Optimization of a Cargo Terminal

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Abstract

Nowadays in air cargo terminals one of the most important problems is the scheduling of freight handling employees. The build-up and break-down of the unit load devices (ULDs) are the most manpower-intensive operations at air cargo terminals. This particular area is critical for achieving cost reductions while maintaining customer service levels. Efficient management of manpower resources for cargo handling personnel can help terminals improve the manpower utilization and reduce operating costs accordingly.

This Master Thesis aims at optimizing the operations of the Spirit Air Cargo Terminal at Kastrup airport in Copenhagen by fully utilizing the manpower resources for cargo handling. Based on the demands of incoming and outgoing cargo and on the handling capacities of the individual build and break workers as well as an effective demand leveling mechanism, an optimization model for personnel scheduling can be formulated. The solution of the optimization model can provide high (well above 90%) manpower utilization and 100% customer service levels (no delayed cargo). Therefore, the manpower cost at the terminal can be reduced greatly while maintaining a high customer service levels. How to perform this theoretical manpower utilization and customer service levels is an important, interesting and challenging subject in practice.

The optimization model differs from reality mainly because the aggregate demand for the outgoing and incoming air cargo is in kilograms while in practice the outgoing cargo must be consolidated into individual ULDs by build workers and the incoming cargo must be unloaded from ULDs by break workers at the workstations. Therefore the ULD release mechanism from the storage area into the workstations can affect the practical manpower utilization greatly.

This thesis integrates the optimization model for manpower scheduling and the simulation model of the air cargo operations to find the best ULD release mechanism in order to efficiently utilize manpower resources in practice while maintaining the customer service levels.

Keywords: air cargo terminal, personnel shift scheduling, simulation model, optimization model, manpower utilization.
Preface

This Master Thesis has been submitted to the Department of Management Engineering at the Technical University of Denmark by 2\textsuperscript{nd} of June 2008. It has been written by Nuria Rovirosa Ortoll (s060904) and supervised by Professor Martin Grunow, Aiying Rong and Peter Jacobsen at DTU Management department. The aim of this Master Thesis is to optimize the operations of the Spirit Air Cargo Terminal at Kastrup airport in Copenhagen by fully utilizing the manpower resources.

Nuria Rovirosa Ortoll

2\textsuperscript{nd} June 2008
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS/RS</td>
<td>Automated storage/retrieval system</td>
</tr>
<tr>
<td>CONWIP</td>
<td>Constant work in progress</td>
</tr>
<tr>
<td>DD</td>
<td>Dolly Dock</td>
</tr>
<tr>
<td>ETV</td>
<td>Elevating Transfer Vehicle</td>
</tr>
<tr>
<td>LRT</td>
<td>Latest Release Time</td>
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<tr>
<td>LPT</td>
<td>Lowest Processing Time</td>
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<tr>
<td>HPT</td>
<td>Highest Processing Time</td>
</tr>
<tr>
<td>EPT</td>
<td>Expected Production Time</td>
</tr>
<tr>
<td>FIFO</td>
<td>First In First Out</td>
</tr>
<tr>
<td>PA</td>
<td>Parcel availability</td>
</tr>
<tr>
<td>TD</td>
<td>Truck Dock</td>
</tr>
<tr>
<td>TT</td>
<td>Turn table</td>
</tr>
<tr>
<td>TTD</td>
<td>Time To Departure</td>
</tr>
<tr>
<td>ULD</td>
<td>Unit Load Device</td>
</tr>
<tr>
<td>WIP</td>
<td>Work in progress</td>
</tr>
<tr>
<td>WS</td>
<td>Work station</td>
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<tr>
<td>BNB</td>
<td>Builders not breaking</td>
</tr>
</tbody>
</table>
Table of Contents

1 Introduction and purpose ........................................................................................................ 10
   1.1 Introduction ....................................................................................................................... 10
   1.2 Purpose ............................................................................................................................... 11
2 Theoretical background ........................................................................................................... 14
   2.1 Air cargo handling .............................................................................................................. 14
   2.2 Optimization and Simulation ............................................................................................. 19
3 Spirit Air Cargo Handling ....................................................................................................... 25
   3.1 Air Cargo Facilities at Spirit ............................................................................................ 25
   3.2 Air cargo handling at Spirit ............................................................................................. 27
4 Optimization ........................................................................................................................... 30
   4.1 Optimization model ............................................................................................................. 30
   4.2 Model formulation .............................................................................................................. 32
5 Simulation ............................................................................................................................... 34
   5.1 Simulation Model ............................................................................................................... 34
   5.2 Output analysis ................................................................................................................... 38
   5.3 WS Release. Locations, mechanisms and policies ............................................................. 41
   5.4 Departure release ............................................................................................................... 51
6 Coordination between Simulation and Optimization models ................................................. 52
7 Simulations and results discussion ........................................................................................ 56
   7.1 Stage A. Choosing the most suitable Release Mechanism ................................................ 56
   7.2 Stage B. Selecting the release policies ............................................................................... 63
   7.3 Stage C. Accurate analysis of Policy B ............................................................................. 76
Simulation-Optimization feedback process .............................................................................. 89
   7.4 Stage 1. Optimization model 1b. Builders breaking validation ........................................ 89
   7.5 Stage 2. Optimization model 2. Arrival curve and capacities .......................................... 97
   7.6 Stage 3. Optimization model 3. Capacities ...................................................................... 107
   7.7 Stage 4. Release Policy B2 ............................................................................................. 109
   7.8 Stage 5. Release mechanism. PA depending on WIP level at WS .................................. 115
   7.9 Last stage. ULDs’ release at the Spirit Air Cargo terminal and leveling ......................... 120
8 Global conclusions .................................................................................................................. 124
9 Further work .......................................................................................................................... 126
10 Acknowledgments ................................................................................................................ 127
11 References ............................................................................................................................ 128
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Table of Figures</td>
<td>132</td>
</tr>
<tr>
<td>13</td>
<td>Table of Tables</td>
<td>134</td>
</tr>
<tr>
<td>14</td>
<td>Table of graphs</td>
<td>135</td>
</tr>
<tr>
<td>15</td>
<td>Appendix</td>
<td>i</td>
</tr>
<tr>
<td>15.1</td>
<td>Optimization model. Formulation and notation</td>
<td>i</td>
</tr>
<tr>
<td>15.2</td>
<td>Simulation Model</td>
<td>vi</td>
</tr>
<tr>
<td>15.3</td>
<td>A, B and C policies’ comparison (Simulations with WIP check)</td>
<td>xxvii</td>
</tr>
<tr>
<td>15.4</td>
<td>Stage C. Accurate analysis of Policy B (Simulations with WIP check)</td>
<td>xxix</td>
</tr>
<tr>
<td>15.5</td>
<td>Stage 2. Optimization model 2. Arrival curve and capacities</td>
<td>xxxi</td>
</tr>
<tr>
<td>15.6</td>
<td>Stage 3. Optimization model 3. Capacities</td>
<td>xxxiv</td>
</tr>
<tr>
<td>15.7</td>
<td>Stage 1. Optimization model 1b. Builders breaking validation</td>
<td>xxxvi</td>
</tr>
<tr>
<td>15.8</td>
<td>Stage 2. Optimization model 2. Arrival curve and capacities</td>
<td>xxxvii</td>
</tr>
<tr>
<td>15.9</td>
<td>Stage 3. Optimization model 3. Capacities</td>
<td>xxxviii</td>
</tr>
<tr>
<td>15.10</td>
<td>Last stage. ULDs’ release at the Spirit Air Cargo terminal leveling</td>
<td>xxxix</td>
</tr>
</tbody>
</table>
1 Introduction and purpose

1.1 Introduction

Airfreight is the fastest transport mode available today. The incredible speed of airplanes together with high frequency of flights scheduled around the world lead to very short travel times. Because of this, air transport has become one of the main modes of global transportation. Furthermore, air transport is no longer confined to rapid shipment or to fulfill emergent demands but to ship any kind of cargo at any time.

The air cargo industry has been growing greatly in the last years and this trend will continue in the future. Markets are therefore more competitive now than ever before.

This forces air cargo handling companies to make a big effort to plan operations and resources very carefully so that they can fulfill the customers’ increasing demands and quickly adapt to the changing environment. In order to maintain their competitive edge air cargo operators must provide lower processing times and higher handling capacities for a lower cost.

It is known that manpower costs of the terminal make up for the largest part of all operating costs. Efficient management of manpower resources can help air cargo terminals to improve the manpower utilization and reduce the operating costs accordingly while maintaining customer service levels.

The whole air transportation process does not depend highly on the flight time but on how efficiently the cargo is handled while it is on the ground. The freight handling takes place in the airport, at the air cargo terminals, which act as both warehouses and workstations.

The air cargo is usually carried in special containers called unit load devices (ULDs). ULD handling consists of two main operations: build-up and break-down. Build-up means consolidating of the loose cargo into ULDs while break-down means taking the cargo out of the ULDs. These operations are carried out by workers at workstations. Therefore, they are the most manpower intensive operations at the terminal.
Spirit Air Cargo Handling is the leading air cargo operator for Scandinavian Airline System (SAS). It serves about 1.000 SAS passenger and cargo flights to and from 100 destinations all over the world every day. It operates as a separate business unit within SAS cargo throughout its cargo terminals in Scandinavia. In Copenhagen airport, Kastrup, the main Spirit cargo terminal (Copenhagen Terminal North) is located next to the passenger terminals.

For manpower scheduling at the terminal, the optimization model for handling personnel scheduling has been formulated by [20]. The arrival rates of the inbound and outbound cargo vary significantly throughout the day. To utilize the manpower resources efficiently, this model implemented a new demand leveling mechanism. The solution of this model can provide high manpower utilization, well above 90% and 100% customer service levels meaning that no outgoing cargo missed flights and no incoming cargo was delivered to customers after the due day. Therefore, the manpower cost can be reduced greatly. An important and interesting subject in practice is how to realize this theoretical manpower utilization while maintaining the customer service levels.

1.2 Purpose

This Master Thesis aims at optimizing the operations of the Spirit Air Cargo Terminal at Kastrup airport in Copenhagen by fully utilizing manpower resources for cargo handling. More accurately, it integrates the optimization model for manpower scheduling and the simulation model of the air cargo operations to find the best ULD release mechanism in order to efficiently utilize manpower resources in practice while maintaining the customer service levels. The motivation for combining these two models is given below.

Many practical factors can be taken into account in the simulation models to make them suitable for studying operations of the air cargo and finding the best configuration of the terminal which leads to optimal performance. On the other hand, the models do not support the selection of a good solution, according to predefined criteria, from a large set of feasible activities. For instance, they are not able to generate workers’ schedules in terms of optimizing the manpower costs. This is the purpose of the optimization models.
In terms of optimization models, firstly, the aggregate demand of the outgoing and incoming cargo in the optimization model is measured in kilograms while in practice the outgoing cargo must be consolidated into individual ULDs by build workers and the incoming cargo must be taken out of ULDs by break workers at the workstations. Consequently, the ULD release mechanism from the storage area into the workstations can affect manpower utilization greatly. If the ULDs cannot be sent to workstations at the right time, the workers at workstations become idle. As a result, both manpower utilization and customer service levels decrease. Secondly, the optimization model does not consider the uncertainty in the handling of the cargo all the way from the landside to the airside or from the airside to the landside. Due to this uncertainty it is hard to obtain 100% customer service levels in practice. Thirdly, it is impractical to model the problem considering every practical detail. It would result in a far too complex mathematical model which is difficult to solve. Finally, some parameters in the optimization model are estimated values. For instance, the workers’ handling capacities. They affect the number of workers working in the workstations generated by the optimization model and the manpower utilization.

In some cases the practical problem can be solved running only the optimization model or only the simulation model. However, this is not the case for the problem addressed by this thesis.

In case the simulation model is run without the support of the optimization model, numerous combinations of workers’ schedules need to be enumerated by trial–and–error method in order to select the best one in terms of customer service levels and manpower utilization. This is impossible due to the fact that it is expensive to run the simulation model numerous times.

If the optimization model is run without the support of the simulation model, it is not possible to know whether the solution generated by the optimization model is a suitable schedule in practice. It is especially not possible to know how to realize the high theoretical manpower utilization and customer service levels in practice.

To sum up the above analysis it can be said that the solution generated by the optimization model can limit the configurations of worker schedules for the simulation model. Moreover the simulation model can be useful to find the best ULD release
mechanism by searching limited manpower configurations. Furthermore, the simulation model can introduce uncertainty and other environmental factors so that the workers’ schedules can be tested in a scenario similar to reality. The simulation model can also provide the basis for validating the optimization model and revising the parameters in the optimization model.

An important fact to remark is that the manpower utilization highly depends on the interaction between the workers’ schedules and the ULD release mechanism. Thus, this can only be achieved by combining the optimization model and the simulation model.

This thesis will coordinate optimization and simulation models in order to first, find the best release mechanism to fully utilize the while maintaining the customer service levels and second, to use the simulation model to provide the basis for validating the optimization model.

This thesis will evaluate different release mechanisms and policies based on the coordination between the simulation model and optimization model. On the one hand, this coordination will find the best release mechanism to fully utilize the manpower resources while maintaining the customer service levels. On the other hand, the simulation model will provide the basis for validating the optimization model.

The thesis is organized as follows. Section 2 describes the theoretical background. Section 3 introduces the existing situation of the Spirit Air Cargo Handling. Section 4 and 5 briefly present the optimization and the simulation model used in the project respectively. Section 6 presents the coordination between simulation and optimization models. Section 7 presents the simulation results and the improved optimization model based on the feedback from the simulation results. Section 8 is the conclusion. Besides, the Appendix contains the whole optimization and simulation models and the simulations results which have not been presented in the main report.
2 Theoretical background

2.1 Air cargo handling

2.1.1 Introduction

In the past, many airlines and airports neglected their air cargo operations and facilities due to their small contribution to revenue when compared with passenger traffic. Nowadays, air cargo industry is witnessing an impressive growth and its markets are more competitive now than ever before.

This makes the planning of the cargo operations at the terminal a complicated and challenging task to fulfill the increasing customer’s demands and quickly adapt to the changing environment. To maintain the competitive edge, the air cargo operator must provide higher speed and higher handling capacity with lower cost while maintaining customer service levels.

Air cargo business is different from passengers business. While passengers are able to find their own way and take care of themselves in most of the steps required to take a flight, cargo needs to be moved or processed by handling personnel at the terminal. Cargo is usually carried in the special containers called unit load devices (ULDs). The build-up and break-down of the unit load devices (ULDs) are the most manpower-intensive operations at air cargo terminal.

Combination of both passengers and cargo in the same aircraft is also a big issue that complicates handling activities even more. Passengers department and cargo division compete for a common limited flight capacity when the aircraft is used in combined carriage. Thus the coordination between them is required. When conflicting interests appear, priority is usually given to passengers’ luggage, meaning that cargo division has to deal with the uncertainty of how much space it will have until the departure time. Therefore, it has to be ready to reschedule departures and arrivals to fit them with passengers’ demand.
2.1.2 General operations

Airfreight is nowadays the fastest transport mode available, within 12 hours a shipment can practically move to the other side of the globe. The time the whole process takes does not depend that highly on the flight duration but on how efficient cargo is handled while it is on the ground. Since speed is usually required, efficiency is absolutely necessary when it comes to handle the freight before and after the flight.

