               | 76.62%                | 12.63%           | 3.65%                |
|                      | 07           | 0.04%               | 2.92%                 | 32.84%           | 64.20%               |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 64.60%                | 30.40%           | 4.90%                | Transferor 2             | 37 and 38    | 7.28%               | 74.53%                | 12.45%           | 5.73%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.88%                 | 27.04%           | 71.04%               | Electro-Coloring         | 39           | 0.00%               | 68.70%                | 22.97%           | 8.33%                |
|                      | 11           | 0.04%               | 1.63%                 | 24.69%           | 73.65%               | Electro-Coloring Rinsing | 40           | 0.00%               | 75.12%                | 22.80%           | 2.08%                |
|                      | 12           | 0.04%               | 1.38%                 | 25.98%           | 72.60%               |                          | 41           | 0.00%               | 75.31%                | 22.61%           | 2.08%                |
|                      | 13           | 0.04%               | 2.51%                 | 23.01%           | 74.44%               | Demi-Rinsing             | 42           | 7.49%               | 74.53%                | 12.24%           | 5.73%                |
|                      | 14           | 0.04%               | 1.55%                 | 21.92%           | 76.49%               | Hot Sealing              | 43           | 7.67%               | 15.58%                | 11.13%           | 65.63%               |
|                      | 15           | 0.04%               | 1.35%                 | 20.77%           | 77.85%               |                          | 44           | 8.51%               | 16.06%                | 9.80%            | 65.63%               |
|                      | 16           | 0.04%               | 0.94%                 | 19.37%           | 79.65%               |                          | 45           | 9.73%               | 16.08%                | 8.57%            | 65.63%               |
|                      | 17           | 0.04%               | 1.07%                 | 28.20%           | 70.69%               |                          | 46           | 10.52%              | 21.07%                | 7.47%            | 60.94%               |
| Alkaline             | 18           | 0.13%               | 49.31%                | 18.68%           | 31.88%               | Output Buffers Zone      | 47           | 12.44%              | 32.24%                | 6.36%            | 48.96%               |
|                      | 20           | 24.16%              | 23.31%                | 50.03%           | 2.50%                |                          | 48           | 13.28%              | 58.89%                | 19.50%           | 8.33%                |
| Alkaline Rinsing     | 19           | 0.83%               | 74.94%                | 18.51%           | 5.73%                |                          | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 24.80%                | 17.95%           | 56.25%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 2.06%               | 34.53%                | 16.54%           | 46.88%               |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 3.12%               | 74.95%                | 16.20%           | 5.73%                |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 74.95%                | 15.86%           | 5.73%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 74.95%                | 15.69%           | 5.73%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 51.39%                | 18.39%           | 2.71%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 51.39%                | 18.21%           | 2.71%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 47.56%                | 5.93%            | 32.92%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 63.26%                | 19.05%           | 3.23%                |

Results of Utilization of the Different Positions in Day no.3

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage               | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|---------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                     |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing           | 30           | 3.83%               | 16.56%                | 17.11%           | 62.50%               |
| Loading              | 02           | 0.04%               | 0.42%                 | 40.07%           | 59.48%               |                     | 31           | 4.88%               | 32.57%                | 16.09%           | 46.46%               |
|                      | 03           | 0.04%               | 0.38%                 | 42.60%           | 56.98%               |                     | 33           | 6.92%               | 72.16%                | 15.91%           | 5.00%                |
|                      | 04           | 0.04%               | 0.38%                 | 41.28%           | 58.30%               |                     | 34           | 6.09%               | 48.59%                | 19.69%           | 25.63%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 4.24%                 | 34.79%           | 60.94%               | Anodizing Rinsing   | 32           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 06           | 0.04%               | 2.66%                 | 38.90%           | 58.40%               |                     | 35           | 7.11%               | 75.39%                | 15.73%           | 1.77%                |
|                      | 07           | 0.04%               | 2.09%                 | 36.66%           | 61.22%               |                     | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 61.11%                | 34.61%           | 4.17%                | Transferor 2        | 37 and 38    | 7.28%               | 72.16%                | 15.55%           | 5.00%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.93%                 | 33.27%           | 64.76%               | Electro-Coloring    | 39           | 0.00%               | 53.82%                | 21.49%           | 24.69%               |
|                      | 11           | 0.04%               | 1.00%                 | 31.01%           | 67.95%               | Electro-Coloring    | 40           | 0.00%               | 75.45%                | 21.32%           | 3.23%                |
|                      | 12           | 0.04%               | 0.98%                 | 29.33%           | 69.65%               | Rinsing             | 41           | 0.00%               | 75.64%                | 21.13%           | 3.23%                |
|                      | 13           | 0.04%               | 0.99%                 | 32.13%           | 66.84%               | Demi-Rinsing        | 42           | 7.49%               | 72.16%                | 15.34%           | 5.00%                |
|                      | 14           | 0.04%               | 0.97%                 | 26.88%           | 72.12%               | Hot Sealing         | 43           | 7.67%               | 19.78%                | 11.61%           | 60.94%               |
|                      | 15           | 0.04%               | 1.19%                 | 26.52%           | 72.26%               |                     | 44           | 8.51%               | 15.28%                | 10.58%           | 65.63%               |
|                      | 16           | 0.04%               | 0.58%                 | 23.90%           | 75.49%               |                     | 45           | 9.73%               | 24.04%                | 14.67%           | 51.56%               |
|                      | 17           | 0.04%               | 1.11%                 | 22.89%           | 75.97%               |                     | 46           | 10.52%              | 28.43%                | 14.18%           | 46.88%               |
| Alkaline             | 18           | 0.13%               | 48.92%                | 22.20%           | 28.75%               | Output Buffers Zone | 47           | 12.44%              | 38.53%                | 10.49%           | 38.54%               |
|                      | 20           | 0.83%               | 72.15%                | 22.03%           | 5.00%                |                     | 48           | 13.28%              | 65.80%                | 9.46%            | 11.46%               |
| Alkaline Rinsing     | 19           | 24.16%              | 48.78%                | 25.82%           | 1.25%                |                     | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 27.28%                | 21.09%           | 50.63%               |                     | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 71.99%                | 19.89%           | 5.00%                |                     | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 38.51%                | 20.06%           | 39.38%               |                     | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 71.83%                | 19.71%           | 5.00%                |                     | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 71.83%                | 19.54%           | 5.00%                |                     | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 48.12%                | 19.36%           | 5.00%                |                     | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 48.12%                | 19.19%           | 5.00%                |                     | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 52.87%                | 47.13%           | 0.00%                |                     | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading          | 59           | 13.60%              | 38.53%                | 9.33%            | 38.54%               |
|                      |              |                     |                       |                  |                      |                     | 60           | 14.46%              | 65.80%                | 8.28%            | 11.46%               |

Results of Utilization of the Different Positions in Day no.4

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     | 0.38%                 | 50.52%           | 49.06%               | Anodizing                | 30           | 3.83%               | 11.16%                | 27.82%           | 57.19%               |
| Loading              | 02           | 0.04%               | 0.38%                 | 49.27%           | 50.31%               |                          | 31           | 4.88%               | 19.66%                | 30.45%           | 45.00%               |
|                      | 03           | 0.04%               | 0.35%                 | 52.22%           | 47.40%               |                          | 33           | 6.92%               | 60.64%                | 27.64%           | 4.79%                |
|                      | 04           | 0.04%               | 4.17%                 | 47.15%           | 48.65%               |                          | 34           | 6.09%               | 26.35%                | 28.50%           | 39.06%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 2.83%                 | 45.67%           | 51.46%               | Anodizing Rinsing        | 32           | 0.00%               | 40.81%                | 33.88%           | 25.31%               |
|                      | 06           | 0.04%               | 1.91%                 | 48.50%           | 49.55%               |                          | 35           | 7.11%               | 61.89%                | 27.46%           | 3.54%                |
|                      | 07           | 0.04%               | 50.43%                | 45.51%           | 3.96%                |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 0.38%                 | 50.52%           | 49.06%               | Transferor 2             | 37 and 38    | 7.28%               | 60.64%                | 27.28%           | 4.79%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.06%                 | 41.82%           | 57.08%               | Electro-Coloring         | 39           | 0.00%               | 46.19%                | 52.56%           | 1.25%                |
|                      | 11           | 0.04%               | 1.14%                 | 41.46%           | 57.36%               | Electro-Coloring Rinsing | 40           | 0.00%               | 46.36%                | 52.39%           | 1.25%                |
|                      | 12           | 0.04%               | 1.43%                 | 38.85%           | 59.69%               |                          | 41           | 0.00%               | 46.55%                | 52.20%           | 1.25%                |
|                      | 13           | 0.04%               | 2.22%                 | 36.57%           | 61.18%               | Demi-Rinsing             | 42           | 7.49%               | 60.64%                | 27.07%           | 4.79%                |
|                      | 14           | 0.04%               | 1.38%                 | 37.79%           | 60.80%               | Hot Sealing              | 43           | 7.67%               | 18.82%                | 25.60%           | 47.92%               |
|                      | 15           | 0.04%               | 2.16%                 | 34.30%           | 63.51%               |                          | 44           | 8.51%               | 14.49%                | 20.75%           | 56.25%               |
|                      | 16           | 0.04%               | 1.94%                 | 44.41%           | 53.61%               |                          | 45           | 9.73%               | 12.77%                | 27.50%           | 50.00%               |
|                      | 17           | 0.04%               | 1.71%                 | 43.43%           | 54.83%               |                          | 46           | 10.52%              | 28.60%                | 23.38%           | 37.50%               |
| Alkaline             | 18           | 0.13%               | 40.64%                | 33.60%           | 25.63%               | Output Buffers Zone      | 47           | 12.44%              | 35.64%                | 19.63%           | 32.29%               |
|                      | 20           | 0.83%               | 60.95%                | 33.43%           | 4.79%                |                          | 48           | 13.28%              | 45.72%                | 26.38%           | 14.62%               |
| Alkaline Rinsing     | 19           | 24.16%              | 31.98%                | 40.74%           | 3.13%                |                          | 49           | 0.00%               | 71.99%                | 26.20%           | 1.81%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 20.64%                | 31.48%           | 46.88%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 60.79%                | 31.30%           | 4.79%                |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 23.62%                | 34.95%           | 39.38%               |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 60.62%                | 31.13%           | 4.79%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 60.62%                | 30.95%           | 4.79%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 36.92%                | 30.78%           | 4.79%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 36.92%                | 30.61%           | 4.79%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 34.60%                | 18.47%           | 33.33%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 45.75%                | 25.21%           | 14.58%               |