Handling this freight to get it on time at any destination is a complex process which includes freight processing operations as well as its storage. This process takes place in the airport at air cargo terminals, which act as both warehouse and workstation.

Most of the cargo is carried in containers or ULDs. These containers might either be customized to fit only in a certain mode of aircraft or have standard dimensions that allow fitting them in most aircrafts. They are built in aluminum and polycarbonate, which provides them of endurance but also lightness.

An order consists of one or more ULDs with the same origin and destination specification. All the ULDs included in the order have to be shipped in the same flight.

Air cargo operations can be divided in two parts: transportation and handling. At the same time, transportation can be divided into incoming and outgoing. Incoming cargo consists of the arrival of ULDs from either landside, in trucks, or airside, in aircrafts to the terminal. Outgoing cargo can be done using the same transport modes and it consists of the ULDs departure from the terminal either to landside or airside. Also loose freight to fill the containers arrives at the terminal and parcels from unloaded ULDs leave it using several transportation models such as truck, van, and train.

For the transshipment cargo, when containers get to the terminal they are unloaded from the aircraft or track and they are then verified, traced, labeled and registered in the system. After this process, ULDs are then ready to be transshipped onto outgoing flights, without being built up or broken down, stored or released to be processed.
For the outgoing cargo, when it comes to ULDs that need to be stored a crane picks them up and takes them to the appropriate storage, depending on their load. In the storage, containers wait until enough parcels are available to fill them, then both the empty ULDs and loose cargo are from the storage into workstations.

For the incoming cargo, when ULDs get to the terminal they need be sent to WS in order to unload them. Afterwards, a crane picks them up and takes them to the empty ULDs storage. They wait there until they can be released from the storage into building workstations to be filled with new parcels.

Handling of ULDs consists of two main operations: build-up and break-down. Both operations are done in workstations where containers are sent directly from incoming docks or from storages by cranes and turn tables. When the ULD arrives at workstations, it may wait there until there are any workers available to work on it and then the breaking or building process is carried out.

Breaking consists in unloading some or all the current parcels from a ULD. After the parcels are unloaded, they may be stored and used to build other ULDs or sent them loose to customers. When the process is finished the empty container is ready to be sent to storage again, waiting to be sent to building workstations where it will be filled with new parcels and then sent to outgoing docks if is ready to be shipped.

Building process consist of filling the ULD with outgoing parcels. When all the parcels are already in the ULD it is sent to outgoing docks if departure time is close or it is sent to storage again. The process can not be completed until all the parcels are received. This means that sometimes ULDs will have to remain at workstations even though they are not being processed, just waiting for cargo to arrive.

The whole process is carried out depending on urgency of orders, availability of resources, including cranes, work stations and workers, availability of outgoing parcels and arrival and departure scheduled times.
2.1.3 **Proper resources’ scheduling**

Cargo handling is, as mentioned before, a complex process. Airfreight is usually chosen when an order needs to get to destination as soon as possible and speed is supposed to be its most important characteristic. Due to its nature, air cargo needs to be processed as fast as possible.

Dealing with urgent orders and rush hours requires a large quantity of resources. This means that there is a surge of manpower and equipment demand when a large number of flights are scheduled to depart or arrive within a short time interval. Therefore resources need to be carefully planned and manpower shifts need to be elaborately designed in order to cover all of the demand during peak hours.

When scheduling manpower resources, two main considerations need to be taken into account. Firstly, the arrival rates of the inbound and outbound cargo vary significantly throughout the days. Secondly, workers’ shifts need to cover the highly irregular demand with the minimum cost.

It is difficult to schedule a regular workforce that meets the highly irregular demand with minimum cost. Therefore, in peak hours there might be manpower shortages while workers are idle in peak-off hours, meaning that regular work shifts will never meet unbalanced workload distribution if demand is not leveled. Therefore, it is important not only to find a proper schedule for workers based on suitable demand leveling mechanism but also to coordinate the work schedule with a ULD release mechanism that allows balancing the workload along the time. A proper ULD release mechanism plays an important role in realizing the balanced work schedules.

*Planning operations*

Managing an air cargo terminal encounters dealing with several problems with different horizon times. Long term problems need to be solved first and the solution is used as the input for mid-term ones. Then solution of mid-term one is used in the study of short term problems [6].
Long-term problems for managing an air cargo terminal concern mainly the container storage policy. This includes a job-shop problem to determine the yard configuration that optimizes the loading and unloading operations of ULDs. Different yard configurations need to be tested and compared to the original one in order to choose the one that performs better results with a lower deviation to original storage policy when different scenarios are taken into account. This problem is only needed to solve for new terminals. For an operating terminal, this problem is supposed to be previously solved.

Mid-term optimization problem refers to resources allocation. This problem has a time horizon of a few shifts and deals with a function that depends on costs of resource usage, incoming and outgoing flights and tracks and distribution of operations.

Short-term optimization problem is concerned with schedules to load and unload ULDs. It assumes that a complete knowledge of the terminal status at any given time is known. This part decides how to release ULDs from storage or docks to workstations for building and breaking operations.

**Scheduling problem**

Probably, one of the biggest challenges for managing an air cargo terminal is scheduling freight handling workers. Schedule needs to cover the demand at any time while minimizing the cost.

This scheduling problem is traditionally broken down into two sub-problems [15]. The first one is about determining manpower requirements for every period during the planning period. This has to be done for every job type, build and break, existing in the terminal. To make this schedule, data about the demand for arrivals and departures or historical data is required and workers capacity needs to be calculated. This is not an easy task because freight handling performance might vary according to shipments characteristics, workers skills, working method and terminal configuration. Usually an average obtained from historical data is taken as a reference and then a variation is added to the average depending on specific scenarios.

In order to determine manpower requirements, some leveling mechanism needs to be considered. Demand leveling means allowing the cargo to be handled over a time
interval of a few hours so that the manpower requirements can be leveled while no
demand leveling means that the cargo is handled within one period and manpower
supplies must satisfy the peak cargo demand. If worker scheduling is created without
taking into account any leveling policy for the demand, it will probably lead to inefficient
shifts, meaning that workers will be overloaded during peak-hours and underutilized or
even idle in peak-off hours. The more leveled the demand, the better workers’ utilization
of workers is. Consequently, the lower cost can be achieved.

The second sub-problem consists of designing workers shifts. These shifts have to
meet the requirements calculated in the previous sub-problem and satisfy all the rules,
regulations and constraints that might exist depending on the geographical, political and
company frame.

For planning terminal operations and scheduling manpower resources, simulation
and mathematical optimization techniques are generally used [10, 15, 16, 26, 27]. In the
following section, a brief review of these techniques is presented.

2.2 Optimization and Simulation

2.2.1 Optimization

The term optimization refers to the study of problems in which the main objective
is to minimize or maximize a real function by systematically choosing the values of real or
integer variables from within an allowed set [28].

Techniques for optimization vary a lot depending on the characteristics of the
problem. One of the most important distinguishing factors is the decision variables type,
the second factor is the objective functions type and the third is the constraints type.

Decision variables can be continuous (real) and discrete (integer). The objective
function can be linear and non-linear. Based on types of objective function and types of
constraints, the optimizations can be classified into Non-linear programming (NLP) and
Linear programming (LP) based models. NLP model studies the general case in which the
objective function, the constraints or both contain nonlinear parts. LP based model
studies the case in which both objective function and constraints are linear.
Generally NLP, models are much more difficult to solve than LP models. In the case of LP based models, they can further be classified into continuous models, pure integer problems and mixed integer problems based on the types of decision variables. The solution methods for the problems with continuous and discrete variables differ greatly. In the following discussion, the optimization models are referred to LP based models which can be solved by standard commercial softwares.

A solution to an optimization problem is the set of values given to the decision variables. In continuous problems, solution consists of a set of real values. In pure integer problems the solution consists of a set of integer values and in mixed integer problems the solution consists of both integer and real values. A special case of integer problem is the Boolean called one, where variables can only take two values: zero and one.

How difficult to find a solution for the problem depends on the variables type. Solving a problem containing integer variables is much more difficult than solving a problem with continuous variables. In the case of large scale integer programming (including mixed integer programming), it is difficult to obtain the satisfactory solution within acceptable time limits. In practice, when the problems are formulated, only the major characteristics of them can be reflected in the model in order to reduce its complexity and thus increase its solvability.

Optimization models can quickly provide a theoretical solution for many problems if they are solvable. On the other hand, many real world problems are too complex to be modeled mathematically if practical factors are considered. Consequently, the model is not able to provide an acceptable solution. This is why, in some situations, simulation techniques can provide satisfactory solution especially when such factors as uncertainty and variability are not considered in the optimization.

2.2.2 Simulation

Simulation has lately been largely discussed in several papers and has become a very useful tool for companies to make their decisions. Simulation allows evaluating the impact that new processes or changes on them have in an organization through the creation of different “what if” scenarios [1]. It enables to test and examine decisions
before they are taken in real environment, which will probably make the organization save money and avoid making some mistakes.

Simulation permits the inclusion of uncertainty and variability into forecasts of process performances due to the fact that it approximates reality [1].

When a mathematical model of a system is studied using simulation it is called simulation model. The model is run for a fixed period of time to evaluate the system behavior when different input variables are introduced. A test or series of test where meaningful changes are made to the input variables in order to observe and identify the changes in the output variables, called responses, is a simulation experiment [7]. The input parameters and structural assumptions done when building the model are called factors [2].

Computer simulation is a powerful tool in evaluating complex systems but when the number of input variables is too large and the model becomes too complex, experiments may become computationally prohibitive. Cost and time spent on them are too long and the tool is not useful anymore. Then, simulation optimization models are required.

2.2.3 Simulation optimization

Simulation optimization has been defined in several ways. Some definitions are given below.

“Process of finding the best input variable values from among all possibilities without explicitly evaluating each possibility. Its objective is to minimize the resources spent while maximizing the information obtained in simulation experiment.” [7].

“Process of finding the best values of some decision variables for a system where the performance is evaluated based on the output of a simulation model of this system.” [18].

The need for an optimization simulation model comes when an analyst wants to find the set of model specifications, such as input parameters and/or structural
assumptions that lead to the optimal performance. The number of parameters’ values and their combinations may be too large to simulate them all. As a consequence, a way to guide the search for good solutions is needed.

Since pure optimization models are not capable of taking into account all the complexities and dynamics of a certain system and simulation cannot easily find the best solutions, then, simulation optimization resolves the conundrum by combining both methods.

Dealing with the simulation, the input parameter and structural assumptions are called factors and the output performance measures, responses. For the optimization, the factors become decision variables and the responses are used to model the objective function and constraints. Figure 2.1 shows the simulation optimization model.

![Simulation Optimization Model](image_url)

The optimization looks for those factors that minimize or maximize the response and the simulation works on finding which factors have a greater effect on the response.

In the context of business, simulation is a way to understand and communicate uncertainty related to changes made in a model or in the environment and optimization is the way to manage that uncertainty [1].

Until a few years ago, experts on simulation were reluctant to use optimization tools. They thought that optimization oversimplified real problems and even tough it gave the optimal solution, it was not clear why it was the best one. Nowadays, the merging of optimization and simulation is experiencing a remarkable growth and it is regarded as the best way to test strategies and changes in companies with better results and lower cost.

The simulation models can take many practical factors into account but they do not support the selection of one or a few solutions that are good in terms of predefined criteria from a large set of feasible activities. This is the purpose of the optimization
models. Simulation and optimization models can be combined to make up for the shortcomings of each other (Figure 2.1).

2.2.4 Simulation optimization in this study case

This Master Thesis works with a simulation model and an optimization model which work separately based on the same concept of simulation optimization model. The simulation model takes into account the uncertainty and variability which approximates the real world and the optimization model guides the search for good solutions. They were used together as to make up for their weaknesses. Figure 2.2 illustrates the coordination between the simulation model and optimization model in this project.

The optimization model provides the workers’ schedule to the simulation model. The simulation model provides results which give information in order to revise the parameters in the optimization model.

![Figure 2.2 Illustration of the coordination between the simulation model and optimization model in this project.](image)

For planning the air cargo operation, a simulation model [11] was developed to represent the process at the terminal. The model captures the random nature of the freight behavior at the terminal within a robust framework. This allows different policies’ analysis with the aim of finding the best configuration according to some performance measures. Random nature of the freight behavior includes unexpected issues such as delays and breakdowns or issues of the system itself which can cause wastes of time such as bottlenecks, system blockings, crane priorities and queues.

When the processes are complex, as the one in the Spirit Air Cargo terminal, the configuration depends on a number of strategic choices such as the most suitable release mechanism or the best workers’ schedule to fully utilize the resources. Finding the best
configuration by time-consuming trial-and-error methods, by only running simulation model, would certainly have no success. In these cases, it is wise to combine the optimization model for guiding the search for the best configuration.

Based on the handling capacities of the build and break workers, on the demands of incoming and outgoing cargo and on an effective demand leveling mechanism, an optimization model [20] for personnel shift schedules was formulated. The solution of the model can provide high manpower utilization (well above 90%) and 100% customer service levels (no delayed cargo). Of course, this solution is ideal because it is impossible to reach 100% customer service levels in practice due to some disturbances. Consequently, the schedules generated by the optimization model need to be validated before it is put into practice. However, it can provide rough guides for the simulation model in order to search for further improvement in a realistic environment.

The optimization model differs from reality mainly in that the aggregate demand for the outgoing and incoming air cargo is measured in kilograms while in practice the outgoing cargo must be consolidated into individual ULDs by build workers and the incoming cargo must be unloaded from ULDs by break workers at the workstations. Therefore the ULD release mechanism from the ULD storage into the workstations can affect the practical manpower utilization greatly.

This thesis integrates the simulation model and optimization model (Figure 2.2) to find the best release mechanism for the ULDs to approximate the theoretical manpower utilization and thus reduce manpower cost.

The existing situation of the Spirit Air Cargo terminal is introduced on the next section, which is the basis for both the optimization model and the simulation model. The optimization model for handling personnel scheduling and simulation model for cargo terminal operations will be presented individually throughout the following sections.
3 Spirit Air Cargo Handling

Spirit Air Cargo Handling is the leading air cargo career to, from and within Scandinavia. It is member of WOW, an alliance that consists in Spirit, Lufthansa Cargo, the world’s biggest international airfreight career, Singapore airlines Cargo, the second largest, and Japan Airlines Cargo.

Spirit deals with about 1.000 SAS passengers and over 100 destinations worldwide every day and serves more than 30 airlines.

3.1 Air Cargo Facilities at Spirit

Late in 1998, a new Cargo facility was inaugurated in Kastrup Copenhagen Airport. This facility, belonging to Spirit Air Cargo, cost about $ 85 million to SAS Cargo and was designed to deal with 350.000 tones of cargo annually. The Spirit terminal is located right next to the passenger terminal, which gives certain advantages of coordinating passenger transportation with cargo transportation.

The facility consists of a multi-level building totally automated by the Production and Logistics System Group of Siemens AG, which allows the terminal to deal not only with general goods but also with temperature controlled, radioactive and high value cargo.

The center of the terminal is the integral control system, a series of net-worked computers connected to a host computer. All data from incoming and outgoing freight is sent from the lower level computer to the host, which controls the cargo flow. Data is collected trough bar labels assigned to every shipment when it gets to the terminal.