Results of Utilization of the Different Positions in Day no.5

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       | 51.32%           | 48.26%               | Anodizing                | 30           | 3.83%               | 11.30%                | 30.91%           | 53.96%               |
| Loading              | 02           | 0.04%               | 0.38%                 | 52.46%           | 47.12%               |                          | 31           | 4.88%               | 16.16%                | 28.85%           | 50.10%               |
|                      | 03           | 0.04%               | 0.38%                 | 53.75%           | 45.87%               |                          | 33           | 6.92%               | 60.11%                | 28.18%           | 4.79%                |
|                      | 04           | 0.04%               | 0.35%                 | 45.34%           | 49.02%               |                          | 34           | 6.09%               | 26.91%                | 28.35%           | 38.65%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 5.61%                 | 49.16%           | 45.87%               | Anodizing Rinsing        | 32           | 0.00%               | 35.78%                | 57.35%           | 6.88%                |
|                      | 06           | 0.04%               | 4.93%                 | 48.86%           | 48.02%               |                          | 35           | 7.11%               | 60.73%                | 27.99%           | 4.17%                |
|                      | 07           | 0.04%               | 3.08%                 | 45.17%           | 3.96%                |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 50.77%                | 51.32%           | 48.26%               | Transferor 2             | 37 and 38    | 7.28%               | 60.11%                | 27.82%           | 4.79%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.52%                 | 43.93%           | 54.51%               | Electro-Coloring         | 39           | 0.00%               | 58.43%                | 37.04%           | 4.53%                |
|                      | 11           | 0.04%               | 1.33%                 | 40.75%           | 57.88%               | Electro-Coloring Rinsing | 40           | 0.00%               | 62.51%                | 36.87%           | 0.63%                |
|                      | 12           | 0.04%               | 1.42%                 | 39.00%           | 59.55%               |                          | 41           | 0.00%               | 62.70%                | 36.68%           | 0.63%                |
|                      | 13           | 0.04%               | 1.41%                 | 37.41%           | 61.15%               | Demi-Rinsing             | 42           | 7.49%               | 60.11%                | 27.61%           | 4.79%                |
|                      | 14           | 0.04%               | 3.02%                 | 35.28%           | 61.67%               | Hot Sealing              | 43           | 7.67%               | 20.55%                | 25.95%           | 45.83%               |
|                      | 15           | 0.04%               | 1.40%                 | 36.38%           | 62.19%               |                          | 44           | 8.51%               | 11.40%                | 23.84%           | 56.25%               |
|                      | 16           | 0.04%               | 0.98%                 | 44.40%           | 54.58%               |                          | 45           | 9.73%               | 18.99%                | 21.28%           | 50.00%               |
|                      | 17           | 0.04%               | 1.62%                 | 41.23%           | 57.12%               |                          | 46           | 10.52%              | 19.62%                | 26.11%           | 43.75%               |
| Alkaline             | 18           | 0.13%               | 42.16%                | 34.58%           | 23.13%               | Output Buffers Zone      | 47           | 12.44%              | 40.31%                | 20.17%           | 27.08%               |
|                      | 20           | 0.83%               | 59.97%                | 34.41%           | 4.79%                |                          | 48           | 13.28%              | 40.99%                | 24.82%           | 20.90%               |
| Alkaline Rinsing     | 19           | 24.16%              | 30.19%                | 40.03%           | 5.63%                |                          | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 20.43%                | 33.56%           | 45.00%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 59.82%                | 32.27%           | 4.79%                |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 24.25%                | 32.44%           | 41.25%               |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 59.65%                | 32.10%           | 4.79%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 59.65%                | 31.92%           | 4.79%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 37.30%                | 31.75%           | 3.44%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 37.30%                | 31.57%           | 3.44%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 45.83%                | 19.01%           | 21.56%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 45.02%                | 23.65%           | 16.88%               |

Results of Utilization of the Different Positions in Day no.6

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage               | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|---------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                     |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing           | 30           | 3.83%               | 16.42%                | 19.86%           | 59.90%               |
| Loading              | 02           | 0.04%               | 0.38%                 | 43.78%           | 55.80%               |                     | 31           | 4.88%               | 22.40%                | 20.63%           | 52.08%               |
|                      | 03           | 0.04%               | 0.38%                 | 41.42%           | 58.16%               |                     | 33           | 6.92%               | 68.60%                | 19.68%           | 4.79%                |
|                      | 04           | 0.04%               | 0.35%                 | 44.93%           | 54.69%               |                     | 34           | 6.09%               | 32.30%                | 23.17%           | 38.44%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 4.20%                 | 38.50%           | 57.26%               | Anodizing Rinsing   | 32           | 0.00%               | 64.98%                | 27.83%           | 7.19%                |
|                      | 06           | 0.04%               | 3.15%                 | 37.51%           | 59.31%               |                     | 35           | 7.11%               | 71.52%                | 19.49%           | 1.88%                |
|                      | 07           | 0.04%               | 2.51%                 | 41.07%           | 56.39%               |                     | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 58.59%                | 37.35%           | 3.96%                | Transferor 2        | 37 and 38    | 7.28%               | 68.60%                | 19.32%           | 4.79%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.06%                 | 33.59%           | 65.31%               | Electro-Coloring    | 39           | 0.00%               | 51.31%                | 45.15%           | 3.54%                |
|                      | 11           | 0.04%               | 1.04%                 | 31.98%           | 66.94%               | Electro-Coloring    | 40           | 0.00%               | 52.10%                | 44.98%           | 2.92%                |
|                      | 12           | 0.04%               | 2.40%                 | 30.62%           | 66.94%               | Rinsing             | 41           | 0.00%               | 52.29%                | 44.79%           | 2.92%                |
|                      | 13           | 0.04%               | 2.24%                 | 30.05%           | 67.67%               | Demi-Rinsing        | 42           | 7.49%               | 68.60%                | 19.11%           | 4.79%                |
|                      | 14           | 0.04%               | 1.52%                 | 28.27%           | 70.17%               | Hot Sealing         | 43           | 7.67%               | 26.68%                | 17.73%           | 47.92%               |
|                      | 15           | 0.04%               | 1.95%                 | 26.45%           | 71.56%               |                     | 44           | 8.51%               | 16.20%                | 12.79%           | 62.50%               |
|                      | 16           | 0.04%               | 1.66%                 | 36.18%           | 62.12%               |                     | 45           | 9.73%               | 24.65%                | 15.63%           | 50.00%               |
|                      | 17           | 0.04%               | 0.98%                 | 35.17%           | 63.82%               |                     | 46           | 10.52%              | 40.26%                | 17.97%           | 31.25%               |
| Alkaline             | 18           | 0.13%               | 51.61%                | 25.76%           | 22.50%               | Output Buffers Zone | 47           | 12.44%              | 43.60%                | 11.67%           | 32.29%               |
|                      | 20           | 0.83%               | 68.80%                | 25.58%           | 4.79%                |                     | 48           | 13.28%              | 54.42%                | 16.60%           | 15.69%               |
| Alkaline Rinsing     | 19           | 24.16%              | 40.26%                | 29.33%           | 6.25%                |                     | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 28.55%                | 25.44%           | 45.00%               |                     | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 68.64%                | 23.45%           | 4.79%                |                     | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 33.07%                | 23.62%           | 41.25%               |                     | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 68.48%                | 23.27%           | 4.79%                |                     | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 68.48%                | 23.10%           | 4.79%                |                     | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 45.09%                | 22.92%           | 4.48%                |                     | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 45.09%                | 22.75%           | 4.48%                |                     | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading          | 59           | 13.60%              | 45.06%                | 10.51%           | 30.83%               |
|                      |              |                     |                       |                  |                      |                     | 60           | 14.46%              | 55.22%                | 15.43%           | 14.90%               |

Results of Utilization of the Different Positions in Day no.7

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing                | 30           | 3.83%               | 13.49%                | 29.03%           | 53.65%               |
| Loading              | 02           | 0.04%               | 0.38%                 | 52.46%           | 47.12%               |                          | 31           | 4.88%               | 20.07%                | 29.74%           | 45.31%               |
|                      | 03           | 0.04%               | 0.35%                 | 54.55%           | 45.07%               |                          | 33           | 6.92%               | 61.34%                | 27.05%           | 4.69%                |
|                      | 04           | 0.04%               | 0.35%                 | 53.57%           | 46.04%               |                          | 34           | 6.09%               | 24.60%                | 27.22%           | 42.08%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 3.29%                 | 49.14%           | 47.53%               | Anodizing Rinsing        | 32           | 0.00%               | 57.93%                | 32.07%           | 10.00%               |
|                      | 06           | 0.04%               | 3.10%                 | 45.51%           | 51.35%               |                          | 35           | 7.11%               | 64.57%                | 26.86%           | 1.46%                |
|                      | 07           | 0.04%               | 1.35%                 | 50.01%           | 48.61%               |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 50.70%                | 45.34%           | 3.85%                | Transferor 2             | 37 and 38    | 7.28%               | 61.34%                | 26.68%           | 4.69%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.14%                 | 39.66%           | 59.17%               | Electro-Coloring         | 39           | 0.00%               | 59.16%                | 37.61%           | 3.23%                |
|                      | 11           | 0.04%               | 1.68%                 | 36.97%           | 61.32%               | Electro-Coloring Rinsing | 40           | 0.00%               | 59.34%                | 37.43%           | 3.23%                |
|                      | 12           | 0.04%               | 3.07%                 | 35.95%           | 60.94%               |                          | 41           | 0.00%               | 59.52%                | 37.25%           | 3.23%                |
|                      | 13           | 0.04%               | 0.00%                 | 44.46%           | 65.90%               | Demi-Rinsing             | 42           | 7.49%               | 61.34%                | 26.48%           | 4.69%                |
|                      | 14           | 0.04%               | 1.17%                 | 34.55%           | 64.24%               | Hot Sealing              | 43           | 7.67%               | 20.09%                | 24.32%           | 47.92%               |
|                      | 15           | 0.04%               | 0.76%                 | 42.85%           | 56.35%               |                          | 44           | 8.51%               | 13.90%                | 27.59%           | 50.00%               |
|                      | 16           | 0.04%               | 0.53%                 | 41.86%           | 57.57%               |                          | 45           | 9.73%               | 18.31%                | 21.96%           | 50.00%               |
|                      | 17           | 0.04%               | 1.03%                 | 39.91%           | 59.03%               |                          | 46           | 10.52%              | 26.99%                | 24.99%           | 37.50%               |
| Alkaline             | 18           | 0.13%               | 41.01%                | 33.85%           | 25.00%               | Output Buffers Zone      | 47           | 12.44%              | 36.51%                | 20.85%           | 30.21%               |
|                      | 20           | 0.83%               | 60.81%                | 33.68%           | 4.69%                |                          | 48           | 13.28%              | 46.82%                | 23.19%           | 16.70%               |
| Alkaline Rinsing     | 19           | 24.16%              | 33.79%                | 38.93%           | 3.13%                |                          | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 22.26%                | 31.73%           | 45.00%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 60.64%                | 31.55%           | 4.69%                |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 25.47%                | 33.10%           | 39.38%               |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 60.48%                | 31.38%           | 4.69%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 60.48%                | 31.20%           | 4.69%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 37.29%                | 31.03%           | 4.17%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 37.29%                | 30.86%           | 4.17%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 37.97%                | 20.41%           | 28.02%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 48.32%                | 22.02%           | 15.21%               |

Results of Utilization of the Different Positions in Day no.8

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing                | 30           | 3.83%               | 13.93%                | 20.47%           | 61.77%               |
| Loading              | 02           | 0.04%               | 0.42%                 | 46.77%           | 52.78%               |                          | 31           | 4.88%               | 20.15%                | 24.45%           | 50.52%               |
|                      | 03           | 0.04%               | 0.42%                 | 46.32%           | 53.23%               |                          | 33           | 6.09%               | 24.05%                | 30.59%           | 39.27%               |
|                      | 04           | 0.04%               | 0.42%                 | 48.61%           | 50.94%               |                          | 34           | 0.00%               | 54.07%                | 39.26%           | 6.67%                |
| Input Buffers Zone 1 | 05           | 0.04%               | 2.31%                 | 40.75%           | 56.91%               | Anodizing Rinsing        | 32           | 6.92%               | 67.57%                | 20.30%           | 5.21%                |
|                      | 06           | 0.04%               | 4.45%                 | 41.83%           | 53.68%               |                          | 35           | 7.11%               | 67.78%                | 20.11%           | 5.00%                |
|                      | 07           | 0.04%               | 2.37%                 | 42.98%           | 54.62%               |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 54.95%                | 40.57%           | 4.38%                | Transferor 2             | 37 and 38    | 7.28%               | 67.57%                | 19.93%           | 5.21%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.28%                 | 31.39%           | 67.29%               | Electro-Coloring         | 39           | 0.00%               | 20.54%                | 79.25%           | 0.21%                |
|                      | 11           | 0.04%               | 1.67%                 | 27.91%           | 70.38%               | Electro-Coloring Rinsing | 40           | 0.00%               | 20.72%                | 79.08%           | 0.21%                |
|                      | 12           | 0.04%               | 1.83%                 | 39.52%           | 58.61%               |                          | 41           | 0.00%               | 20.90%                | 78.89%           | 0.21%                |
|                      | 13           | 0.04%               | 2.19%                 | 38.43%           | 59.34%               | Demi-Rinsing             | 42           | 7.49%               | 67.57%                | 19.72%           | 5.21%                |
|                      | 14           | 0.04%               | 1.00%                 | 35.73%           | 63.23%               | Hot Sealing              | 43           | 7.67%               | 24.76%                | 17.57%           | 50.00%               |
|                      | 15           | 0.04%               | 0.89%                 | 36.99%           | 62.08%               |                          | 44           | 8.51%               | 11.61%                | 17.38%           | 62.50%               |
|                      | 16           | 0.04%               | 0.88%                 | 34.68%           | 64.41%               |                          | 45           | 9.73%               | 12.36%                | 21.66%           | 56.25%               |
|                      | 17           | 0.04%               | 0.68%                 | 31.64%           | 67.64%               |                          | 46           | 10.52%              | 20.97%                | 24.76%           | 43.75%               |
| Alkaline             | 18           | 0.13%               | 45.80%                | 27.19%           | 26.88%               | Output Buffers Zone      | 47           | 12.44%              | 39.01%                | 16.26%           | 32.29%               |
|                      | 20           | 24.16%              | 40.81%                | 30.66%           | 4.38%                |                          | 48           | 13.28%              | 51.18%                | 16.44%           | 19.10%               |
| Alkaline Rinsing     | 19           | 0.83%               | 66.95%                | 27.02%           | 5.21%                |                          | 49           | 0.00%               | 74.90%                | 24.06%           | 1.04%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 25.18%                | 25.07%           | 48.75%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 2.06%               | 24.42%                | 28.52%           | 45.00%               |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 3.12%               | 66.78%                | 24.89%           | 5.21%                |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 66.62%                | 24.72%           | 5.21%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 66.62%                | 24.54%           | 5.21%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 46.56%                | 24.37%           | 1.56%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 46.56%                | 24.19%           | 1.56%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 55.47%                | 15.83%           | 15.10%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 58.82%                | 15.27%           | 11.46%               |

Results of Utilization of the Different Positions in Day no.9

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage               | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|---------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                     |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing           | 30           | 3.83%               | 12.49%                | 25.35%           | 58.33%               |
| Loading              | 02           | 0.04%               | 0.38%                 | 54.96%           | 44.62%               |                     | 31           | 4.88%               | 17.56%                | 27.14%           | 50.42%               |
|                      | 03           | 0.04%               | 0.38%                 | 53.26%           | 46.32%               |                     | 33           | 6.92%               | 63.01%                | 25.17%           | 4.90%                |
|                      | 04           | 0.04%               | 0.38%                 | 51.77%           | 47.81%               |                     | 34           | 6.09%               | 21.25%                | 31.82%           | 40.83%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 4.40%                 | 46.91%           | 48.65%               | Anodizing Rinsing   | 32           | 0.00%               | 22.27%                | 70.86%           | 6.88%                |
|                      | 06           | 0.04%               | 3.67%                 | 48.41%           | 47.88%               |                     | 35           | 7.11%               | 62.77%                | 26.78%           | 3.33%                |
|                      | 07           | 0.04%               | 2.34%                 | 49.81%           | 47.81%               |                     | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 49.09%                | 46.74%           | 4.06%                | Transferor 2        | 37 and 38    | 7.28%               | 62.85%                | 24.97%           | 4.90%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.29%                 | 46.45%           | 52.22%               | Electro-Coloring    | 39           | 0.00%               | 71.03%                | 24.54%           | 4.43%                |
|                      | 11           | 0.04%               | 1.45%                 | 41.32%           | 57.19%               | Electro-Coloring    | 40           | 0.00%               | 74.07%                | 24.36%           | 1.56%                |
|                      | 12           | 0.04%               | 0.98%                 | 39.54%           | 59.44%               | Rinsing             | 41           | 0.00%               | 74.26%                | 24.18%           | 1.56%                |
|                      | 13           | 0.04%               | 1.23%                 | 39.18%           | 59.55%               | Demi-Rinsing        | 42           | 7.49%               | 63.61%                | 24.00%           | 4.90%                |
|                      | 14           | 0.04%               | 1.45%                 | 35.70%           | 62.81%               | Hot Sealing         | 43           | 7.67%               | 22.57%                | 21.85%           | 47.92%               |
|                      | 15           | 0.04%               | 1.22%                 | 34.68%           | 64.06%               |                     | 44           | 8.51%               | 9.57%                 | 25.67%           | 56.25%               |
|                      | 16           | 0.04%               | 1.58%                 | 32.76%           | 65.63%               |                     | 45           | 9.73%               | 15.52%                | 24.75%           | 50.00%               |
|                      | 17           | 0.04%               | 0.82%                 | 42.93%           | 56.22%               |                     | 46           | 10.52%              | 25.66%                | 20.07%           | 43.75%               |
| Alkaline             | 18           | 0.13%               | 41.55%                | 32.07%           | 26.25%               | Output Buffers Zone | 47           | 12.44%              | 36.32%                | 18.95%           | 32.29%               |
|                      | 20           | 0.83%               | 62.38%                | 31.90%           | 4.90%                |                     | 48           | 13.28%              | 46.32%                | 23.63%           | 16.77%               |
| Alkaline Rinsing     | 19           | 24.16%              | 34.25%                | 38.47%           | 3.13%                |                     | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 24.05%                | 29.94%           | 45.00%               |                     | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 62.22%                | 29.77%           | 4.90%                |                     | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 22.97%                | 31.85%           | 43.13%               |                     | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 62.05%                | 29.59%           | 4.90%                |                     | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 62.05%                | 29.42%           | 4.90%                |                     | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 40.95%                | 29.24%           | 2.29%                |                     | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 40.95%                | 29.07%           | 2.29%                |                     | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading          | 59           | 13.60%              | 47.36%                | 17.80%           | 21.25%               |
|                      |              |                     |                       |                  |                      |                     | 60           | 14.46%              | 52.88%                | 23.19%           | 9.48%                |