The terminal is provided with more than a dozen dolly docks (DD) for incoming and outgoing cargo designed to load and unload cargo from the aircrafts. Cargo from Denmark is arriving at the terminal by truck. There are six truck docks (TD) where there is an elevating transfer vehicle (ETV) to move the ULDs from the TD to the fast lane. The fast lane consists of two conveyers going to and from the ETV at the TDs to the ETV in the ULD storage.
The four levels storage uses a completely automated storage and retrieval system (AS/RS) which has 1,560 positions for Euro-pallets and also positions for loose freight and ULDs and can handle 204 operations per hour.

Automated storage/retrieval systems (AS/RS) are broadly used in warehousing. A typical AS/RS is an automated warehousing system that comprises one or multiple parallel aisles with rack openings on both sides of the aisles. A Storage/Retrieval (S/R) machine or crane in an AS/RS serves one or several aisles by carrying all the storage and retrieval orders. The crane can travel horizontally and vertically simultaneously. At air cargo terminals, AS/RS are also key storage elements to deal with cargo handling operations. Loaded containers are held here until it is time for the designated flight. The containers are automatically extracted from the storage location and moved to the DD and onto the airplane. Also empty ULDs are stored here until they are needed.

The facility has three main lines, each consisting of 10 workstations, where ULDs are manually built up and broken down. The first line is for breaking processes, the second one for both breaking and building processes and the third one only for building
processes. In addition, there are two larger workstations, numbers 31 and 32, to handle 20 feet ULDs. Workstations are lift tables able to move about two feet in order to accommodate it to the best working level as load grow and can hold 19,000 tones of freight each.

Work stations are connected to the rest of the terminal with driverless transfer vehicles (TV) that move the load to the ETV crane pickup and drop positions, which are three turntables. The turntables are served by two ETVs that have 404 positions on four levels to store ULDs. It takes about 65 seconds to move the load from the workstation to the ETV.

3.2 Air cargo handling at Spirit

The arrival and service rates vary throughout the day and the terminal systems should be capable of dealing with the uneven elements in the flow process.

![Figure 3.2 Main processes involved in air cargo handling when it comes to build ULDs from booking to take-off [23]](image)

Spirit’s first contact with a shipment occurs when the agent books the shipment, normally 24 to 36 hours before the planned departure. If there is space on the required flight, the agent gets a booking confirmation with LAT (Latest Acceptance Time) and TOA (Time Of Availability); i.e. when the shipment has to be delivered to the handling company at the origin airport and when it can be picked up at the destination airport. If the flight is full, the agent is provided with alternative routing options.

As the Latest Acceptance Time approaches, the agent delivers the shipment to the airport. Spirit then makes an acceptance check and the shipment proceeds to a security check where (normally) a random 5% of the cargo is scanned. Then ULDs, loose freight and euro pallets are immediately labeled and information is sent to the host; loose freight and euro pallets are then assigned to a specific ULD. When the trucks are unloaded, the ULDs go via the fast track to either the ULD storage or to one of the turntables and from there a workstation to be broken down or built up. Those that are sent to storage wait
there until the host decides that is the time for them to be processed. If a ULD arrives fully pre built it goes to storage until the Dolly Dock opening time, which is 3 hours before the flight leaves. The finished ULD leaves from one of the 14 dolly docks (DD).

Where to send a shipment depends on the planning department, which decides which pallet each shipment is to be placed on and where each pallet will be placed in the aircraft. A determining factor is the flight planning data, for example, how many passengers are expected or the projected weather conditions. All these variables combine to create an exact specification of how much cargo can be put on the flight.

Work stations deal with ULDs that need to be broken down or built up. Those that are built up are loaded with the freight coming from other ULD that have been broken down, freight that was stored and freight coming directly from incoming dolly docks.

When the manual process is completed, ULDs are sent back to AS/RS, if it is not time to ship them yet. If it is the time to ship them, they will be sent to outgoing dolly docks where they will be loaded onto an aircraft. Approximately one hour before take-off, the cargo is transported to the aircraft, where loading is performed under the supervision of Spirit. For the loose freight, it is sent also to AS/RS or to outgoing truck docks where trucks or tractors will pick it up.

In the terminal there are two main kinds of workers: breakers and builders. The first ones can only break down a ULD and the second ones can both build up and break down. This is do to the fact that building process is considered to be more complicated than breaking one, so builders need to be more qualified than breakers, meaning that builders are capable of breaking but breakers are not trained to build. Only one or two workers can work in a workstation at a time due to room restrictions.

As described above, an extensive planning and a number of critical handling functions are performed in the terminal. It is a demanding task building the ULDs, choosing the most suitable ULD type depending on the cargo type and the aircraft type. The last one can have different weight and volume capacities, but its maximum capacity can vary, depending on the routing, number of passengers, turn-around time and current weather.
3.2.1 **Known Bottlenecks**

The ETVs by the ULD storage (ET02 and ET03) can not pass each other, so it is only ET02 that can serve the fast track. This ETV can be a bottleneck according to Spirit and this can be a problem especially during breakdowns. If ET02 breaks down nothing can be transported to and from the TDs.

In the ULD storage, there are cooler storage for six ULDs and freezer storage for two ULDs. This limited storage can become a problem during the weekends.

3.2.2 **Breakdowns**

There are two types of breakdowns; human errors and mechanical breakdowns. The most common human error is ‘man in a forklift’, which actually was seen during the first visit to the terminal. Both the TVs and the ETVs have photocells so they stop if something is in the way. Usually the system stops 10-20 times a day because of wrapping plastic that hangs out and blocks the photocells.
4 Optimization

The optimization model in the present report is mainly focusing on scheduling personnel shifts for workers assigned to build-up and break-down activities in order to allocate the manpower resources efficiently to cover demanded costumer service level and to achieve cost reductions in this area.

Rong and Grunow (2007) formulated this problem as an integrated mixed integer programming (MIP) model for determining manpower requirement and personnel shifts simultaneously to minimize the manpower costs over the planning horizon. In the model a new mechanism for demand leveling is applied to improve manpower utilization.

The above mentioned mathematical model is the one used to get the optimal workers’ schedule in the present project and it is presented in the following section.

4.1 Optimization model

In the mentioned paper, the problem of scheduling freight handling employees at airport terminals is divided into two parts for a single integrated model. The first one consists in determining the manpower requirements based on the kilograms that need to be built up or broken down in the terminal every hour. The second one is to design efficient work schedules to cover the customer’s demand. The model is able to determine simultaneously the build-up and break-down quantities, the manpower requirements in each period as well as the shifts schedules for employed persons.

The model aims at matching the manpower supplies with actual manpower requirements as close as possible in order to avoid, or at least reduce, the surplus manpower in the terminal by introducing a new demand leveling mechanism.

Since the incoming and outgoing cargo varies significantly from hour to hour during the day, it is necessary to implement the leveling mechanism in the model in order to achieve efficient manpower utilization. This leveling mechanism allows the cargo to be handled over a time interval of a few hours. In this way, the manpower requirement can also be leveled. Note that no demand leveling means that the cargo is handled only within
the demand period meaning that manpower supplies must satisfy the peak cargo demand and consequently they will be underutilized during peak-off hours.

In the optimization model, the demand is leveled according to the arrival pattern of the outbound cargo. It means that the build-up process for the outgoing cargo is driven by the Parcel Availability Curve (Graph 4.1). The due time of the inbound cargo is used for spreading the break down activities over the time interval. It means that the break-down process is driven by the due time when the inbound cargo must be ready for the customers.

![Parcel availability curve](image)

Graph 4.1 Parcel Availability curve for the outbound cargo defined for the optimization model

*Graph 4.1* illustrates the arrival pattern of loose parcels. The cargo is expected to be loaded onto the aircraft when it begins to arrive at the terminal six periods before the scheduled departure. The curve represents the percentage of the total cargo demand for the flights departing at the end of period six which is available at the terminal in each period.

A lot of the literature about workers’ schedule mentioned that flexible management in shift scheduling is a good strategy. This model also considers the flexible shifts. However, the flexible shifts cannot get much benefit [20] if the demand leveling mechanism is introduced. Consequently, fixed shift schedule without overlap is used in this project.
Shifts without overlap are those where there are no overlap hours between the shifts, the next one start when the previous is finished meaning that when the starting time for any shift is fixed the starting time of the remaining shifts can be determined automatically. The model considers the cyclic nature of weekly planning problem which includes the repetition of the shifts starting times from day to day.

The terminal can employ full-time and part-time workers, which work in shifts of different lengths. The maximum number of shifts in each day for full and part time workers is different.

The model introduces the qualification hierarchy between build-up and break-down workers and thus introduces the coordination between build-up and break-down activities. Builders can handle both built-up and break-down operations while breakers can only handle break-down.

### 4.2 Model formulation

The optimization model is solved using ILOG CPLEX software based on the real cargo demand data and handling capacity of break and build workers provided by Spirit Air cargo Handling.

In order to deal with the scheduling problem, six days of the week were chosen as planning horizon due to the fact the available real data used for simulations and tests concerns six days only. The planning period starts on Monday 00:00 and lasts until Saturday 23:59 (144 periods, 1 period = 1 hour).

In the model, it was assumed that build-up process of outgoing cargo can begin six hours before the scheduled departure time based on cargo arrival curve (Graph 4.1) and the break-down process of the incoming cargo is spread over 4 hours. The maximum ratio between part and full-time workers is 0.25.

In order to generate the initial workers’ schedules for the simulation model, the handling capacity of the build workers was set to 927 kg/hour and the break workers one, to 954 Kg/hour. These values were estimated based on the average time of building up and breaking down 10 different ULDs’ types. A maximum of 2 workers can be assigned to
one workstation so the maximum number of workers able to work at the same time was set to 60 (30 stations ×2 workers/station).

In terms of manpower cost, it was assumed that the breakers’ cost is 80% of the builders’ one and the cost of the daytime shift is 80% of the nightshift. No difference between the cost of part-time workers and the full-time workers was considered. Full time workers work in 8-hour shift and part-time workers in 4-hour shift.

The full model is given in *Appendix 15.1*. 

5 Simulation

The simulation work in the present report is used not only to verify the suitability of the shift schedules created by the optimization model, but also to find the best ULD release mechanism in order to efficiently utilize manpower resources in practice while maintaining the customer service levels. This can be done due to the fact that the simulation makes possible to introduce uncertainty and other environmental factors, so shifts schedules can be tested in a scenario very similar to reality. The simulation model can also provide the basis for validating the optimization model and revising its parameters, so that it can provide better personnel shift schedules.

The simulation model used in the present Mater Thesis is based on an already existing simulation model which was used in the previous project “Simulation and analyzing of freight handling activities and personnel shifts at Spirit Air Cargo Handling in Copenhagen” carried out by student from DTU Management Department in DTU [11]. Moreover, this simulation model was further modified and improved.

5.1 Simulation Model

The simulation software used to build the simulation model is PRO-MODEL 4.2, which is discrete event simulation software, used for planning, designing and evaluating warehouses, logistics and other operational and strategic situations.

5.1.1 Simulation model build-up

The aim of this section is to give a very basic description of the simulation model in order to enable the reader to understand the simulation work carried out in this project. The whole and detailed description of the simulation model used in this Master Thesis is given on the Appendix 15.2.

Locations in ProModel can be physical or just for simulation purposes. Routing is the definition of the different ways an entity can move in the model. Processing is done when an entity enters a location and it is processed by a resource.
The following Figure 5.1 shows the main locations in the simulation model.

![Figure 5.1 Overview of the simulation model](image)

The landside arrival area consists of the **Truck arrival & Departure (1)** where the ULDs get into the terminal or out of the terminal, the **Conveyor (2)** which moves the ULDs from air- to landside and vice versa depending on the ULD destination and the **USIN airside (3)** where a routing process needs to be carried out in order to send the ULD to the right location into the terminal. The routing carried out at USINairside will be explained on *Section 5.3*.

The airside arrival area consists of the **Airside arrival & Departing (4)** where the ULDs are get into the terminal or out of the terminal, the **Dolly Dock outgoing (5) (DDoutgoing)** where the ULDs are delivered out to the airplanes and the **Dolly Docks incoming (5) (DDincoming)** where the ULDs are delivered into the terminal and a routing process needs to be carried out in order to sent the ULD to the right location into the terminal. The routing carried out at DDincoming will be explained on *Section 5.3*.

The workers area consists of the **Meeting point for Breakers (6)** and the **Meeting point for Builders (7)**. The workers are waiting there until they find work to do in the workstations. Since builders also have the ability to break, they are looking for breaking
work to do too if there’s currently no build activity that needs to be done. The logic that determines on which ULD has to work a worker can be found on the Appendix 15.2.2.

There are three main storages in the terminal: **Euro Pallet Store (8)**, **Any ULD storage (9)** for partly or totally built ULDs and **Empty ULD storage (10)** for empty ULDs. The processing and routing carried out in the storages will be explained on Section 5.3.

The working area is composed of **Turn Tables (TT) (11)** which is the link between the WS lines and the crane that takes the ULDs to the storages (capacity for 1 ULD) and **Workstations (WS) (12)** which are divided into three workstation three lines: 1 for break, 2 for build (workstations 11-15) and break (workstations 16-20) and 3 for build.

The **entities** in this simulation model are the **ULDs**. They are shipped to, from and within the terminal.

The **resources** are the items moving the entities around the terminal in the simulation. They can be the equipment or personnel. The main equipment used in the model is **cranes** and **forklifts**. The personnel are **Breaker** who breaks down ULDs and **Builder** who is able to both break down and build up ULDs. The model has been designed so that there can never be more than two workers on the same WS at the same time.

The remaining elements of the simulation model can be found on the Appendix 15.2

### 5.1.2 Input data

An excel file called “order sequencing test.xls”, which includes the input data to import to ProModel was created.

The sheet **Order Schedule** contains all the ULD’s input data and it has been constructed based on several data sources which can be found in the Appendix 15.2.2.

Columns B and C in **Figure 5.2**, orders are groups of ULDs with the same departure time, due to the fact that they belong to the same flight. The figure also shows which
percentage of freight a single ULD means for the order, the cumulative Kg per each order and the initial and target load for each ULD.

<table>
<thead>
<tr>
<th>#</th>
<th>Order</th>
<th>Sequence</th>
<th>Origin</th>
<th>Time of arrival</th>
<th>Destination</th>
<th>Time of departure</th>
<th>Cumulative Kg per order</th>
<th>% of total order</th>
<th>Initial ULD load</th>
<th>Target ULD load</th>
<th>Build/break</th>
<th>Total order load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>800</td>
<td>478</td>
<td>200</td>
<td>0</td>
<td>178</td>
<td>3</td>
<td>203</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>6400</td>
<td>188</td>
<td>44</td>
<td>0</td>
<td>188</td>
<td>3</td>
<td>203</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>6400</td>
<td>399</td>
<td>80</td>
<td>0</td>
<td>251</td>
<td>3</td>
<td>433</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>6100</td>
<td>3</td>
<td>6100</td>
<td>428</td>
<td>100</td>
<td>0</td>
<td>84</td>
<td>0</td>
<td>423</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>479</td>
<td>167</td>
<td>100</td>
<td>0</td>
<td>170</td>
<td>3</td>
<td>170</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>5000</td>
<td>249</td>
<td>57</td>
<td>0</td>
<td>1454</td>
<td>3</td>
<td>1598</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>4040</td>
<td>3</td>
<td>5000</td>
<td>2598</td>
<td>100</td>
<td>0</td>
<td>1113</td>
<td>0</td>
<td>2698</td>
</tr>
</tbody>
</table>

Figure 5.2 Data used as an order schedule in the simulation model.