Results of Utilization of the Different Positions in Day no.10

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage               | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|---------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                     |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing           | 30           | 3.83%               | 16.60%                | 24.05%           | 55.52%               |
| Loading              | 02           | 0.04%               | 0.38%                 | 50.28%           | 49.31%               |                     | 31           | 4.88%               | 22.91%                | 23.56%           | 48.65%               |
|                      | 03           | 0.04%               | 0.42%                 | 48.47%           | 51.08%               |                     | 33           | 6.92%               | 64.59%                | 23.39%           | 5.10%                |
|                      | 04           | 0.04%               | 0.42%                 | 47.98%           | 51.56%               |                     | 34           | 6.09%               | 26.03%                | 26.00%           | 41.88%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 7.39%                 | 43.59%           | 48.98%               | Anodizing Rinsing   | 32           | 0.00%               | 46.52%                | 46.82%           | 6.67%                |
|                      | 06           | 0.04%               | 1.81%                 | 42.57%           | 55.59%               |                     | 35           | 7.11%               | 67.09%                | 23.20%           | 2.60%                |
|                      | 07           | 0.04%               | 2.83%                 | 45.61%           | 51.53%               |                     | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 53.22%                | 42.40%           | 4.27%                | Transferor 2        | 37 and 38    | 7.28%               | 64.59%                | 23.02%           | 5.10%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.51%                 | 38.76%           | 59.69%               | Electro-Coloring    | 39           | 0.00%               | 66.22%                | 26.33%           | 7.45%                |
|                      | 11           | 0.04%               | 1.55%                 | 30.60%           | 67.81%               | Electro-Coloring    | 40           | 0.00%               | 71.35%                | 26.15%           | 2.50%                |
|                      | 12           | 0.04%               | 1.85%                 | 35.76%           | 62.36%               | Rinsing             | 41           | 0.00%               | 71.53%                | 25.97%           | 2.50%                |
|                      | 13           | 0.04%               | 1.00%                 | 36.98%           | 61.98%               | Demi-Rinsing        | 42           | 7.49%               | 64.59%                | 22.82%           | 5.10%                |
|                      | 14           | 0.04%               | 0.96%                 | 34.04%           | 64.97%               | Hot Sealing         | 43           | 7.67%               | 21.19%                | 21.15%           | 50.00%               |
|                      | 15           | 0.04%               | 2.37%                 | 33.02%           | 64.57%               |                     | 44           | 8.51%               | 12.49%                | 16.49%           | 62.50%               |
|                      | 16           | 0.04%               | 2.33%                 | 39.92%           | 57.71%               |                     | 45           | 9.73%               | 18.51%                | 21.76%           | 50.00%               |
|                      | 17           | 0.04%               | 1.01%                 | 30.93%           | 68.02%               |                     | 46           | 10.52%              | 26.81%                | 18.92%           | 43.75%               |
| Alkaline             | 18           | 0.13%               | 42.13%                | 30.24%           | 27.50%               | Output Buffers Zone | 47           | 12.44%              | 37.81%                | 15.38%           | 34.38%               |
|                      | 20           | 0.83%               | 64.36%                | 29.70%           | 5.10%                |                     | 48           | 13.28%              | 49.97%                | 20.02%           | 16.74%               |
| Alkaline Rinsing     | 19           | 24.16%              | 42.84%                | 29.88%           | 3.13%                |                     | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 24.00%                | 28.12%           | 46.88%               |                     | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 64.38%                | 27.40%           | 5.10%                |                     | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 25.20%                | 27.74%           | 45.00%               |                     | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 64.38%                | 27.06%           | 5.10%                |                     | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 64.38%                | 26.89%           | 5.10%                |                     | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 39.26%                | 30.52%           | 2.71%                |                     | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 39.26%                | 30.34%           | 2.71%                |                     | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading          | 59           | 13.60%              | 46.98%                | 14.94%           | 24.48%               |
|                      |              |                     |                       |                  |                      |                     | 60           | 14.46%              | 56.18%                | 19.57%           | 9.79%                |

Results of Utilization of the Different Positions in Day no.11

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage               | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|---------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                     |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing           | 30           | 3.83%               | 15.12%                | 21.37%           | 59.69%               |
| Loading              | 02           | 0.04%               | 0.45%                 | 42.39%           | 57.12%               |                     | 31           | 4.88%               | 16.60%                | 23.51%           | 55.00%               |
|                      | 03           | 0.04%               | 0.42%                 | 44.76%           | 54.79%               |                     | 33           | 6.92%               | 67.30%                | 20.36%           | 5.42%                |
|                      | 04           | 0.04%               | 0.45%                 | 43.37%           | 56.15%               |                     | 34           | 6.09%               | 39.72%                | 20.54%           | 33.65%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 4.74%                 | 40.64%           | 54.58%               | Anodizing Rinsing   | 32           | 0.00%               | 67.99%                | 25.65%           | 6.35%                |
|                      | 06           | 0.04%               | 5.94%                 | 39.37%           | 54.65%               |                     | 35           | 7.11%               | 69.38%                | 20.18%           | 3.33%                |
|                      | 07           | 0.04%               | 5.92%                 | 38.11%           | 55.94%               |                     | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 57.37%                | 37.94%           | 4.58%                | Transferor 2        | 37 and 38    | 7.28%               | 67.30%                | 20.00%           | 5.42%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.28%                 | 32.61%           | 66.08%               | Electro-Coloring    | 39           | 0.00%               | 68.86%                | 23.85%           | 7.29%                |
|                      | 11           | 0.04%               | 1.19%                 | 30.44%           | 68.33%               | Electro-Coloring    | 40           | 0.00%               | 74.24%                | 23.67%           | 2.08%                |
|                      | 12           | 0.04%               | 1.27%                 | 28.38%           | 70.31%               | Rinsing             | 41           | 0.00%               | 74.43%                | 23.48%           | 2.08%                |
|                      | 13           | 0.04%               | 1.25%                 | 27.36%           | 71.35%               | Demi-Rinsing        | 42           | 7.49%               | 67.30%                | 19.79%           | 5.42%                |
|                      | 14           | 0.04%               | 0.96%                 | 37.06%           | 61.94%               | Hot Sealing         | 43           | 7.67%               | 23.87%                | 18.47%           | 50.00%               |
|                      | 15           | 0.04%               | 1.25%                 | 35.52%           | 63.19%               |                     | 44           | 8.51%               | 12.54%                | 16.45%           | 62.50%               |
|                      | 16           | 0.04%               | 0.84%                 | 34.37%           | 64.76%               |                     | 45           | 9.73%               | 14.31%                | 13.47%           | 62.50%               |
|                      | 17           | 0.04%               | 0.68%                 | 31.44%           | 67.85%               |                     | 46           | 10.52%              | 20.90%                | 18.57%           | 50.00%               |
| Alkaline             | 18           | 0.13%               | 40.71%                | 26.66%           | 32.50%               | Output Buffers Zone | 47           | 12.44%              | 35.63%                | 12.35%           | 39.58%               |
|                      | 20           | 0.83%               | 67.27%                | 26.48%           | 5.42%                |                     | 48           | 13.28%              | 54.80%                | 17.30%           | 14.62%               |
| Alkaline Rinsing     | 19           | 24.16%              | 0.00%                 | 100.00%          | 0.00%                |                     | 49           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 22.82%                | 25.55%           | 50.63%               |                     | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 67.28%                | 24.18%           | 5.42%                |                     | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 26.55%                | 24.52%           | 46.88%               |                     | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 67.28%                | 23.84%           | 5.42%                |                     | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 67.28%                | 23.67%           | 5.42%                |                     | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 44.72%                | 24.85%           | 2.92%                |                     | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 44.72%                | 24.67%           | 2.92%                |                     | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                     | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading          | 59           | 13.60%              | 49.48%                | 11.92%           | 25.00%               |
|                      |              |                     |                       |                  |                      |                     | 60           | 14.46%              | 57.75%                | 16.13%           | 11.67%               |

Results of Utilization of the Different Positions in Day no. 12

| Stage                | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) | Stage                    | Position No. | Idleness Period (%) |                       |                  | Treatment Period (%) |
|----------------------|--------------|---------------------|-----------------------|------------------|----------------------|--------------------------|--------------|---------------------|-----------------------|------------------|----------------------|
|                      |              | Before Treatments   | In-between Treatments | After Treatments |                      |                          |              | Before Treatments   | In-between Treatments | After Treatments |                      |
| Outside              | 01           |                     |                       |                  |                      | Anodizing                | 30           | 3.83%               | 12.09%                | 25.43%           | 58.65%               |
| Loading              | 02           | 0.04%               | 0.42%                 | 48.57%           | 50.97%               |                          | 31           | 4.88%               | 19.35%                | 23.27%           | 52.50%               |
|                      | 03           | 0.04%               | 0.42%                 | 47.08%           | 52.47%               |                          | 33           | 6.92%               | 64.78%                | 23.09%           | 5.21%                |
|                      | 04           | 0.04%               | 0.42%                 | 46.11%           | 53.44%               |                          | 34           | 6.09%               | 30.85%                | 27.22%           | 35.83%               |
| Input Buffers Zone 1 | 05           | 0.04%               | 4.49%                 | 43.39%           | 52.08%               | Anodizing Rinsing        | 32           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 06           | 0.04%               | 3.58%                 | 41.84%           | 54.55%               |                          | 35           | 7.11%               | 62.18%                | 26.86%           | 3.85%                |
|                      | 07           | 0.04%               | 2.20%                 | 44.81%           | 52.95%               |                          | 36           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Transferor 1         | 08 and 09    | 0.11%               | 53.85%                | 41.67%           | 4.38%                | Transferor 2             | 37 and 38    | 7.28%               | 64.61%                | 22.89%           | 5.21%                |
| Input Buffers Zone 2 | 10           | 0.04%               | 1.36%                 | 32.46%           | 66.15%               | Electro-Coloring         | 39           | 0.00%               | 72.02%                | 22.46%           | 5.52%                |
|                      | 11           | 0.04%               | 2.62%                 | 30.19%           | 67.15%               | Electro-Coloring Rinsing | 40           | 0.00%               | 76.36%                | 22.28%           | 1.35%                |
|                      | 12           | 0.04%               | 2.47%                 | 40.93%           | 56.56%               |                          | 41           | 0.00%               | 76.55%                | 22.10%           | 1.35%                |
|                      | 13           | 0.04%               | 1.30%                 | 39.18%           | 59.48%               | Demi-Rinsing             | 42           | 7.49%               | 65.38%                | 21.92%           | 5.21%                |
|                      | 14           | 0.04%               | 1.28%                 | 37.95%           | 60.73%               | Hot Sealing              | 43           | 7.67%               | 19.10%                | 21.15%           | 52.08%               |
|                      | 15           | 0.04%               | 1.74%                 | 36.73%           | 61.49%               |                          | 44           | 8.51%               | 14.44%                | 20.80%           | 56.25%               |
|                      | 16           | 0.04%               | 1.16%                 | 35.47%           | 63.33%               |                          | 45           | 9.73%               | 18.43%                | 15.60%           | 56.25%               |
|                      | 17           | 0.04%               | 1.21%                 | 34.24%           | 64.51%               |                          | 46           | 10.52%              | 21.77%                | 23.96%           | 43.75%               |
| Alkaline             | 18           | 0.13%               | 42.90%                | 29.47%           | 27.50%               | Output Buffers Zone      | 47           | 12.44%              | 39.75%                | 14.48%           | 33.33%               |
|                      | 20           | 0.83%               | 64.67%                | 29.30%           | 5.21%                |                          | 48           | 13.28%              | 49.68%                | 20.02%           | 17.01%               |
| Alkaline Rinsing     | 19           | 24.16%              | 5.91%                 | 66.18%           | 3.75%                |                          | 49           | 0.00%               | 58.44%                | 38.96%           | 2.60%                |
|                      | 21           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 50           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching              | 22           | 1.01%               | 22.90%                | 27.35%           | 48.75%               |                          | 51           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 24           | 3.12%               | 64.50%                | 27.17%           | 5.21%                |                          | 52           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Etching Rinsing      | 23           | 2.06%               | 21.53%                | 31.41%           | 45.00%               |                          | 53           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 25           | 3.46%               | 64.34%                | 27.00%           | 5.21%                |                          | 54           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 26           | 3.63%               | 64.34%                | 26.82%           | 5.21%                |                          | 55           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting           | 27           | 27.51%              | 40.74%                | 26.65%           | 5.10%                |                          | 56           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
| Desmutting Rinsing   | 28           | 27.69%              | 40.74%                | 26.47%           | 5.10%                |                          | 57           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      | 29           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |                          | 58           | 0.00%               | 0.00%                 | 100.00%          | 0.00%                |
|                      |              |                     |                       |                  |                      | Un-Loading               | 59           | 13.60%              | 37.66%                | 13.32%           | 35.42%               |
|                      |              |                     |                       |                  |                      |                          | 60           | 14.46%              | 50.76%                | 18.85%           | 15.94%               |