The sheet **Number of workers** contains the number of builders and breakers per hour over the whole simulation period. It is used as an input in order to analyze Conwip theory (See Section 5.3), where the number of workers every hour is required to make calculations.

All the workers’ individual **Shift files** are defined in ProModels Shift Editor to make builders and breakers work according to shift plans provided by the optimization model. Shifts for full-time workers are 8 hours long with a break of 30 minutes and the ones of part-time workers are 4 hours long with a break of 15 minutes. The breaks are spread out along the shifts in order to avoid all the workers to have breaks at the same time.

A detailed explanation of the input data can be found on the Appendix 15.2

### 5.1.3 Output data

Figure 5.3 Sheet of "order sequencing test" excel file where all the results are summarized.
Figure 5.3 shows the sheet Results which summarizes all the desired outputs of each simulation. An explanation of all the results is given on the following section according to the key numbers (in red in the sheet).

5.2 Output analysis

Several outputs from the simulations are analyzed in order to verify how good the applied workers shifts are and release mechanisms. Moreover, future improvements in both the simulation and the optimization model can be decided.

The simulation results are presented on the previous Figure 5.3. The analyzed factors for each simulation are presented in the following paragraphs. Further information about output data can be found on the Appendix 15.2.

- ULDs on time (1)

Gives information about which percentage of departing flights and trucks get all their ULDs on time. The higher this percentage is the best service the company is offering to customers, so it can be used for companies to as an index of how sure they can be to get their freight on time when it is handled in the terminal.

- Built / Broken Kg (4)

The terminal is supposed to break a fixed amount of kg from incoming ULDs and to build a fixed amount of Kg for outgoing ULDs.

Built and broken Kg gives the percentage of the total kg that were to be built or broken in the terminal are processed on time, meaning the ULDs get the trucks or aircrafts on time. Note that it was assumed in the Simulation model the fact that the percentage of kg which is not processed on time will never be processed.

This information is complementary to the % of ULDs on time, because it allows knowing not only how many orders are properly processed but how big the ones that the terminal is not able to handle are. For example, if two simulations are compared, even if the percentage of ULDs on time is the same for both of them, it could be possible that the
kilograms built or broken are very different. The one with the more kg missed has bigger ULDs missing the flights. Consequently, the workers’ utilization will also decrease.

- **Builders’ and breakers’ utilization (6)**

Builders’ and breakers’ utilization is the percentage of time that the workers are working on a ULD. It is calculated as an average of the number of kg workers can handle each hour (handling capacity) and the kilograms built and broken that hour. It is also taken into account when builders have extra capacity, meaning that the one which is not used for building up processes is used to do breaking operations.

In order to do an accurate calculation of the workers’ utilization, the value of workers’ handling capacity set in the simulation model cannot be used do to the fact that it does not include workers’ breaks, which are already included in the simulation model. Consequently, workers’ handling capacity was reduced one sixteenth, which is the fraction of time workers have to take a break in every shift. Note that this change only affect to this calculation How calculations were done can be seen on Figure 5.4 and results are presented on Table 5.1.

\[
\text{New capacity} = \text{Old capacity} \times \frac{15}{16}
\]

Figure 5.4 Equation showing how calculations of the new capacity were done

<table>
<thead>
<tr>
<th></th>
<th>Old capacity</th>
<th>New Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Builders</td>
<td>927 Kg/h</td>
<td>869,06 Kg/h</td>
</tr>
<tr>
<td>Breakers</td>
<td>954 Kg/h</td>
<td>894,38 Kg/h</td>
</tr>
</tbody>
</table>

Table 5.1 New builders and breakers capacities used to make the workers’ utilization calculations

The percentage of time workers are moving across the terminal, taking a break or idle waiting for some work to be done are also measured. In this way, it is pretended to see how good manpower resources are profited and get as much information as possible in order to find out the causes why workers are not fully used.

- **WS occupation (8 & 9)**

In this case occupation of building and breaking WS is measured. In order to do that some percentages of time are calculated: time with no ULD at WS, time with a ULD
but no worker processing it and time with one and two workers building or breaking the container.

This information is obtained to understand in a better way how ULD are processed when they are in WS and see if the possible delays of ULDs are due to lack of WS or if a some other policies could be found to profit them more.

- **Building and breaking duration (5)**

  Most ULDs have to be broken, built or both. It is important to know how long building and breaking processes take so that policies can be changed in order to start processing the containers enough time before their departing time to get them all on time. It can be verified also if the building and breaking duration set in the optimization model is the proper one.

  Two different building and breaking durations are calculated:

  - Amount of time that a ULD spends on a WS, since it gets into it until it leaves it.
  - Total duration of the processes, since the ULD is ready to be released to WS until it gets back to storages or to DD after being processed.

  Matching both durations it is possible to know how much of the total duration time is due to processing and how much is due to transportations and waits.

- **Waiting time for the crane (2)**

  Cranes were assumed to be the bottleneck of the system; this is why it is important to know how much time a ULD has to wait for it as an average and how much this time means for the total process duration. Note that this measurement it does not only include the wait but also the transportation time that the ULD spends on the crane.

  Two different waiting times for the crane are calculated:

  - Wait for the crane from storages to WS. This time is the time since the ULD is ready to be sent to WS, so that it is the first on its location in the queue
to be picked up by the crane, until it gets to the TT that will transfer it to the WS.

- Wait for the crane from WS to storages or DD. Once the ULD has been processed it has to be sent either to storages or to outgoing DD. This second wait for the crane measures how long it takes for the container to reach that location from the TT, which has transferred the container from WS.

- **Number and duration of blockings (7)**

  It can happen that a ULD is ready and already queuing to be sent to a WS but it cannot be sent because there are no WS available; this is called blocking.

  Three different measurements, for both building and breaking processes, are done about this issue:

  - Number of blockings for ULDs coming from storages.
  - Number of blockings for ULDs coming from Usinair or DD incoming.
  - Average duration of blockings for ULDs coming from storages. This gives information of how long containers have to wait until there is WS available for them.

Since the general aim of this project is to optimize the Spirit Air Cargo Terminal, the percentage of ULDs on time and the percentage of built Kg or broken are the parameters to be optimized. However, the rest of the outputs from simulations is necessary to find out the causes why one release mechanism is better than the other, why the simulation model does not perform results as good as the optimization ones and which parameters should be changed in ILOG so that it includes uncertainty and irregularity.

### 5.3 WS Release. Locations, mechanisms and policies

The WS release is the interface between the control of the material flow through the entire logistic chain and the control of the production units. This addresses the fundamental question of when initiate the building or breaking operation for a ULD.
5.3.1 Release locations

There are four different locations from where a ULD can be sent to the WS. They are *UsinAirside*, *DDoutgoing*, where the ULD arrives from the landside or airside, respectively, and *AnyULDstorage* and *EmptyULDstorage*, where the ULD is in the storages. All these locations are shown in yellow in *Figure 5.1*.

5.3.2 Release mechanisms

Release mechanism refers to the logic that determines whether and when a ULD should be sent to the WS for operation or to the DD for departure.

Four different release mechanisms which determine when a ULD is suitable to be released to the WS were designed in the existing simulation model [11]. These release mechanisms do only affect the building operations. ULDs that need to be broken are ready to be sent to the WS as soon as they arrive to the release location, except for the Conwip Release Mechanism (explained on Section 5.3), which could affect both building and breaking operations. Note that these mechanisms can work isolated as well as combined.

When the ULD is ready to be sent to the WS according to the release mechanisms, the number of available WS to place a ULD is always checked. If there is no WS available, the ULD has to wait until there is one.

It needs to be mentioned that the simulation model does not check the workers availability (if there is any worker who is currently idle). It has been considered better for the system the ULD to wait in a WS rather than in the storage, where it might collapse other ULD, and in this way freeing the crane as soon as possible.

In order to understand how these release mechanisms work, a variable called “FACTOR” needs to be introduced. Factors are set to different values in order to be able to analyze how the results can vary depending on how restrictive release mechanisms are.
The four release mechanisms in the existing simulation model [11] are:

- **Parcel availability**

  The building process of a ULD can only take place if the parcels that need to be loaded are currently available. Parcel availability curve describes how many of an order’s parcels have arrived at given point prior to departure. Note that Parcel availability is measured for an entire order and not for a single ULD. See Section 5.1.2 for further information.

  The parcel availability curve used in the present simulation model, which starts 72 hours before the flight departure time, has been generated from Toronto Pearson Airport’s data and it has been taken from [16].

![](image)

**Figure 5.5 Parcel availability curve [16].** The horizontal axis gives the time in minutes (72 hours) before cut-off departure time (the latest time the cargo must leave the terminal without delaying the flight departure). The vertical axis shows the percentage of available parcels as a function of time.

In the simulation model, ULDs are released only when the percentage of parcels available at the terminal is the one set by the *Parcel availability factor*. The parcels available at a certain time to build a ULD belonging to an order depend on the *Parcel availability curve*, the time to departure and the current time. The following **Figure 5.6** shows the code used by the simulation model in order to know if the ULD is ready to be released to the WS according to the Parcel Availability release mechanism.
The *Parcel availability factor* was set to values from 50 up to 100% for all the simulations. Currently Spirit employs this release mechanism when 80-90% of the parcels are available. In order to see how these factors perform they were simulated also in this project. It was also considered interesting to see the impact on system’s performance if ULDs were released when all the parcels were available and what the impact if the value significantly decreased.

The main advantage of this mechanism is that it does not release ULDs unless there are parcels available. The disadvantage is that large ULDs might not have sufficient time to be completely produced.

- **Latest release time**

Currently, in the Spirit Air Cargo terminal, there is a release mechanism which releases the ULDs that have not already been sent to the WS by another release mechanism a predetermined time before the flight departure.

In the simulation model, a factor called *Latest release time factor* is defined and it is the deadline to send ULDs to WS. The ULDs are released to WS when the departure time is equal or smaller than the *Latest release time factor*. The code used by the simulation model is showed on *Figure 5.7*. 
The *Latest release time factor* in performed simulations was set from 30 up to 150 minutes before departure time with intervals of 15 minutes. It was found interesting to test what would happen if ULDs were sent to WS just half an hour before the departure time which means that the ULDS might be processed in a hurry with the possibility that those ULDs miss the flight. Otherwise, it would also be reasonable to test what would happen if the ULDs were sent a long time before the departure. In this way, it is ensured that they have enough time to be finished with the processing before the departure but there is also a high probability of them to collapse the WS.

The main advantage of this mechanism is that it is very simple. However, it should not be used alone, but rather as a supplement to other mechanisms.

- **Expected production time**

  In the simulation model ULDs are released only when the time to departure is equal or smaller than the expected production time for the ULD. The Expected production time is the time required to build or/and break the specified kg for a given ULD using the number of workers set by the *Expected production time factor*. The code used by the simulation model is showed on *Figure 5.8*.

  *Expected production time factor* was set to values from 0.2 up to 1.8 in the performed simulations. It was thought reasonable to run the simulations with the expected production time calculated for one man, but since the workers do not always work constantly on a ULD, the factor was set as minimum value to 0.2. As the workers
work often in pairs it was also found interesting to see what would happen if the factor was set to 1.8 at the most. The intermediate values were also simulated.

The advantage of this policy is that large jobs are released earlier to the WS, so that they have enough time to be completed. As the expected production time can be calculated for less than one worker, there is a chance that more ULDs are finished on time but, on the other hand, the system will probably collapsed.

- **Conwip**

  Conwip might be defined as: “CONWIP control strives to maintain a constant work-in-progress by establishing a WIP level and when the present WIP level is reached, no new job is allowed to enter the system until a job leaves. “ [22]

  The idea is to keep the work load in relation to the capacity as constant as possible at any time. A predetermined work load is specified and if the current load at the WS is lower than this specified work load, then a new ULD is released to WS. In this way it is insured that the system is not overloaded, whilst trying to keep the workload as stable as possible, by releasing jobs whenever possible.

  Note that the load to be built or broken for this new released ULD is not taken into account before being released.
In this project, the Conwip release mechanism is defined in a way that WIP load is measured depending on the number of builders and breakers per period and the kilograms they can handle per hour.

It is worthy mentioning again that this release mechanism is the only one that is applied for both building and breaking operations. It can also be regarded as an availability check that decides whether the ULD can be sent to the WS or it may wait until the work load is lower.

ULDs are released to a WS when the work load that is being built or broken at the WS lines is lower than the one which workers can handle times the Conwip factor. The code used by the simulation model is shown in Figure 5.9.

When Conwip factor is equal to 1 the level of WIP at the WS is the same number of kilograms that workers can currently handle. Conwip factor was set also to higher values which increase the allowed level of WIP at WS, meaning that ULDs can be sent earlier to the WS.

The advantage of Conwip is that it tries to even the production load on the system, which none of the other mechanisms do. The disadvantage is that it does not take parcel availability into consideration and might release ULDs when no parcels are actually available.
5.3.3 Release Policies.

Release policy is defined in this report as the combination of a Queuing method and a Priority to be picked up by the crane method. Every release policy can be combined with any of the release mechanism described in the previous Section 5.3.2.

- Queuing

When the ULDs are ready to be sent to the WS according to one of the release mechanisms previously explained, they are sorted in a queue. The first ULD of the queue is the one which is waiting for the crane to pick it up.

Note that this queuing procedure is not done in all the release locations but only in the Any and the EmptyULDStorages. This is due to the fact that the storage capacity of Usinairside and DDincoming locations is one ULD, so the queuing is not possible there. Consequently, if the ULDs are not ready to be released according to the release mechanisms they are sent directly to the storages.

- Priority to be picked up

Once ULDs are ready to be released to WS, they queue in different locations and the first in the queue is the first picked up by the crane from that location in order to be sent to WS. The problem is that there are four different locations from where the ULD can be picked up, Usinairside, DDincoming and Any and EmptyULDStorage, and there is only one crane in the system, so higher priority has to be given to one of the ULDs placed in the release locations.

In case a ULD placed either in Usinairside or DDincoming does not have the highest priority, compared to those in the other three locations; it is sent directly to the storages and sorted there in the queue. On the other hand, if a ULD placed in one of the storages (Any or Empty) does not have the highest priority, it is waiting there until it has the highest priority.

The Release policy used in the initial simulation model is called Policy A and it is presented as follows:
**Policy A: Lowest Slack and LPT**

Policy A uses a queuing method called *Lowest Slack* and it sets the priority to be picked up by using the *Lowest processing time* method. Policy A needs to be combined with any of the previously mentioned release mechanisms.

- **Queuing method: Lowest Slack**

  The *Slack* is the ULD’s *Time to Departure* minus the *current time* and minus its *Total Processing Time*. The *Total processing time* is the time they need to be built up, broken down or both when processed by one worker. Table 5.2 shows the calculation of *Slack* for each type of ULDs. Note that TargetULDload refers to the final load of the ULD in the simulation model and CurrentULDload, to the load currently in the ULD.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Slack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build and Break</td>
<td>Time to departure – clock - [(TargetULDload - CurrentULDload) / Capacity 1 builder + + (TargetULDload - CurrentULDload) / Capacity 1 breaker]</td>
</tr>
<tr>
<td>Break</td>
<td>Time to departure – clock - [(TargetULDload - CurrentULDload) / Capacity 1 breaker]</td>
</tr>
<tr>
<td>Build</td>
<td>Time to departure – clock - [(TargetULDload - CurrentULDload) / Capacity 1 builder]</td>
</tr>
</tbody>
</table>

Table 5.2 Slack for each ULD depending on its attribute

ULDs are sorted in a queue depending on how much time is left before their departure taking into account the current time (clock) and how long it would take to process the ULDs by one worker. In other words, they are sorted depending on their *Slack*.

Once the ULD is ready to be released according to any of the release mechanisms, the *Slack* before its departure is calculated. Then it will be placed in the queue, where the ULD with *Lowest Slack* is the first one and one with Highest Slack the last one.

- **Priority to be picked up method: Lowest Processing Time (LPT)**

  The *Total processing time* is the time the ULDs need to be built, broken or both when they are processed by one worker.
At a certain moment there might be up to four ULD waiting to be moved to the WS, one in each release location. Their *Processing time* is compared and the one with the lowest one is picked up first and sent to WS.

*Policy A works as follows:*

The ULD is in the storages waiting there to become ready to be released according to the release mechanisms which are being currently used. When the ULD is ready to be sent to the WS it is sorted in a queue ordered according to its *Slack*. The ULD waits until it gets to the first position in the queue and then its *LPT* is compared with the one of ULDs placed in the other three release locations in order to decide which one has the highest *Priority to be picked up*.

When the ULD arrives to *Usinairside* or *DDincoming*, if the ULD cannot be released according to the release mechanisms, it is sent to the storages. In case it is ready to be sent to the WS, then its *LPT* is compared with the one of the ULDs placed in the other three release locations to check if it is the one with the highest *Priority to be picked up*. If this ULD is the one with highest priority, it is then the one picked by the crane; otherwise, it is sent to the storages.

Policy A does not need to be necessarily the most suitable one for the simulation model, therefore other methods will be presented on further sections along this report.

*Figure 5.10 shows step by step the different phases of this release policy for both types of the release location: Any/EmptyULDstorage and Usinairside / DDincoming.*

Note that, only when *Policy A* is combined with Conwip release mechanism, the WIP level is checked just before sending the ULDs to WS. It is done in this way in order to check it right before the ULD is sent to WS, so that the measurement is as accurate as possible.
### Departure release

The departure release is much simpler than the WS release. In the simulation model ULDs are released to DDoutgoing at a predetermined time before departure. As mentioned before, Spirit has a Dolly Dock opening time of 3 hours. This means that a completed ULD at a WS, due to depart from the airside, is either sent to the ULD storage or to the Dolly Dock. If the container it is completed within 3 hours before departure; then it is sent directly to DD; otherwise, it is sent to storages. The same happens to ULDs due to depart from the landside, except that in this case the opening time is half an hour before departure.
6 Coordination between Simulation and Optimization models

The management of the Spirit Air Cargo terminal aims at optimizing terminal operations by fully utilizing manpower resources while maintaining high customer service levels.

Based on the handling capacities of the build and break workers, on the demands of incoming and outgoing cargo and on an effective demand leveling mechanism, an optimization model for personnel shift schedules was constructed. The solution of the model can provide high manpower utilization (well above 90%) and 100% customer service levels (no delayed cargo). How to perform this high manpower utilization with good customer service levels is a challenging task in practice.

One big difference between the optimization model and reality is that the optimization model measures the aggregate cargo demand in kilograms while in reality the outgoing cargo must be consolidated into ULDs by builders and the incoming cargo must be unloaded from ULDs by breakers at workstations. Consequently, the ULD release mechanism from storage into workstations can affect manpower utilization greatly.

Different release mechanisms are easy to test in the simulation model but difficult to model in the mathematical optimization model. In addition, different unexpected factors such as waiting time for the crane, waiting time in the queue, delays and workstation blockings are easy to consider in the simulation model but difficult to consider in the optimization model because it would be too difficult to solve the resulting model due to its complexity. On the other hand, the optimization model can find the best workers’ schedules within a short time while the simulation model can only test different configurations by time consuming trial- and -error method.

Based on the concept of the simulation optimization discussed in Section 2.2, it is wise to integrate the simulation and the optimization models in this context to find the best ULD release mechanism for fully utilizing manpower. Figure 6.1 shows the coordination between the optimization model (ILOG) and the simulation model (Pro-Model).

In Figure 6.1, the ILOG’s input data is specified in the top box to the right. The parameters marked in orange are the ones that can be changed based on the simulation
results. These parameters are the Parcel Availability curve, the workers’ handling capacity and the number of builders and breakers working at the same time.

Figure 6.1 Coordination between simulation and optimization models.
Based on Figure 6.1, simulation model (Pro-Model) needs the workers’ schedules generated by the optimization model to be in operation. After the optimization model is solved, setting the relative optimality gap to 1.2%, the results of the decision variables (e.g. starting time of the shift and number of workers in each shift and each period) are obtained.

The input data for the simulation model provided by the optimization is the yellow one in the bottom box to the left.

Simulation plays a fundamental role in evaluating the performance of different release mechanism and policies in the realistic and non deterministic environment of the terminal with given workers’ schedules. The suitability of the workers’ schedule can be evaluated based on the worker utilization and the customer service levels. Then based on these main factors manpower handling capacity of the workers and other parameters can be revised in the optimization model. The manpower handling capacity is very important in scheduling the number of workers in the workstations. Too few workers are not able to fulfill customer service levels while too many workers just reduce the manpower utilization. Besides, other responses such WS occupation, time waiting for the crane and blockings’ number and duration are considered to provide help when the changes in the optimization model have to be decided.

The customer service levels are evaluated based on the ULDs on time. Certain amount of ULDs misses their flight because they were not completely processed before the flight’s departing time probably because they have not been released to workstations timely because of the following factors.

- WS lines were blocked
- The release mechanism releases them too late to the WS
- They have been waiting for the crane or in a queue.

Besides, the effective handling capacity of the workers in the optimization model needs to be modified based on the feedback from the simulation model do to the fact that it uses an ideal capacity without considering factors like:

- Workers taking breaks during their shifts
- Workers wasting time:
- Time spent moving around the terminal
- Workers do not always have work to be done (workstations are empty while there are workers there or there are ULDs at WS but they are waiting for parcels to be built)
- There are too many workers per shift and not all of them can work at the same time

That means the most valuable information from the simulation results is guiding optimization model to revise the manpower handling capacity. Based on the revised manpower capacity and other parameters, the optimization model can generate new workers’ schedule. Then simulation model enters a new turn of evaluation process based on the revised schedule. This feedback process needs to be repeated multiple times until the manpower utilization and customer service levels in the simulation model is close to the one in the optimization model.
7 Simulations and results discussion

This section focuses on coordinate the simulation and optimization model in such a way that the optimization model provides a workers’ schedule which is used for the simulation model in order to test different release mechanisms and policies. In this way the best combination of release policy and release mechanism can be found to fully utilize the manpower resources while maintaining the customer service levels. Besides, the simulation results can be used as the basis for validating the parameters in the optimization model.

The following sections describe the testing methodology. The simulation results and the required feedback with the optimization model in every stage are discussed.

Note that Stages A, B and C are prior steps in order to obtain the proper simulation model for the feedback process with the optimization model.

7.1 Stage A. Choosing the most suitable Release Mechanism

An optimization was run, using the values for the parameters already defined before on Section 4.2 (Optimization Model 1). With the output obtained from optimization, shifts schedules were defined in the simulation model. Also built and broken Kg per hour were used to calculate the workers’ utilization obtained in ILOG’s optimization.

The aim of this first group of simulations is to decide which release mechanism of the four already defined ones in the existing simulation model is the one that might be better to feed the optimization model back while providing good results in the simulations, so it will be the one used in the following stages.

In order to come up with a decision, the following release mechanisms were tested with the workers’ schedule previously found by the optimization model:

- Parcel Availability (PA)
- Latest Release Time (LRT)
- Expected Production Time (EPT)
Note that the simulations were run releasing the ULDs to the terminal according to Policy A already defined on Section 5.3.3 which can be combined with each of the just mentioned release mechanisms.

### 7.1.1 Simulations with only one release mechanism

First, the release mechanisms were run isolated in the simulation model, therefore the other release mechanisms’ factors were set to default values so that those would not apply in the specific scenario. The default values are as follows:

<table>
<thead>
<tr>
<th>Release mechanism</th>
<th>Default value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Production Time</td>
<td>99999</td>
</tr>
<tr>
<td>Parcel availability</td>
<td>1000</td>
</tr>
<tr>
<td>Latest release time</td>
<td>-99999</td>
</tr>
</tbody>
</table>

Table 7.1 Default values for the WS release mechanisms

Since this is only a test to decide which release mechanism of the four existing ones is the most suitable to achieve the purpose of this project, only results about the number of ULDs on time, workers’ utilization and build and broken Kg were analyzed.

**Parcel availability**

Different scenarios for the parcel availability (PA) were run in the simulation model. PA factor was set to values from 50 up to 100% in order to check the response of the system under different policies.

Graph 7.1 shows the results obtained from the simulations. Firstly, the percentage of ULDs on time, meaning those shipments which get into the departing aircraft or truck with no delay. Secondly, the workers’ utilization which means the percentage of time workers spend processing ULDs during their shifts. Finally, the built and broken kg meaning the percentage of Kg which do not miss their flight. All of them are shown depending on the Parcel Availability factor.
As seen in Graph 7.1, the best results using the workers’ schedule provided by the Optimization Model 1 and releasing according to Policy A combined with PA release mechanism are performed for PA factors lower than 75%. Better results mean a higher number of ULDs on time, so a higher number of customers are satisfied with the service.

However, since optimization and simulation models use different parcel availability curves, it is difficult to define which PA factor would perform the best results at the terminal.

When dealing with building operations, the graph shows that built Kg curve decreases for PA factors higher than 75%. When PA factor is too high ULDs are sent to WS too late, meaning that most of them will not have enough time to be completely built before their departure and they will miss the flight. On the other hand, builders’ utilization is not decreasing as fast as the built Kg do.

Concerning breaking operations, the broken Kg curve is increasing for PA factors higher than 75%. However, the breakers utilization is almost equal for all the PA factors, which makes sense since the breaking operations do not depend of the PA curve.

These two last facts can be explained by the following reason: since the optimization model is not able to take into account the risk of having missed kg, the workers are scheduled to be able to process the whole demand for each period. In case simulation model does not process all of the demanded Kg because several ULDs miss their flight, building manpower is over dimensioned. As a consequence, free builders can...
carry out breaking operations so the broken Kg curve increases while the breakers utilization does not vary.

Besides that, the built Kg curve decreases faster than the number of ULDs on time. This is due to the fact that ULDs which do not make their flights or trucks are the very heavy ones, those that are bigger and have a higher load, so workers build first mainly those with less kg to be built.

**Expected production time**

The simulation model was run by releasing ULDs according to the expected production time that it takes to build up and/or break down the specified kg for a given ULD for the number of workers set by the Expected production time factor.

The following Graph 7.2 shows the results obtained from the simulations. The percentage of flights on time, the built and broken Kg and the workers’ utilization are shown depending on the Expected Production Time factor which was set to factors from 0,2 up to 1,8.

As it can be seen in Graph 7.2 the percentage of ULDs on time is lower for higher Expected production time factors.

![Graph 7.2 Graph of the number of ULDs on time and builders and breakers’ utilization depending on the Expected production time factor](Graph 7.2 Graph of the number of ULDs on time and builders and breakers’ utilization depending on the Expected production time factor)

The lower the factor is the earlier the ULD is sent to the WS to be built up or broken down. As soon as the ULDs are sent to WS it is ensured that workers will have
time to build them up or broken them down, so they will not miss the flight. Although, if the factor is too low, meaning very close to zero, there would be a risk that ULDs have to wait for parcels for a long time, collapsing the WS.

When the factor is set to one or higher than one it is expected to have always at least one builder processing the ULDs. This is risky, because if for some reason there are not enough workers available the ULD will not have the time to be built up and will miss the flight.

The results for this Release Mechanism are similar to the ones for PA concerning builders’ utilization, which decreases for high Expected production time factors, but not as fast as the built Kg’s curve does. Besides breakers’ utilization does not vary a lot for different Expected production time factors but broken Kg’s curve increases because they are processed by builders. Both facts are due to the same reason previously explained.

**Latest release time**

Currently the latest release time at Spirit is 1 hour. In order to test new policies, the Latest Release Time factor was set from 30 up to 150 minutes before departure time with intervals of 15 minutes.

The following *Graph 7.3* shows the simulation results depending on the release time when the ULD is sent to WS.

Graph 7.3 Graph of the number of ULDs on time and builders and breakers’ utilization depending on the Latest release time
The previous graph shows that ULDs on time, built and broken Kg and workers’ utilization are increasing for higher Latest release time factors.

In this case a high factor means the ULD is sent earlier to the WS, so it will have more time to be built, and a low one means it will be sent later, so there is the chance that there is no enough time to build it if it is too big and, as a consequence, it will miss the flight.

Note that for the Latest release factors simulated both builders’ utilization and built Kg are relatively low. This could be due to, taken into account that the workers have been scheduled to start working on ULDs 6 hours before their departure in the optimization model, even with the highest Latest release time factor, 2.5 hours, ULDs are sent to WS too late. This might be the reason why this high percentage of missed ULDs is obtained.

**Conwip**

For this first group of simulations, Conwip policy was only applied for building ULDs. Breaking ULDs were sent straight to WS as soon as there was one available and the crane was free to pick them up.

Simulations were run setting Conwip factor at different values, from 1 to 10. The number of ULDs on time, workers’ utilization and built and broken Kg obtained in the simulations are shown in the next Graph 7.4.
No clear trend can be easily found when analyzing results for different Conwip factors. Some of them are enable to make a higher number of ULDs on time, but it is not possible to determine why.

7.1.2 Simulations with two release mechanism

The next step in developing the policies was to run simulations by combining two release mechanisms at a time; one of the factors was hold while the other was set to a different value in every simulation.

Several combinations where done, and even though when combining two release mechanisms the number of flights on time is generally higher, due to the fact that ULDs are released to WS according to the most restrictive Release Mechanism of the two used, it was decided to continue simulating using, at least for the next simulations, only one release mechanism. This is because using one release mechanism allows analyzing easier the influence that different policies have on the results and feedback with the optimization model will be easier to reach.

7.1.3 Conclusions

As said in the previous section, release policies do usually perform better results when two Release mechanisms work together. Nevertheless, since the aim of this project is not only to obtain the best simulation results but also to be able to analyze the response of the simulation model in order to find possible changes in the optimization model’s parameters, it was considered more convenient to use only one release mechanism at a time.

First of all, it was decided that it makes no sense to send ULDs to the WS without checking if there are enough parcels to build it. Therefore, it was considered essential the use of the PA release mechanism in the simulation model.

It can also be observed that the simulations’ results when releasing according to PA factor are related somehow with the workers’ schedule provided by the optimization model, which make sense since the ULDs release is performed based on the same concept.
However, since optimization and simulation model use different parcels availability curves, it is difficult to conclude which PA factor would perform the best results at the terminal.