## Appendix (8): Results of Combinations 2 to 9

Combination 2

| Results of Combination 2: Sequence 1 and Configuration 2 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 1                                                        | 1   | 14:25:00           | 12:48:43  | 1:36:17     | 15:35:56            | 14:03:29  | 1:32:27     | 0:02:50            |
| 2                                                        | 2   | 14:39:00           | 13:38:40  | 1:00:20     | 15:42:56            | 14:46:37  | 0:56:19     | 0:03:00            |
| 3                                                        | 3   | 14:49:00           | 12:53:55  | 1:55:05     | 15:59:56            | 14:08:40  | 1:51:16     | 0:03:00            |
| 4                                                        | 4   | 14:59:00           | 11:09:11  | 3:49:49     | 16:24:56            | 12:38:54  | 3:46:02     | 0:02:16            |
| 5                                                        | 5   | 14:15:00           | 11:13:06  | 3:01:54     | 15:40:56            | 12:42:50  | 2:58:06     | 0:02:02            |
| 6                                                        | 6   | 15:01:00           | 12:54:27  | 2:06:33     | 16:26:56            | 14:24:11  | 2:02:45     | 0:02:43            |
| 7                                                        | 7   | 15:54:00           | 11:25:29  | 4:28:31     | 17:19:56            | 12:55:12  | 4:24:44     | 0:02:13            |
| 8                                                        | 8   | 15:07:00           | 11:36:05  | 3:30:55     | 16:32:56            | 13:05:49  | 3:27:07     | 0:02:06            |
| 9                                                        | 9   | 15:32:00           | 11:41:02  | 3:50:58     | 17:01:22            | 12:36:32  | 4:24:50     | 0:02:10            |
| 10                                                       | 10  | 15:31:00           | 11:48:47  | 3:42:13     | 16:49:56            | 12:31:32  | 4:18:24     | 0:02:20            |
| 11                                                       | 11  | 15:38:00           | 11:52:33  | 3:45:27     | 16:56:56            | 13:15:16  | 3:41:40     | 0:02:10            |
| 12                                                       | 12  | 16:00:00           | 11:41:38  | 4:18:22     | 17:29:22            | 13:17:06  | 4:12:16     | 0:02:35            |

Combination 3

| Results of Combination 3: Sequence 1 and Configuration 3 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 13                                                       | 1   | 14:25:00           | 12:48:43  | 1:36:17     | 15:35:56            | 14:03:29  | 1:32:27     | 0:02:40            |
| 14                                                       | 2   | 14:39:00           | 13:55:33  | 0:43:27     | 15:42:56            | 15:03:28  | 0:39:28     | 0:03:09            |
| 15                                                       | 3   | 14:49:00           | 12:53:55  | 1:55:05     | 15:59:56            | 14:08:40  | 1:51:16     | 0:03:01            |
| 16                                                       | 4   | 14:59:00           | 10:58:57  | 4:00:03     | 16:24:56            | 12:28:41  | 3:56:15     | 0:02:01            |
| 17                                                       | 5   | 14:15:00           | 11:21:26  | 2:53:34     | 15:40:56            | 12:51:10  | 2:49:46     | 0:02:05            |
| 18                                                       | 6   | 15:01:00           | 12:47:46  | 2:13:14     | 16:26:56            | 14:17:31  | 2:09:25     | 0:02:41            |
| 19                                                       | 7   | 15:54:00           | 11:14:51  | 4:39:09     | 17:19:56            | 12:04:48  | 5:15:08     | 0:02:11            |
| 20                                                       | 8   | 15:07:00           | 11:33:25  | 3:33:35     | 16:32:56            | 13:03:09  | 3:29:47     | 0:02:04            |
| 21                                                       | 9   | 15:32:00           | 11:41:10  | 3:50:50     | 17:01:22            | 12:36:40  | 4:24:42     | 0:02:11            |
| 22                                                       | 10  | 15:31:00           | 11:33:16  | 3:57:44     | 16:49:56            | 12:16:01  | 4:33:55     | 0:02:11            |
| 23                                                       | 11  | 15:38:00           | 12:29:13  | 3:08:47     | 16:56:56            | 13:51:57  | 3:04:59     | 0:02:28            |
| 24                                                       | 12  | 16:00:00           | 11:43:21  | 4:16:39     | 17:29:22            | 13:18:48  | 4:10:34     | 0:02:22            |

### Combination 4

| Results of Combination 4: Sequence 2 and Configuration 1 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 25                                                       | 1   | 14:25:00           | 13:40:10  | 0:44:50     | 15:46:52            | 15:08:09  | 0:38:43     | 0:02:46            |
| 26                                                       | 2   | 14:39:00           | 13:54:31  | 0:44:29     | 16:00:52            | 15:22:30  | 0:38:22     | 0:02:56            |
| 27                                                       | 3   | 14:49:00           | 12:48:11  | 2:00:49     | 16:23:52            | 14:29:11  | 1:54:41     | 0:02:36            |
| 28                                                       | 4   | 14:59:00           | 11:24:27  | 3:34:33     | 16:25:52            | 12:17:39  | 4:08:13     | 0:02:10            |
| 29                                                       | 5   | 14:15:00           | 13:23:59  | 0:51:01     | 15:51:52            | 14:26:58  | 1:24:54     | 0:02:48            |
| 30                                                       | 6   | 15:01:00           | 11:55:21  | 3:05:39     | 16:30:22            | 13:30:48  | 2:59:34     | 0:02:25            |
| 31                                                       | 7   | 15:54:00           | 11:50:19  | 4:03:41     | 17:20:52            | 12:43:31  | 4:37:21     | 0:02:17            |
| 32                                                       | 8   | 15:07:00           | 12:02:48  | 3:04:12     | 16:33:52            | 12:55:48  | 3:38:04     | 0:02:14            |
| 33                                                       | 9   | 15:32:00           | 11:15:49  | 4:16:11     | 17:01:22            | 12:51:17  | 4:10:05     | 0:02:07            |
| 34                                                       | 10  | 15:31:00           | 12:30:16  | 3:00:44     | 17:00:22            | 13:25:57  | 3:34:25     | 0:02:26            |
| 35                                                       | 11  | 15:38:00           | 12:57:55  | 2:40:05     | 17:07:22            | 14:33:23  | 2:33:59     | 0:02:40            |
| 36                                                       | 12  | 16:00:00           | 12:34:04  | 3:25:56     | 17:36:52            | 14:17:01  | 3:19:51     | 0:03:16            |

### Combination 5

| Results of Combination 5: Sequence 2 and Configuration 2 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 37                                                       | 1   | 14:25:00           | 11:34:12  | 2:50:48     | 15:46:52            | 13:02:10  | 2:44:42     | 0:02:01            |
| 38                                                       | 2   | 14:39:00           | 13:23:12  | 1:15:48     | 16:00:52            | 14:51:10  | 1:09:42     | 0:02:36            |
| 39                                                       | 3   | 14:49:00           | 13:27:52  | 1:21:08     | 16:23:52            | 15:08:50  | 1:15:02     | 0:02:59            |
| 40                                                       | 4   | 14:59:00           | 11:28:19  | 3:30:41     | 16:25:52            | 12:21:30  | 4:04:22     | 0:02:07            |
| 41                                                       | 5   | 14:15:00           | 13:23:59  | 0:51:01     | 15:51:52            | 14:26:58  | 1:24:54     | 0:02:46            |
| 42                                                       | 6   | 15:01:00           | 12:26:32  | 2:34:28     | 16:30:22            | 14:02:00  | 2:28:22     | 0:02:29            |
| 43                                                       | 7   | 15:54:00           | 11:50:59  | 4:03:01     | 17:20:52            | 12:44:11  | 4:36:41     | 0:02:17            |
| 44                                                       | 8   | 15:07:00           | 11:23:44  | 3:43:16     | 16:33:52            | 12:16:44  | 4:17:08     | 0:02:03            |
| 45                                                       | 9   | 15:32:00           | 11:01:59  | 4:30:01     | 17:01:22            | 11:57:28  | 5:03:54     | 0:02:02            |
| 46                                                       | 10  | 15:31:00           | 12:34:33  | 2:56:27     | 17:00:22            | 14:10:00  | 2:50:22     | 0:02:27            |
| 47                                                       | 11  | 15:38:00           | 13:25:03  | 2:12:57     | 17:07:22            | 14:20:45  | 2:46:37     | 0:02:42            |
| 48                                                       | 12  | 16:00:00           | 11:41:00  | 4:19:00     | 17:36:52            | 12:43:59  | 4:52:53     | 0:02:23            |

### Combination 6

| Results of Combination 6: Sequence 2 and Configuration 3 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 49                                                       | 1   | 14:25:00           | 11:34:12  | 2:50:48     | 15:46:52            | 13:02:10  | 2:44:42     | 0:02:00            |
| 50                                                       | 2   | 14:39:00           | 13:48:31  | 0:50:29     | 16:00:52            | 15:16:28  | 0:44:24     | 0:02:46            |
| 51                                                       | 3   | 14:49:00           | 13:12:12  | 1:36:48     | 16:23:52            | 14:53:10  | 1:30:42     | 0:02:42            |
| 52                                                       | 4   | 14:59:00           | 11:28:39  | 3:30:21     | 16:25:52            | 12:21:50  | 4:04:02     | 0:02:10            |
| 53                                                       | 5   | 14:15:00           | 13:32:25  | 0:42:35     | 15:51:52            | 15:15:22  | 0:36:30     | 0:02:49            |
| 54                                                       | 6   | 15:01:00           | 12:26:52  | 2:34:08     | 16:30:22            | 14:02:20  | 2:28:02     | 0:02:28            |
| 55                                                       | 7   | 15:54:00           | 11:50:59  | 4:03:01     | 17:20:52            | 12:44:11  | 4:36:41     | 0:02:19            |
| 56                                                       | 8   | 15:07:00           | 11:24:04  | 3:42:56     | 16:33:52            | 12:17:04  | 4:16:48     | 0:02:19            |
| 57                                                       | 9   | 15:32:00           | 11:16:16  | 4:15:44     | 17:01:22            | 12:11:58  | 4:49:24     | 0:01:57            |
| 58                                                       | 10  | 15:31:00           | 12:35:13  | 2:55:47     | 17:00:22            | 14:10:41  | 2:49:41     | 0:02:28            |
| 59                                                       | 11  | 15:38:00           | 13:25:03  | 2:12:57     | 17:07:22            | 14:20:45  | 2:46:37     | 0:03:01            |
| 60                                                       | 12  | 16:00:00           | 11:41:20  | 4:18:40     | 17:36:52            | 12:44:19  | 4:52:33     | 0:02:35            |

### Combination 7

| Results of Combination 7: Sequence 3 and Configuration 1 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 61                                                       | 1   | 14:25:00           | 12:37:23  | 1:47:37     | 15:28:56            | 13:45:07  | 1:43:49     | 0:02:38            |
| 62                                                       | 2   | 14:39:00           | 13:47:00  | 0:52:00     | 15:42:56            | 14:54:56  | 0:48:00     | 0:03:11            |
| 63                                                       | 3   | 14:49:00           | 13:25:24  | 1:23:36     | 15:59:56            | 14:40:09  | 1:19:47     | 0:02:52            |
| 64                                                       | 4   | 14:59:00           | 11:31:02  | 3:27:58     | 16:24:56            | 13:00:46  | 3:24:10     | 0:02:20            |
| 65                                                       | 5   | 14:15:00           | 11:06:56  | 3:08:04     | 15:33:56            | 12:29:41  | 3:04:15     | 0:02:02            |
| 66                                                       | 6   | 15:01:00           | 12:29:56  | 2:31:04     | 16:19:56            | 13:15:21  | 3:04:35     | 0:02:35            |
| 67                                                       | 7   | 15:54:00           | 11:45:10  | 4:08:50     | 17:12:56            | 13:07:55  | 4:05:01     | 0:02:27            |
| 68                                                       | 8   | 15:07:00           | 11:47:56  | 3:19:04     | 16:25:56            | 13:10:40  | 3:15:16     | 0:02:19            |
| 69                                                       | 9   | 15:32:00           | 11:40:57  | 3:51:03     | 16:50:56            | 13:03:40  | 3:47:16     | 0:02:15            |
| 70                                                       | 10  | 15:31:00           | 12:42:45  | 2:48:15     | 16:49:56            | 14:05:29  | 2:44:27     | 0:02:39            |
| 71                                                       | 11  | 15:38:00           | 12:41:48  | 2:56:12     | 16:56:56            | 13:25:05  | 3:31:51     | 0:02:48            |
| 72                                                       | 12  | 16:00:00           | 12:12:31  | 3:47:29     | 17:18:56            | 13:35:15  | 3:43:41     | 0:02:36            |

### Combination 8

| Results of Combination 8: Sequence 3 and Configuration 2 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 73                                                       | 1   | 14:25:00           | 11:54:29  | 2:30:31     | 15:28:56            | 13:02:12  | 2:26:44     | 0:02:25            |
| 74                                                       | 2   | 14:39:00           | 13:49:34  | 0:49:26     | 15:42:56            | 14:36:10  | 1:06:46     | 0:03:15            |
| 75                                                       | 3   | 14:49:00           | 13:24:15  | 1:24:45     | 15:59:56            | 14:38:59  | 1:20:57     | 0:02:25            |
| 76                                                       | 4   | 14:59:00           | 11:27:04  | 3:31:56     | 16:24:56            | 12:56:47  | 3:28:09     | 0:02:11            |
| 77                                                       | 5   | 14:15:00           | 11:13:07  | 3:01:53     | 15:33:56            | 11:56:05  | 3:37:51     | 0:02:02            |
| 78                                                       | 6   | 15:01:00           | 12:15:07  | 2:45:53     | 16:19:56            | 12:58:04  | 3:21:52     | 0:02:29            |
| 79                                                       | 7   | 15:54:00           | 11:00:23  | 4:53:37     | 17:12:56            | 11:43:07  | 5:29:49     | 0:02:12            |
| 80                                                       | 8   | 15:07:00           | 11:12:19  | 3:54:41     | 16:25:56            | 11:55:04  | 4:30:52     | 0:02:06            |
| 81                                                       | 9   | 15:32:00           | 10:53:30  | 4:38:30     | 16:50:56            | 12:16:15  | 4:34:41     | 0:02:02            |
| 82                                                       | 10  | 15:31:00           | 11:31:48  | 3:59:12     | 16:49:56            | 12:14:45  | 4:35:11     | 0:02:11            |
| 83                                                       | 11  | 15:38:00           | 12:12:29  | 3:25:31     | 16:56:56            | 13:35:12  | 3:21:44     | 0:03:06            |
| 84                                                       | 12  | 16:00:00           | 11:52:09  | 4:07:51     | 17:18:56            | 12:35:07  | 4:43:49     | 0:02:22            |

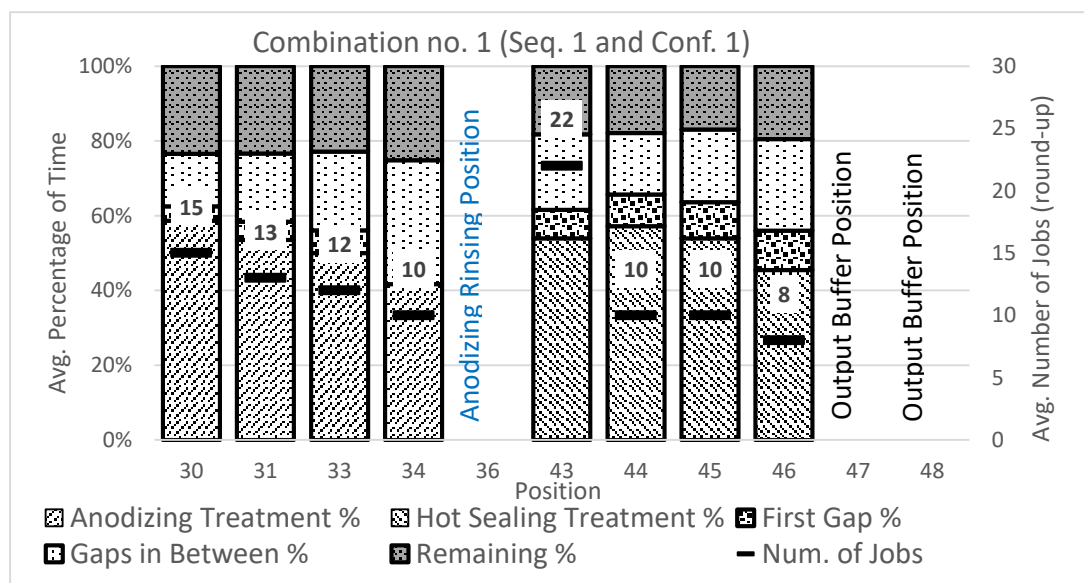
### Combination 9

| Results of Combination 9: Sequence 3 and Configuration 3 |     |                    |           |             |                     |           |             |                    |
|----------------------------------------------------------|-----|--------------------|-----------|-------------|---------------------|-----------|-------------|--------------------|
| Run                                                      | Day | Anodizing Makespan |           |             | Last Stage Makespan |           |             | Computational time |
|                                                          |     | Real               | Algorithm | Difference. | Real (estimated)    | Algorithm | Difference. |                    |
| 85                                                       | 1   | 14:25:00           | 11:46:38  | 2:38:22     | 15:28:56            | 12:54:23  | 2:34:33     | 0:02:21            |
| 86                                                       | 2   | 14:39:00           | 14:37:23  | 0:01:37     | 15:42:56            | 15:22:39  | 0:20:17     | 0:03:26            |
| 87                                                       | 3   | 14:49:00           | 13:26:01  | 1:22:59     | 15:59:56            | 14:40:46  | 1:19:10     | 0:02:57            |
| 88                                                       | 4   | 14:59:00           | 11:27:04  | 3:31:56     | 16:24:56            | 12:56:47  | 3:28:09     | 0:02:11            |
| 89                                                       | 5   | 14:15:00           | 11:13:07  | 3:01:53     | 15:33:56            | 11:56:05  | 3:37:51     | 0:02:04            |
| 90                                                       | 6   | 15:01:00           | 12:15:27  | 2:45:33     | 16:19:56            | 12:58:24  | 3:21:32     | 0:02:32            |
| 91                                                       | 7   | 15:54:00           | 11:23:10  | 4:30:50     | 17:12:56            | 12:45:54  | 4:27:02     | 0:02:13            |
| 92                                                       | 8   | 15:07:00           | 11:05:41  | 4:01:19     | 16:25:56            | 11:48:26  | 4:37:30     | 0:02:03            |
| 93                                                       | 9   | 15:32:00           | 10:48:54  | 4:43:06     | 16:50:56            | 12:11:39  | 4:39:17     | 0:01:59            |
| 94                                                       | 10  | 15:31:00           | 11:32:28  | 3:58:32     | 16:49:56            | 12:15:25  | 4:34:31     | 0:02:11            |
| 95                                                       | 11  | 15:38:00           | 12:14:02  | 3:23:58     | 16:56:56            | 12:56:59  | 3:59:57     | 0:02:50            |
| 96                                                       | 12  | 16:00:00           | 12:55:07  | 3:04:53     | 17:18:56            | 13:38:05  | 3:40:51     | 0:02:44            |