Secondly, when using Expected Production Time and Latest Release Time release mechanisms, there is no strong link between the release in the simulation and in the optimization models do to the fact that they do not take into account the parcels availability at the terminal. This fact makes even more difficult to find the proper feedback process between the models.

Thirdly, as Conwip release mechanism can work together with the Parcel Availability one, to keep on using it in the following simulations was considered to be reasonable. Conwip is considered to be the only release mechanism previously presented on Section 5.3 considered capable to level workload. Since optimization model aims at leveling the demand and so the manpower costs can be minimized, Conwip was used in order to have a better demand leveling in the simulation model and in this way try to improve workers’ utilization avoiding the need of schedule workers for peak hours.

Considering all the presented arguments, it was decided to make next simulation experiments using only the Parcel Availability and Conwip Release mechanisms, setting the other release mechanisms factors to their default values.

Using Parcel Availability as a main release mechanism was decided not only because its factor seems to have a larger influence on results but also because the release mechanism used in the optimization model, in order to achieve leveling on the demand, is also depending on a PA curve. Therefore, it is probably the best one when it comes to feed the optimization model back. It has to be mentioned that this release mechanism achieved also the best percentages of ULDs on time and workers’ utilization.

### 7.2 Stage B. Selecting the release policies

The aim of this second group of simulations is to check if the release policy used in the initial simulation model, already explained on Section 5.3.3, is the most suitable one for the Spirit Air Cargo terminal.
Besides, this section also focuses on finding a release policy which releases ULDs to WS in a way that facilitates the effects’ analysis when any of the parameters in the simulation or optimization model are changed.

In order to do that, first of all, some changes were done in Policy A. After that, two new simpler release policies were designed with the intention of, on the one hand, testing if release the ULDs in a simple way works as good as it works using complicated ways as Policy A, and on the other hand, finding a release policy which facilitates the results’ analysis in the next stages of the feedback process.

All the simulations were run using the workers’ schedule provided by Optimization model 1.

7.2.1 Testing Policy A

If using Policy A, once the ULDs have been released according to the currently used release mechanism, they are sorted in a queue, ordered using their Slack. When the ULD gets to the first position in the queue then its LPT is compared with the one of ULDs placed in the other three release locations in order to decide which one has the highest Priority to be picked up. Taking into account the conclusions of previous Section 7.1, Policy A can be combined with PA or with PA and Conwip release mechanisms.

As said on the previous Section 7.1.1, releasing according to Policy A combined with PA release mechanism, provides good percentage of ULDs on time, between 80% and 90% for the best cases, but there is a high percentage of missed Kg for both building and breaking operations. Consequently, the workers have to process less load than the one they were scheduled for and their utilization decreases.

For simulations applying the release Policy A, the priority to be picked up by the crane for the ULDs was set up according to their LPT, meaning those ULDs which need less time to be built up or/broken down have a higher priority to go to WS. This means that there are probably more chances for small ULD to be built up or broken down on time that for big ones. This fact might not affect the number of ULDs on time but the percentage of built and broken Kg because ULDs involve a larger number of kg. In order to check how much influence this fact had, Policy A was simulated with Higher Processing time, so big ULDs were sent before.
Testing Highest Processing Time (HPT)

In order to try to reduce not the number of ULDs but the number of kg missed, it was decided to test how simulations worked deciding the priority for ULDs to be picked up by the crane according to Highest processing time instead of Lowest.

This method works exactly like the previous one, LPT, but in this case the first ULD to be picked up by the crane is not the one with Lowest but with Highest Processing Time.

Simulations releasing with Policy A with both Lowest and Highest Processing time were run in order to compare them. The PA factor was set to values from 50% up to 100% with intervals of a 5%.

Regarding the number of ULDs on time and built and broken Kg, results are shown in the following Graph 7.5:

![Graph 7.5 Graph comparing the Policy A performances using Lowest or Highest Processing time to give the Priority to be piked up by the crane to ULDs.](image)

Results for Highest and Lowest Processing time are very similar concerning built and broken Kg, meaning that the fact that big or small ULDs have higher priority does not have a large impact on results. The percentage of ULDs on time is always higher when using Lowest Processing time but the differences are very small, around 1%. After these results, it was considered worthless to run more simulations with both Highest and Lowest processing time and the Lowest one will be the only one considered from now.
7.2.2 Defining new policies

The purpose of this section is to simplify the way of releasing the ULDs to WS in order to analyze in a proper way the effects of changes in any of the parameters in the simulation or optimization model. Besides, it can also be checked if the simulation model releasing the ULDs in a simple way is working as good as it works when using complicated mechanisms such as Policy A.

In order to do that, two new release policies, Policy B and Policy C, combining new Queuing and Priority to be picked up by the crane methods were defined.

The motivation of these new methods is to use something else than Slack, for Queuing, and Lowest Processing time, for setting the Priority, and replace them with an alternative methods based on the simpler well known method First in First Out.

The new release policies are the following ones:

**Policy B: FIFO OktoRelease time and Lowest OktoRelease time**

Policy B uses a queuing method called FIFO OktoRelease time and it sets the priority to be picked up by using the Lowest OktoRelease time method. Policy B needs to be combined with any of the previously mentioned release mechanisms.

- **Queuing method: FIFO OktoRelease time**

  FIFO method is used combined with release mechanism, so when ULDs are ready to be released to WS they queue to be picked up by the crane according to FIFO, meaning that the first which is ready to be sent to WS will be the first the carne takes there from that location.

- **Priority to be picked up method: Lowest OktoRelease time**

  The time when a ULD becomes ready to be release to WS can also be used to set the priority for the crane.
Therefore, at a certain moment there might be up to two ULDs waiting to be moved to the WS, one in each release location. The moment when each of them became ready to be released is compared and the one with the lowest one is picked up first and sent to WS.

In case Lowest OktoRelease time is used to set the priority for the crane, those ULD that get to the terminal trough Usinairside and DDincoming are sent straight to the Storages and sorted there. This simplification was done because ULDs that arrive to these locations will always be ready to be released to WS later or at least at the same time than those which are already in the storages, so it is not necessary to compare the four locations but Storages are enough.

Policy B works as follows:

The ULDs are in the storages waiting there to become ready to be released according to the release mechanisms which are being currently used. When the ULDs are ready to be sent to the WS, they are sorted using FIFO depending on the time when the ULD becomes ready to be released. Then, the ULD has to wait until it is the first in the queue and then its OktoRelease Time is compared with the one of ULDs placed in the other storage in order to decide which one has the highest Priority to be picked up by the crane.

When the ULD arrives to Usinairside or DDincoming, as said before, all of them are sent straight to storages, so no checks or queues are done in these locations.

Figure 7.1 shows step by step the different phases of this release policy for both types of the release locations Any/EmptyULDstorage and Usinairside / DDincoming.

Note that, when Policy B is combined with Conwip release mechanism, WIP level is checked just before sending the ULDs to WS. It is done in this way in order to check the WIP level right before the ULD is sent to WS, so that the measurement is as accurate as possible.
Policy C: FIFO Arrival time and Lowest Arrival time

Policy C uses a queuing method called FIFO Arrival time and it sets the priority to be picked up by using the Lowest Arrival time method. Policy C does not use any release mechanism, as soon as the ULDs get to the terminal they can be released to WS. However, Conwip release mechanism can be combined with Policy C only if the WIP level at WS needs to be checked before releasing the ULD.

- Queuing method: FIFO Arrival time

FIFO can also be used as an independent method to queue ULDs. In case there is not release mechanism currently working, as soon as they get to the terminal ULDs become ready to be released, so the first one that arrives it will be the first one on the queue for the crane.
• **Priority to be picked up method: Lowest Processing Time (LPT)**

When using this criterion to set priorities for the crane, the arrival times to the terminal of the every first ULDs in the queues are compared and the one which first arrived to the terminal, meaning with a lower arrival time, is the first to be picked up by the crane.

In case *Lowest Arrival time* is used to set the priority for the crane, those ULD that get to the terminal trough *Usinairside* and *DDincoming* are sent straight to the Storages and sorted there. This simplification was done because the same reason explained for *Lowest Ok to release time*.

*Policy C works as follows*:

With this policy ULDs become ready to be released to WS as soon as they arrive to the storages. In this case, none of the release mechanism is used. The queuing procedure is done with FIFO depending on the arrival time. The ULD has to wait until it is the first in the queue and then its *Arrival time* is compared with the one of ULDs placed in the other storage in order to decide which one has the highest *Priority* to be picked up.

When the ULD arrives to *Usinairside* or *DDincoming*, as said before, all of them are sent straight to storages, so no checks or queues are done in these locations.

*Figure 7.2* shows step by step the different phases of this release policy for both types of the release locations *Any/EmptyULDstorage* and *Usinairside / DDincoming*.

Note that the just explained policies were considered simpler than *Policy A* due to the fact that they only depend on the ULDs’ *Ok to release time*, in case any release mechanism is used, or ULDs’ *Arrival time*, instead of depending on other complicated ULDs’ attributes such as their processing time or departure time like *Policy A* does.
7.2.3  A, B and C policies’ comparison

After defining the two new simpler release policies, it was decided to compare them in order to check how worthy it is to come to complex ones such as Policy A and to find the most suitable one to analyze the next steps’ results.

Table 7.2 summarizes the tested policies on the following simulations:

<table>
<thead>
<tr>
<th>Release Policies</th>
<th>Queueing</th>
<th>Priority to be picked up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slack</td>
<td>FIFO (ok to rel. time)</td>
</tr>
<tr>
<td>A</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.2 Overview of the different release policies tested in the simulations. The release and order mechanisms used in each policy are marked by the crosses.
Taking into account the conclusions of previous Section 7.1, simulations combining Policy A and B with PA release mechanism or with PA and Conwip release mechanism were tested in this section. Note that Policy C does not use any release mechanism.

In order to analyze the different policies performances, three decision factors explained on the previous Section 5.2 were analyzed:

- Flights on time
- Builders and breakers’ utilization
- Built Kg or broken

**Simulations with no WIP check**

On this section simulations where Policy A and B were only combined with PA release mechanism and so WIP was not taken into account were run. The PA factor was set to values from 50% up to 100%, with intervals of a 5%.

The following Graph 7.6 shows the percentage of ULDs processed on time, depending on the PA factor. It can be seen how each of the just mentioned policies performs on simulations.

Graph 7.6 Graph showing the percentage of ULDs processed on time depending on the Parcel Availability factor. The simulations results for the three policies A, B and C are showed.

Regarding the three different release policies tested, the one that performs better results for any PA factor is Policy A. It seems pretty logical that it works better than Policy C, because then ULDs are sent with no check of how many parcels are available, so there
are many chances that ULDs have to wait very long for them to arrive at the WS and consequently collapse them, so more urgent containers can not be built and more ULDs will miss the flight or truck.

Note that Policy C provides the same percentage of ULDs on time for all the PA factors due to the fact that it releases the ULDs to WS with no PA availability check, so it does not depend of PA factor.

Policy A works also a little better than Policy B, although differences between their results are very small. When releasing with Policy A, percentages of ULDs processed on time for any PA factor are between 1 and 5% higher.

The following Graph 7.7 shows, for each release policy, the percentage of built Kg and the percentage of builders’ utilization.

It can be seen that the percentage of built Kg is very similar for Policies A and B. Even though, the percentage is a little higher for Policy A, less than 1%.

Regarding builders’ utilization, it is also a bit higher when releasing according to Policy A. This is logical due to the fact that the percentage of time workers are processing ULDs is directly proportional to the number of kg they build. So the less kg missed, the better workers are utilized.
The same *Graph 7.8* can be done for breaking process:

![Graph 7.8](image)

*Graph 7.8* Graph showing for each release policy (A, B and C) the breakers’ utilization obtained from the simulations compared with the breakers’ utilization of the optimization model. Also the broken kilograms are showed. Everything depends on the PA factor.

When it comes to breaking processes, *Policy A* is still the best and also here *Policy C* is the worst.

*Policy A* works also better than *Policy B*, differences between their results when PA factor is higher than 75% are very small. On the other hand, when PA factor is lower than 75% the results for both percentages, breakers utilization and broken Kg, when using *Policy B* decrease faster than when using *Policy A*.

A reason for this could be that, since Policy B sorts the ULDs in a queue depending on *OktoRelease* time and breaking ULDs become ok to release as soon as they arrive to the storages, for PA factors lower than 75%, breaking ULDs have to wait more time in the queue, so they have more chances to miss their flight. The reason of this long waiting in the queue, is that for PA factors lower than 75%, building ULDs have less chances to miss their flight, as they are ok to release to WS earlier. As a consequence, there are a lot of building ULDs in the queue.

When releasing according to *Policy B*, the effect of sorting building and breaking ULDs in the same queue is clear. A release mechanism which sorts building and breaking queues separately could be applied.
It has to mentioned that when releasing according to Policy A this effect is not that clear due to the fact that ULD release is handled by other ULD’s attributes, such as the Slack and Processing time, which are not possible to analyze graphically.

**Simulations with WIP check**

The same groups of simulations were run combining Policy A and B with PA and Conwip release mechanisms. Note that Conwip was only used for building operations. In order to run this simulations PA factor was fixed and set to 65%, since it seemed to be one of the factors that performed better results in the previous section.

Since the idea was only to verify the influence of checking the WIP level at building WS before releasing the ULDs to there, only simulations where Conwip factor is equal to 1, 5 and 10 were run.

When simulating the three policies A, B and C with WIP check the results for any Conwip factor were similar than the ones provided by the simulations with no WIP check.

As a consequence it is not considered worthy to present the results in this section; however they can be found on Appendix 15.3

### 7.2.4 Conclusions

Firstly, when comparing simulations with Lowest and Highest Processing Time, results are very similar, so it was thought that it was no worthy to run both of them. Consequently, it was decided to keep on using only Lowest Processing Time.

Secondly, Policy A was considered the release policy which performs better at the Spirit Air Cargo terminal. This fact has to be taken into consideration when deciding the optimal configuration at the terminal. However, it was decided to stop using Policy A to analyze the results of the simulations.

Even though, results for Policy A and B are very similar, results for Policy A seem to be the best ones for any PA factor and also for any Conwip factor. Concerning ULDs on time and building operations results (Built Kg and builders’ utilization) for Policy A are generally
between 1 and 5% higher than for Policy B. However, concerning breaking operations (Broken Kg and breakers’ utilization), results for Policy A are much higher than for Policy B mainly when PA factors are low.

Thirdly, it was considered to keep on using Policy B as the release policy to run the next steps’ simulations on the feedback process.

After analyzing the previous graphs, even though Policy A is the release policy which performs the best results and seems to be the best one to release ULDs at the terminal, results of Policy B can show in a clearer way the effect of any previous assumption in the simulation model, such as sorting building and breaking operations in the same queue, or any further changes in the simulation or optimization models’ parameters.

The reason why Policy B fits better in the feedback process is that Policy A sorts and releases ULDs according to their attributes (Slack and Processing time), which can not be taken into account in the optimization since it does not work with ULDs but with Kg. One of the aims of this section is to find the simulation model which works as close as possible to the optimization one and in this way be able to analyze the results when changing parameters, this is why it was decided not to use Policy A and use Policy B instead. Policy B releases ULDs according to its Ok to release time, which seems to be the most similar way to release ULDs to the one used in the optimization model.

Finally, it was decided to rule out Policy C, which uses only FIFO to order the ULDs and no release mechanism.