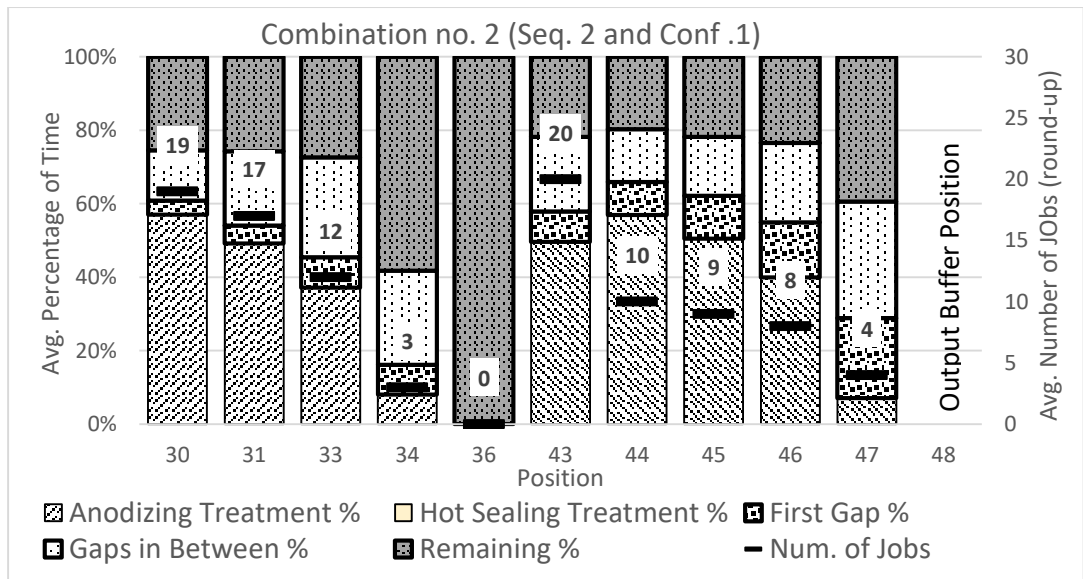
## Appendix (9): Effect of Combinations on Overcoming the Bottleneck Problem

The figures in this appendix, the following percentage are out the total two shifts time (16 hours)

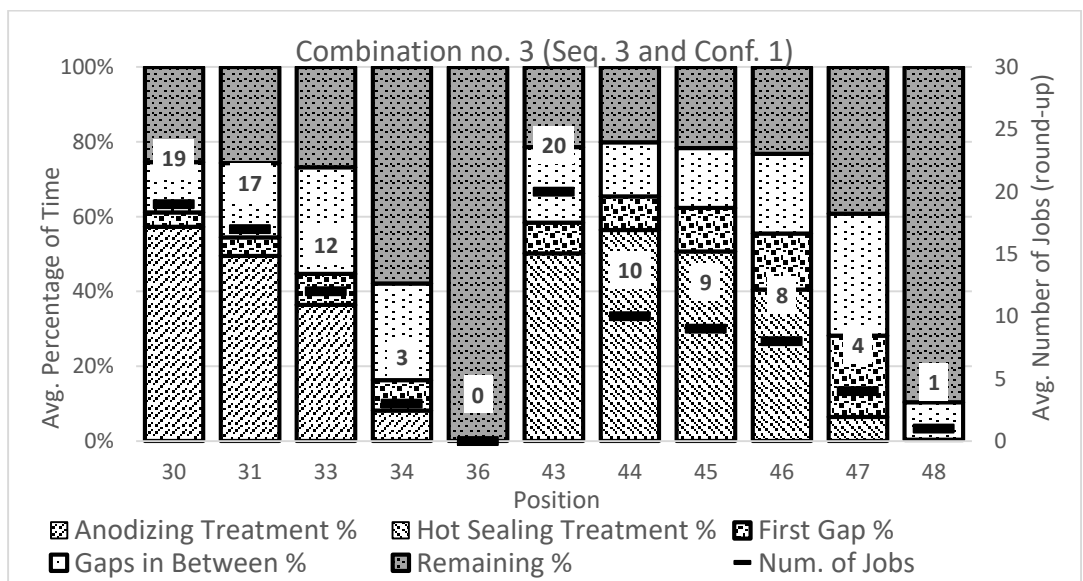
- Anodizing Treatment %: Percentage of the total treatment in the anodizing tanks.
- Hot Sealing Treatment %: Percentage of the total treatment in the hot sealing tanks.
- First Gap %: the percentage of the idle time before the first treatment.
- Gap between treatments %: the idle time between treatments.
- Remaining %: the idle time after the last treatment.