Policy C performs always worse results concerning both ULDs on time and workers’ utilization. Since Policy C was run in order to make sure it was worthy to use more complicated policies such as Polices A and B, it can be said that results were already expected. It was also considered that it makes no sense to use this policy in the following steps since it does not use any release mechanism, which optimization model does.
7.3 **Stage C. Accurate analysis of Policy B**

Taking into account the conclusions of the previous *Sections 7.1* and *7.2*, some more groups of simulations were run. In this section, a detailed analysis of the simulations’ results is carried out, so more accurate conclusions can be drawn in order to obtain a proper feedback with the optimization model. In this way, uncertainty and irregularities, already proved to exist in the simulation model, can be included in the optimization one. This section also focuses on finding the basis to validate the optimization model.

To make this new group of simulations, and according to the conclusions of *Section 7.2* only *Policy B* combined with *PA* and after with *PA* and *Conwip* release mechanisms was simulated. *Policy B* consists in, once the ULDs are ready to be released according to the release mechanisms, sorting them in a queue according to their *Ok to release* time and using their *Ok to release time* to set the priority to pick them up with the crane. The simulations were run using the workers’ schedule provided by the initial Optimization model 1.

In order to make a deeper analysis of simulations and find out which are the real reasons for missed ULDs, besides the data already analyzed, some other output, already commented on previous *Section 5.2*, was analyzed. The studied points were:

- % of ULDs processed on time
- % of built / broken Kg
- Builders’ and breakers’ utilization
- WS occupation
- Building and breaking duration
- Waiting time for the crane
- Number and duration of blockings

The final purpose of the project deals with offering the best possible service to customers while minimizing costs of manpower resources. How good service to customer is here measured using the number of orders or kg that the terminal is able to handle and deliver to customers at the due time. Therefore, number of ULDs processed on time is the value to improve.
On the contrary, optimization model used in this project does not work with orders but with the demand in kg, this is why percentage of ULDs processed on time is not a useful measure when it comes to feedback ILOG. Therefore, percentage of built and broken Kg or workers’ utilization were used to evaluate how good the workers’ schedule provided by the optimization model performs in the simulation model.

In order to analyze how ULDs are processed when they are at WS and see if the delays of ULDs are due to lack of available WS, information about building and breaking WS occupation was also obtained.

Data about duration of processes was also used in order to check if duration of building and breaking processes in the simulation model was in accordance with duration lengths previously set in the optimization model. In case there was no agreement, models should be changed to go so far as to meet them as much as possible.

How long ULDs wait for the crane can be used to know which part of the total processes’ duration is wasted on waiting and take it into account when making the feedback with the optimization model, where there are no wastes.

Besides, the number and duration of blockings were taken into account in this subsection. These measures allowed roughly knowing when workers might be idle due to the fact that WS are full, maybe because they are ULD not being processed but just waiting for parcels. If this happened quite often, then the number of workers should probably be limited so that not that many can work in the same shift and consequently there are less chances that they are idle waiting for new parcels and ULDs to get to WS.

Workers in simulation model showed to have a lower utilization than in the optimization one. One of the main objectives of this group of simulations was to find the causes of this fact in order to be able to make proper changes in simulation and optimization models so the difference was reduced.

### 7.3.1 Simulations with no WIP check

Since the objective was to get enough information from the simulations to make an accurate feedback with the optimization model, a detailed analysis was done. *Policy B*
was simulated combined with PA isolated. Parcel availability factor was set, as in previous sections, from 50 up to 100%.

Regarding the percentage of ULDs that gets to their flight or truck on time and the percentage of built and broken Kg, the following Graph 7.9 was done:

Graph 7.9 shows that the best percentage of ULDs on time, about 90%, is obtained for PA factors between 60 and 75%. The best percentage of built Kg, about 89%, is obtained when PA factor equals 65% and best percentage for broken kg, almost 96%, is achieved for a PA factor of 100%.

However, since optimization and simulation model use different parcels availability curves, it is difficult to say exactly which PA factor would perform the best results at the terminal.

As it can be seen in the graph, the earlier building ULDs are sent to WS, the more time there is to build up them, so the more chances they have to be on time; but this also means than builders are busier building and consequently they have less time to perform breaking operations, so more breaking Kg are missed. The later the building ULDs are sent to WS, the more building ULDs are missed and, as a consequence, builders can carry out breaking operations and less breaking Kg are missed. According to this explanation, it is clear that since builders are able to break down, builders’ and breakers’ performances at the terminal are interconnected.
Workers’ utilization for this policy can be analyzed using the following Graph 7.10 and Graph 7.11. On it, it can be seen how both builders and breakers spend their shift time: working (processing a ULD), taking a break (a sixteenth of the shift), idle (waiting in workers room for some new ULDs or parcels to get to WS so they have some work to do) or transporting (moving around the terminal).

Also ILOG’s utilization is showed in the graph, but since it is not a simulation but an optimization, which does not take into account facts as breaks, transportation or idle times, only percentage of time builders and breakers are working makes sense.

The following Graph 7.10 and Graph 7.11, show workers’ utilization:

![Graph 7.10](image)

When analyzing builders, it is found that best utilization, when builders work about 85-90% of the time, is obtained for PA factor between 55 and 65% and it drastically decreases from then. Idle time for that PA moves between 2 and 4% and transportation takes, at maximum, 8% of the time.

Comparing builders’ utilization in the simulation model to the one in ILOG, it can be seen that they are far to be equal for any of PA factors. ILOG’s utilization is about 10% higher than the best ones in the simulation model.
When analyzing breakers’ utilization, the best percentages, which are around 90%, are obtained for PA factors between 75 and 95%. For these PA factors, transportation and idle times are between 2 and 4% and, at maximum, 8% respectively.

In this case, breakers’ utilizations, for any PA factor, are always smaller that the ones in ILOG, as it happened for builders’ utilizations. ILOG’s utilization is about 10% higher than the best ones in the simulation model, so workers are not profited in the best way neither for breaking operations.

The cause of lower utilization in the simulation model compared with the ILOG’s one, for both building and breaking operations, needs to be found in order to get some feedback with the optimization model and find a better way to release ULDs in the simulation one. Some possible causes for low utilization, from the worker’s point of view, might be:

- Time spent moving around the terminal
- Workers do not always have work to be done. There may not always be ULDs waiting to be processed so the WS are empty or the ULDs are at WS but waiting for parcels to arrive.
- There are too many workers per shift and not all of them can work at the same time.

From ULDs’ point of view, meaning that many ULDs miss their flight and so less Kg have to be processed, some other causes for low utilization might be:
• Time waiting to be picked up by the crane
• Time waiting in the queue
• ULDs released too late to WS and they do not have enough time to be completely processed.
• ULDs cannot be released to WS because there is a blocking in the system.

Note that optimization model does not take into account these facts. Consequently, it schedules the workers using a capacity value which is not accurate due to the fact that even though the workers have this capacity; they are not able to handle all of the demand because of environmental facts as the ones just mentioned.

WS occupation was also analyzed. These results show how much time the ULDs spend at the WS and so if there is any risk of blocking the system. The percentage of time building and breaking WS are empty, with a ULD but no workers processing it and with an ULD and one or two workers processing it can be seen in the following Graph 7.12 and Graph 7.13:

![Graph 7.12](image)

Graph 7.12 Graph showing the build WS occupation. It can be seen the % of time that the WS is empty, with one ULD but without builder working on it and with 1 or 2 builders working on the ULD.

The higher the PA availability factor is, the more time WS are empty. There are two main reasons for this. Firstly, for higher PA factors more ULDs and kg are missed, so less get to WS. Secondly, higher PA means that ULDs get to WS with more parcels already available to be built up, so they do not have to wait so long for new parcels to arrive and they can leave WS earlier. This second reason also leads on the fact that for low PA factor WS have ULDs but no workers processing them for a longer time.
As seen in the graph, ULDs are built up more often by two than by one worker. This is due to the fact that workers do always process the most urgent ULD as long as there is less than two workers already working on it. There is one worker at WS only in case there are no more builders available.

For high PA factors, percentage of time with workers on WS is very low, probably because more ULDs are missed and consequently less get to WS, workers have to process less kg and they spend less time working.

Regarding breaking WS, trend is similar to the building one. Event though, in this case percentage of time with one and two workers processing the ULD does not depend highly on PA factor due to the fact that to perform the whole breaking operation it is not necessary to wait for any parcels, so no clear trend is obtained. For higher PA factors WS are empty for a longer time, probably because builders can perform more breaking operations, since more building ULDs are missed, and consequently breaking containers are processed faster.

Process duration for both building and breaking operations was calculated in two different ways: the total process duration and the processing at WS duration, which can be seen on Graph 7.14.
Total building processes are longer when PA factor takes lower values, which is due to the fact that containers are ready to be released to WS before but with less parcels available, so process will not be finished any way until all parcels have been arrived to the terminal. The whole process can take from about 9 hours down to less than half an hour. For PA equals 65%, which seems to be one of those which perform better results, the process takes almost 5 hours.

Building process duration at WS changes very little depending on PA factor and it takes less than one hour in any case. Comparing both building durations, the total and the one only at WS, it seems obvious that total process duration does not depend highly on processing at WS but on waits, queues, priorities and transportation. Next Graph 7.15 shows how long wait for the crane and transportation takes.

Breaking duration does not change that much depending on PA, because ULDs are always ready to be released and the process at WS can be done as soon as containers get there since no parcels are required. Total breaking process duration takes between 7 and 2 hours and breaking duration at WS takes less than one hour in any case.

Graph 7.15 shows how long ULDs have to wait, as an average, to be picked up by the crane to get to and leave from WS:
Wait for the crane before WS takes from 5 up to 20 minutes, depending on the PA factor. Wait after the crane takes less than 2 minutes in any case. Those times show that, even though it was thought that the crane was the bottleneck, since the results are all lower than 16 minutes, the crane does not seem to be a real bottleneck. The waiting time for ULDs to get to the WS is very small compared with the total building duration. Consequently, it should not be a problem. The waiting times to leave the WS are negligible.

_**Graph 7.16**_ shows the number and duration of blockings at building and breaking WS.

When analyzing blockings for building WS, it can be seen that lower PA factor means more and longer blockings because ULDs are sent earlier to WS and have to wait...
there for more parcels to arrive. In this way, this higher number of blockings can be linked to longer building process at WS already commented.

Even though the number and duration of blockings at breaking WS is more constant along different PA factors, it decreases a bit for higher factors. This might be due to the fact that when the factor is high the builders, as already seen before, build up less kg and ULDs, so they have more time to perform breaking processes and in this way make them faster.

### 7.3.2 Simulations with WIP check

The same groups of simulations were run combining Policy B with PA and Conwip release mechanisms. In this way, it can be tested how good PA combined with a release mechanism which is able to level the demand is. PA factor was fixed and set to 65%, since it seemed to be one of the factors that performed better results.

Since the idea was only to check the influence of Conwip on the results, only simulations where Conwip factor is equal to 1, 5 and 10 were run.

Results of the percentage of ULDs processed on time are presented on following Graph 7.17:

Graph 7.17 Graph showing the percentage of ULDs processed on time depending on the Conwip factor when releasing according to Policy B combined with PA and Conwip

For Conwip factor 5 and 10 results are very similar, which might mean that for any factor that allows a higher load that the one which workers are really able to handle it
does not matter much which the Conwip factor is. This is probably due to the fact that only for small Conwip factors this release mechanism performs a real leveling, for higher ones the limitation of kg that can be handled is so high than only in very few cases ULDs are limited to get to WS, so no real limitation is carried out.

Besides, results for Conwip factor 1 are about a 2% lower than for the other factors. A reason for this could be that Conwip factor 1 is too restrictive, meaning that the limitation of Kg that can be handled at a time at WS is too low and ULDs need to wait longer to be sent to WS. Consequently, they have more changes of missing the flight.

Regarding builders’ utilization and percentage of built Kg over that total demand, the following Graph 7.18 was done:

![Graph 7.18](image)

Conwip factors 5 and 10 give again very similar results and they are a bit lower when factor equals to 1, probably, because the same reason explained before.

In all cases, builders’ utilization is around 10 % lower than the one in ILOG as already happened on previous simulations with no Conwip check.

Dealing with breaking processes, the following Graph 7.19 was done:
Concerning breaking operations the results are parallel to the ones for building operations, but in this case the difference between the breakers’ utilization in the simulation and the one in ILOG is even higher.

Note that, since the simulations with WIP check results and its discussion for any of the facts analyzed in this section were very close to the ones with no WIP check, it was considered not worthy to present them all here. Nevertheless, the graphs showing WS occupation, process duration, time waiting for the crane and number and duration of blockings can be found in the Appendix 15.4.

7.3.3 Conclusions

Concerning simulations with no WIP check, some facts can be pointed according to the previous analysis.

Firstly, the best percentage of ULDs on time, about 90%, is obtained for PA factors between 60 and 75%. However, since optimization and simulation model use different parcel availability curves, it is difficult to say exactly which PA factor would perform the best results at the terminal.

Secondly, after analyzing the built and broken Kg curves the fact that builders and breakers’ performances at the terminal are interconnected in case builders are able to break down seems to be clear. This interconnection drives to the question: Is it worthy to
consider the qualification hierarchy between build-up and break-down workers in the Optimization model?

Thirdly, when comparing workers’ utilization in the simulation model to the one in ILOG, it can be said that they are very different for any of PA factor. ILOG’s utilization is about 10% higher than the best ones in the simulation model for both building and breaking operations. The causes for this low workers’ utilization in the simulation model need to be found.

Besides, according to the WS occupation results, since about 40-80% of the time the WS are empty, it can be said that the risk of blocking the WS low. The highest number of blocking during one week is smaller than 20 for both building and breaking operations.

Building process takes about 4 hours, less than one hour at WS, for PA factors between 50 and 65% which are the ones that perform the best results regarding percentage of ULDs on time and built and broken Kg. Breaking process takes less than 2.5 hours, about half hour at WS.

ULDs spend, as an average, between 8 and 15 minutes waiting for the crane to get to the WS and less than 2 minutes to leave the WS. Consequently, the crane does not seem to be a real bottleneck.

Finally, concerning simulations with WIP check, the best results for any of the factors analyzed, were very close to the ones with no WIP check, which means that Conwip performed results which were good enough to include this check in the Terminal policy. However, it was decided to rule this check out.

The main reason for this decision is that Conwip was used with the intention to provide some demand leveling, which was supposed to be different for different Conwip factors, but since results are almost the same for every factor and they are not better than those for policies with no Conwip, it does not seem to be worthy to complicate policies with Conwip.

However, since Conwip was decided to be ruled out and some demand leveling is desired, a release mechanism which takes into account the WIP level check can be considered for next steps of the feedback process.
Simulation-Optimization feedback process

7.4 Stage 1. Optimization model 1b. Builders breaking validation.

After analyzing the built and broken Kg’s curves, the fact that builders and breakers’ performances at the terminal are interconnected when builders are able to break seems to be clear.

The mentioned connection refers to two main facts: the earlier building ULDs are sent to WS, the less missed building ULDs, but this also means that builders are busier building and they have less time to perform breaking operations, so more breaking kg are missed. On the other hand, the later the building ULDs are sent to WS, the more building ULDs are missed and, as a result, the builders are free and so they can carry out breaking operations and less breaking Kg are missed.

This can happen since one of the main characteristics of builders in the initial simulation and optimization models is that they can perform breaking operations processes.