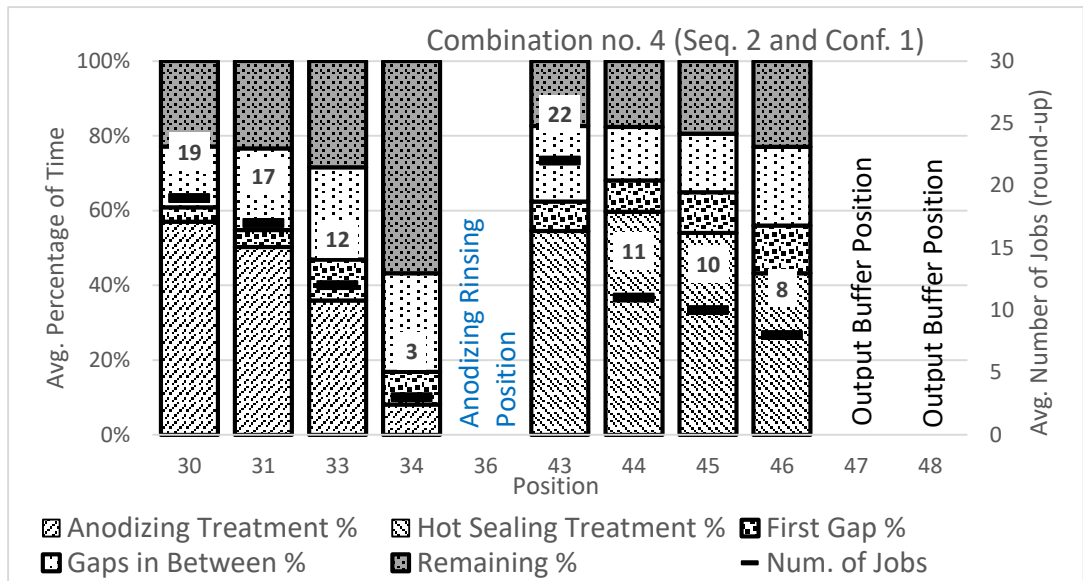
For Combination no.1



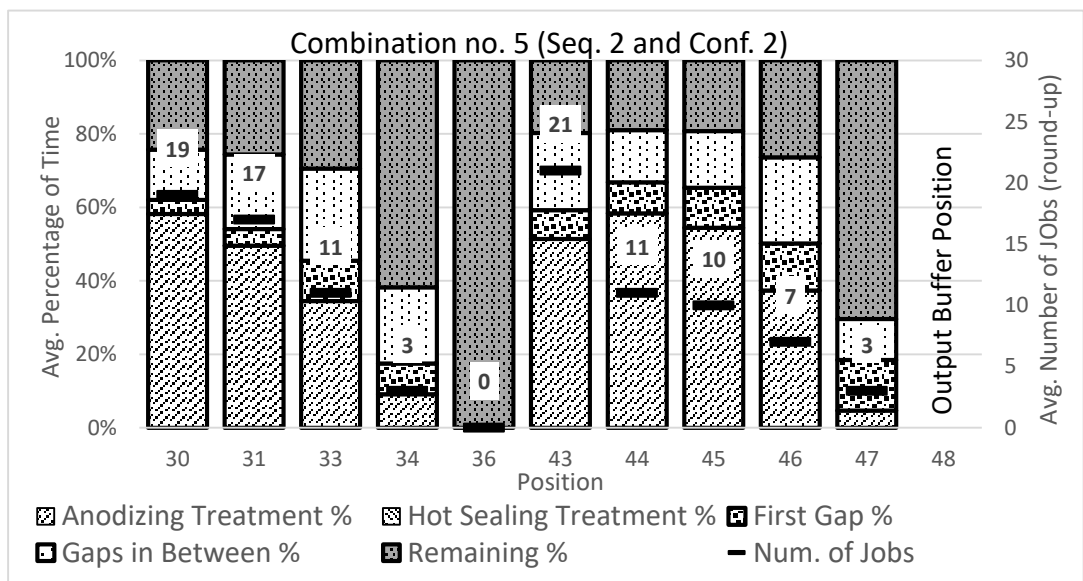
For Combination no.2



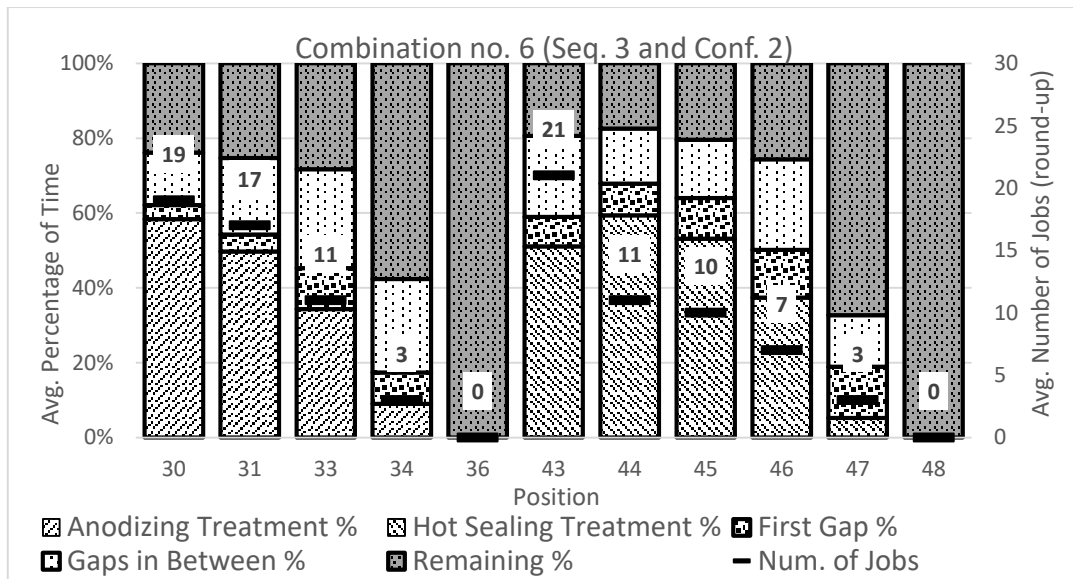
For Combination no.3



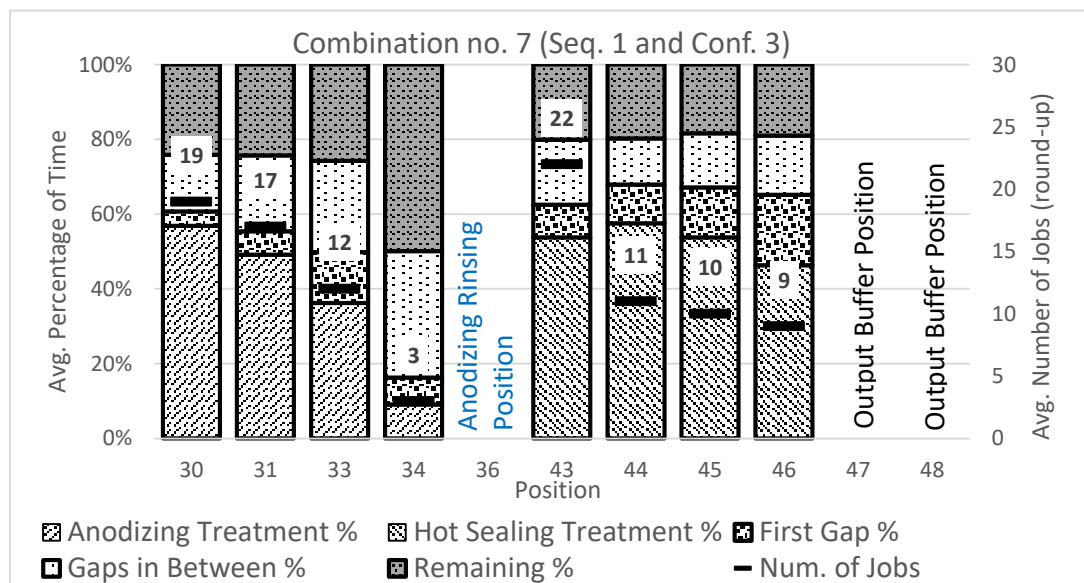
For Combination no.4



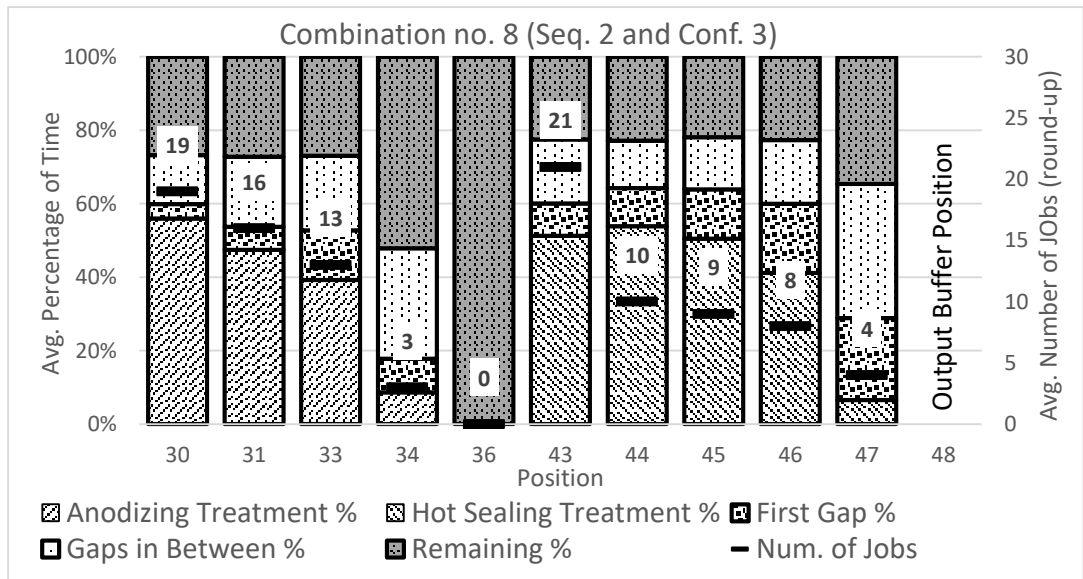
For Combination no.5



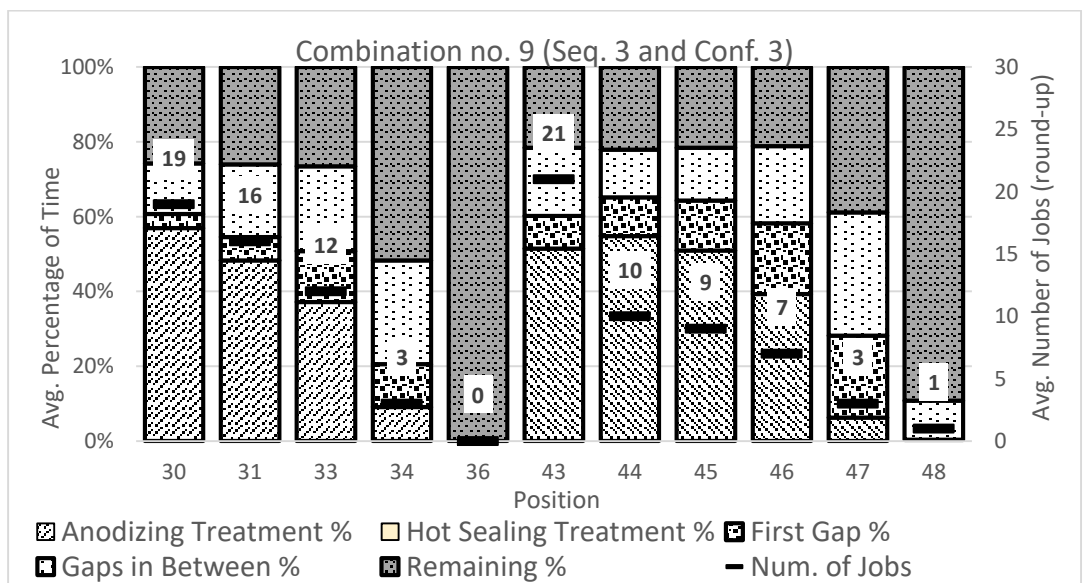
For Combination no.6



For Combination no.7



For Combination no.8



For Combination no.9

## مُلخَص

تُدرس مسألة جدولة معامل معالجة الأسطح المعدنية بكثافة ويُشار إليها بمسألة جدولة الرافعات ( Hoist Scheduling Problem - HSP)، وهي تندرج تحت مسائل جدولة خطوط الإنتاج ولكن تختلف عنها لسببين: الأول لأنها تحتوي على شروط الإنقال، و الثاني لأنها تحتوي على شرط عدم-الانتظار. في هذا البحث تم إتخاذ معمل حقيقي للإنودة في إحدى شركات السحب. وفي هذا المعمل يُثم غمس مجموعة من القطع المعدنية المتعددة الأشكال في أحواض مملوءة بأحماض، ومياه، وأصباغ، وغيرها من مواد كيميائية لفترات متباينة من الزمن؛ كما يوجد خمسة رافعات لنقل القطع من حوض إلى آخر. الأهداف من هذه الدراسة هي: تقليل الوقت الذي تمت فيه معالجة عدد من المشغولات في أيام سابقة، ولزيادة الإنتاج؛ والتغلب على مشكلة عنق الزجاجة (مشكلة ازدحام الإنتاج) الرئيسية. ولتحقيق هذه الأهداف، تمت برمجة خوارزمية تجريبية باستخدام برنامج (Matlab R2015b editor -) لتشغيل نموذج محاكاة وذلك لإعادة جدولة أيام سابقة. ومن ثم تم تقسيم أشواط المحاكاة على ثلاثة مراحل. ففي المرحلة الأولى، تم التأكد (التحقق من معقولية) النتائج عن طريق مقارنة الأوقات الحقيقية والأوقات المُتحصلة من الخوارزمية، وأظهرت النتائج فُدرة الخوارزمية على تقليل الوقت بنسبة تقريبية ١٨% للمتوسط في الإنتاج. وفي المرحلة الثانية، تم إختبار نموذج المحاكاة على عدة تشكيلات المُتمثلة في ترتيب المشغولات وإضافة أحواض أخرى؛ وذلك لدراسة تأثير هذه التشكيلات على وقت الإنتاج وعلى مشكلة عنق الزجاجة، وأُقرحت نتائج هذه المرحلة على إضافة حوض لمرحلة تسديد المسامات بالماء الحار (Hot Sealing) وترتيب المشغولات على حسب أرقام الوصفات (فترة المعالجة الكلية لكل مشغولة) ترتيباً تنازلياً. أما في المرحلة الثالثة تمت زيادة عدد المشغولات لزيادة الإنتاج على تشكيلتين (كلتاها على حسب عدد الأحواض الأصلية، ولكن مُختلفتان في ترتيب المشغولات ففي الأولى الترتيب الأصلي وفي الثانية الترتيب الذي أظهر أقل وقت إنتاج)، وكشفت نتائج هذه المرحلة أنه تم استنفاد حوالي ٩٨% من الوقت الكلي في زيادة عدد القطع بمتوسط قدره ٢٠%. ما قد يجعل هذه الدراسة فريدة من نوعها هو كونها تتعامل مع معمل للإنودة وشمولها (اعتبارها) لمحطات تحميل وتفريغ المشغولات ونقاط الإنتظار قبل وبعد خط الإنتاج الرئيسي، وهو أمر نادراً ما تم التطرق إليه في الدراسات السابقة، حيث أن أكثرها تتعامل مع معامل الطلاء الكهربائي ولا قد تشتمل على نقاط الإنتظار أو محطات تحميل وتفريغ المشغولات.

جامعة البحرين

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أطروحة مقدمة كجزء من متطلبات الحصول على درجة الماجستير  
في الإدارة الهندسية

إعداد

علاء جميل عيسى الصفار

الرقم الجامعي: ٢٠٠٨-٠١١٣

إشراف

أ.د. سعد سليمان

(استاذ)

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مملكة البحرين

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