In order to test how efficient is to not consider this hierarchy between builders and breakers, a new optimization model, Optimization model 1b without allowing the builders perform breaking operations was built.

Optimization model 1b schedules workers in such a way that builders are scheduled to process only the building demand and breakers are able to break down all breaking ULDs without builders’ help.

In order to do that, constraint 8 of the initial Optimization model 1 (See Appendix 15.1) was modified. All the other parameters were set as in Optimization model 1.

Workers’s capacities used in Optimization models 1 and 1b and also the one used in the simulation model can be summarized in the following Table 7.3:
This change could involve a decrease of both builders’ and breakers’ utilizations. In Optimization model 1b, builders need to be scheduled in order to be able to cover the building demand’s peak hours, then during the peak off hours, there would be too many scheduled builders and they cannot perform any work until new ULDs arrive, while in the Optimization model 1, they could work carrying out breaking operations when there is any building job to be done. Thus, in Optimization model 1 the workers are profited on a better way and they are idle for a shorter time.

Also breakers have to be scheduled to cover breaking demand’s peak hours since the builders are not allowed to cover them, then the breakers’ capacity will also be over dimensioned during peak off hours.

7.4.1 Simulations results

Optimization model 1b was run in order to get the new workers’ schedule without allowing builders perform breaking operations. Shifts were then designed to use them in ProModel and several simulations were run.

Simulations were carried out releasing the ULDs to WS according to Policy B, combined with PA release mechanism. PA factor was set, as in previous sections, from 50 up to 100%. In this case simulations were run without builders performing breaking operations.

*Graph 7.20* shows the percentage of ULDs on time obtained by the simulations using the workers’ schedule provided by Optimization model 1 and simulations using the workers’ schedule provided by Optimization model 1b in which the builders are not breaking ULDs (bnb).
One of the facts that stands out the most in the previous graph is that all the simulations where builders are not able to break down perform worse results than those were the builders can work on breaking operations if it is needed. Therefore, a higher number of customers are satisfied with the service when builders perform breaking operations.

Comparisons between the builders’ utilization and built Kg and breakers’ utilization and broken Kg were done in order to analyze how good are used the workers in case no hierarchy between builders and breakers is considered. The results are presented in the following Graph 7.21 and Graph 7.22.
The performances of workers’ schedules provided by both optimization models show that, even both built Kg’s curves are almost equal, builders’ utilization is always better when the builders are able to perform breaking operations. The fact that builders are able to break allows profiting them in a better way because they just perform breaking operations when they do not have any building job to be done. As a result, building manpower is never diminished as long as it is required to build, but might be used to break down ULDs when builders are idle about building operations.

When comparing builders’ utilization and built Kg, on the one hand, when builders are not performing breaking operations, builders’ utilization is decreasing proportionally to built Kg’s curve for any PA factor. On the other hand, when builders can perform breaking operations, for high PA factors it can be seen how built Kg’s curve decreases faster than builders’ utilization. This shows the difference between Optimization model 1 and 1b.

As seen in Graph 7.22, the breakers’ utilization is worse when builders cannot perform breaking operations. In this case breakers have to be scheduled to cover breaking demand’s peak hours since builders are not allowed to cover them, then the breakers’ capacity will be over dimensioned during peak off hours and, as a result, their utilization decreases.

Comparing breakers’ utilization and broken Kg, when builders are not breaking down ULDs, broken Kg’s curve is increasing proportionally to breakers’ utilization. When builders can perform breaking operation, for high PA factors, broken Kg’s curve increases...
faster than breakers’ utilization due to the fact that some of the breaking ULDs are broken down by builders. This also shows the difference between Optimization model 1 and 1b.

### 7.4.2 Optimization outcome

After running the Optimization model 1b to get the new workers’ schedule, it was considered important to compare its outputs with the ones provided by the initial Optimization model 1. The aim of this is to check if after changing the initial optimization model, constraint 8 in this case, with the purpose to obtain a workers’ schedule where builders can not break, the new optimization model works as it should.

First of all, a numerical comparison of the manpower schedules provided by both Optimization models 1 and 1b was carried out. Table 7.4 shows, for each optimization model, the manpower cost, the manpower utilization and the total manpower capacity for the whole week.

<table>
<thead>
<tr>
<th></th>
<th>Optimization model 1</th>
<th>Variation (1b/1)</th>
<th>Optimization model 1b</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST (cost units)</td>
<td>11.793</td>
<td>2.9%</td>
<td>12.132</td>
</tr>
<tr>
<td>Optimization model</td>
<td>Build</td>
<td>99.44%</td>
<td>-2.1%</td>
</tr>
<tr>
<td>Optimization utilization (%)</td>
<td>Break</td>
<td>97.70%</td>
<td>-4.8%</td>
</tr>
<tr>
<td>Total manpower capacity</td>
<td>Build</td>
<td>793.512</td>
<td>-8.4%</td>
</tr>
<tr>
<td>at the terminal (Kg)</td>
<td>Break</td>
<td>557.136</td>
<td>21.2%</td>
</tr>
</tbody>
</table>

Table 7.4 Comparison of the numerical results for Optimization models 1 and 1b. The table is showing results of manpower costs, its utilization and its capacity.

As it can be seen in the previous table, Optimization model 1b is about 3% more expensive than the previous one. In this case, building manpower capacity can decrease due to the fact that it does not need to cover any breaking operation. On the other hand, breaking manpower capacity needs to increase due to the fact that it needs to cover the demands’ peak hours since builders cannot cover them. Moreover, the total manpower capacity should increase to be able to cover peak hours if they exist. As a result, the manpower cost increases.

Besides, as it can also be seen in the previous Graph 7.21 and Graph 7.22 both builders’ and breakers’ utilization obtained in the Optimization model 1b is lower than the one obtained in the Optimization model 1. The reason is that the schedule provided by Optimization model 1b has to be able to cover peak hour’s demand. Then during the peak
off hours the workers do not have any job to be done and so they are not profited in a proper way.

Secondly, a graphical representation along the studied period of how workers’ schedule provided by Optimization models 1 and 1b perform concerning building and breaking operations is presented in the following Figure 7.3 and Figure 7.4.

Graphs show the following results:

- The building and breaking capacity (painted area)
- Kg processed in the simulation model (blue line)
- Kg processed in ILOG Optimization model 1b (red line)

Note that since builders are able to perform breaking processes, the remaining capacity they do not use to build up is added to the breakers’ capacity (yellow area) in the breaking demand leveling. The remaining capacity was calculated as the building capacity for each period minus the Kg built by ILOG during that period.

Besides, the manpower capacity scheduled by the Optimization model 1 is also drawn in the graph (discontinuous grey line). In this way, the effect of the changes in the optimization model’s parameters can be analyzed.

Graphs do not show all the simulation length but only some periods, this is done in order to obtain a more understandable graph. However, Figure 15.17 and Figure 15.18, which include the whole simulation length, can be found in the Appendix 15.7.

Note that in the graphs there are some cases where the of amount kg processed by workers in the simulation model is higher than their capacity. Since the amount of built and broken Kg in the simulation model is not written every second but it has to be written every fifth minute, due to ProModel’s limitations, some imbalances may appear.

The following Figure 7.3 and Figure 7.4 show how the workers’ schedule provided by Optimization model 1b performs concerning building and breaking operations. The manpower capacity scheduled by the Optimization model 1 is also drawn in the graph.
As the previous figures show, the built and broken Kg by ILOG and the manpower capacity meet most of the time. This is why the workers’ utilization in ILOG is always almost 100%, which make sense taking into account that an optimization model aims at finding the optimal workers’ schedule that profits the workers as much as possible.

Besides that, built and broken Kg’s curves in ProModel have almost no delay compared to the ones in ILOG, meaning that ProModel and ILOG are processing the demand almost at the same time so the workers’ schedule is fitting well with the demand.

However, there is a gap between the built and broken Kg by the simulation (blue) and the optimization (red) which explains the amount of Kg which are not processed in the simulation model because they miss their flight.
Finally, the main purpose of these two graphs was to compare manpower capacities of both Optimization models 1 and 1b. It can be easily seen the differences between allowing builders perform or not breaking operations. A clear example can be found during the afternoon hours of the first day (green circle), the building capacity for Optimization model 1 is higher than for Optimization model 1b (Figure 7.3). This over building capacity for Optimization model 1 is used to perform breaking operations (Figure 7.4). This is why the breaking capacity for Optimization model 1 can be lower than for Optimization model 1b (Figure 7.4).

7.4.3 Conclusions

First of all, in order to optimize the operations at the Spirit Air Cargo terminal, a workers’ schedule where builders are able to break down is the best option. Simulations where builders can work on breaking operations if it is needed perform always better results than those were the builders are not able to break down. Therefore, a higher number of customers are satisfied.

Secondly, workers’ utilizations results, for any PA factor, are always lower when builders cannot perform breaking operations, do to the fact that they need to be scheduled to cover demand’s peak hours and consequently they are not profited during peak off hours.

Thirdly, concerning the analysis of the optimization model’s response in case one of its constraints was changed shows that the optimization and simulation results were the expected ones.

In conclusion, the effectiveness of considering the qualification hierarchy between builders and breakers in the optimization model has been proved by the simulation results obtained in this section. As a consequence, not only because of the simulation results but also because it is how it works at the terminal, it has been decided to include the qualification hierarchy between build-up and break-down workers in the following optimization models.
### 7.5 Stage 2. Optimization model 2. Arrival curve and capacities

The aim of this section is to coordinate the simulation and optimization models to find the best ULD release mechanism in order to efficiently utilize manpower resources in practice while maintaining the customer service levels. In order to do this, basic changes need to be done in the optimization model to make simulation and optimization models as close as possible.

The just mentioned basic changes consist in, first of all, changing the arrival curve in the optimization model in such a way simulation and optimization models release ULDs according to the same parcel availability curve and, secondly, including the time which the workers spend taking a break in the simulations into the handling capacity in the optimization model. The way to do both changes will be explained as follows.

A new optimization model, Optimization model 2, was built, taking the previous one but including these changes regarding arrival pattern and worker’s capacity.

**Arrival pattern and build/break duration**

One of the first elements wanted to be changed was the arrival pattern of ILOG. It was currently different than the one in the simulation model and it was thought that the two of them should be the same if results of the two models had to meet.

To decide how to establish the new curve for the optimization model, duration of building process was taken into account. Best results regarding percentage of ULDs on time and built and broken Kg are for PA factor of 65%, for which average building duration process takes 4 hours.

In the Parcel Availability Curve used in ProModel, 65% of the parcels of an order are available 5 hours before departure, so containers are built in less time than provided by the curve. This is due to the fact that parcel availability curve in the simulation model is not a straight line but a curve that grows faster when the time to departure is closer, so it does not arrive to the terminal the same amount of freight during every period before departure and, consequently, when an order has more than one ULD not them get all the
parcels in the same amount of time, both because of the curve and because of different weight of different containers of the order.

Parcel availability curve in ILOG was currently set to six hours. This could fit with the 5 hours before departure when ProModel can begin to release ULDs to WS for a PA factor of 65% plus one hour that containers might spend on DD waiting to be loaded into the aircraft.

Even so, some changes were done in order to establish a new 6-hour curve in ILOG which is working as the last 6 hours in the 72-hour curve used in ProModel.

The comparison between the old curve used in the optimization model and the new one is showed in the following *Graph 7.23*:

![Graph 7.23 Parcel Availability curve for the outbound cargo defined for the optimization model](image)

About breaking process, for PA of 65%, the whole process takes about 2.5 hours. ILOG is set in a way that parcels have to be broken down from a ULD, the latest, 4 hours after arrival because that is customers’ demand. In this case, it is not necessary to change the breaking due time in the optimization model, because even though in the simulation one it is done faster it is not a customers’ request.

**Workers’ capacity**

The second element to be changed on this second stage of the feedback process with ILOG was workers’ capacity. How it was changed can be seen on *Figure 7.5*. 
The way of changing both building and breaking capacities from the initial optimization model is to reduce them in order to include breaks, which are already included in the simulation model. The capacity was reduced one sixteenth, which is the fraction of time workers spend taking a break.

The changing capacity step is presented in the following Figure 7.5:

![Diagram showing the change in the capacity from the previous Optimization model 1 to 2](image)

Figure 7.5 Diagram showing the change in the capacity from the previous Optimization model 1 to 2

Capacities used in Optimization model 2 and the ones used in the simulation model can be then summarized in the following Table 7.5:

<table>
<thead>
<tr>
<th></th>
<th>Building capacity</th>
<th>Breaking capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization model 2</td>
<td>869.06 Kg/h</td>
<td>894.38 Kg/h</td>
</tr>
<tr>
<td>Simulation model</td>
<td>927 Kg/h</td>
<td>954 Kg/h</td>
</tr>
</tbody>
</table>

Table 7.5 Builders and breakers capacity used in the Optimization model 2 and in the simulation model

Note that these two changes, parcel availability curve and workers’ capacity were done at the same time, which is not the best due to it would be better to analyze how a worker’s schedule performs at the terminal after each change in optimization model’s parameters. However, these two changes were considered essential in order to achieve the simulation and the optimization model as coordinate as possible so Optimization model 2 was built taking into account both changes.

Nevertheless, the intermediate optimization model, only changing the arrival curve was also run but it is not considered worthy to present the results on this section due to the reason explained before. The results can be found in the Appendix 15.5.
7.5.1 Simulation results

Optimization model 2 was run in order to get the new worker’s schedule. Shifts were then designed to use them in ProModel.

Simulations were run releasing the ULDs to WS according to Policy B combined with PA release mechanism. PA factor was set to values from 50 up to 100%.

Results regarding percentage of ULDs on time using the workers’ schedules provided by Optimization model 1 and 2 are drawn on the following Graph 7.24.

![Graph 7.24 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 1 and simulation using the workers’ schedule provided by Optimization model 2](image)

As it can be seen in the previous graph the workers’ schedule that performs better for any of the PA factors is the one provided by Optimization model 2. The reason for this is that a higher number of workers is scheduled by Optimization model 2 do to the workers’ handling capacity in the optimization model was reduced; As a consequence, the manpower capacity in the simulation model increases and a higher number of ULDs can be built or broken on time.

The graph also shows that the higher percentages of ULDs on time in any of the optimization models is when PA factors are between 60 and 70% which make sense since 6 hours before the flight departure time, when the optimization model starts building the ULDs, 65% of the parcels are available at the terminal.
Graph 7.25 and Graph 7.26 show the comparisons between the builders' utilization and built Kg and breakers' utilization and broken Kg.

Regarding both built Kg and builders' utilization, the best results are obtained for low PA factors. Besides, workers' schedule provided by Optimization model 2 performs better for any PA factors.

For low PA factors percentages of built Kg's are clearly higher when Optimization model 2 is used, however when PA factors are higher the difference becomes very small. Since the workers' handling capacity was reduced in the optimization model, a higher number of workers is scheduled by Optimization model 2 so more manpower capacity is available in the simulation model. Consequently, for low PA factors, a higher percentage of built Kg can be processed on time. On the other hand, for high PA factors, even if the available manpower in the simulation model is higher, ULDs are sent too late to WS and they do not have enough time to be processed anyway.

A release mechanism which releases the ULDs with a lower percentage of parcels available to build them in case the work load at WS is lower than the one workers can handle could be applied. In this way there are less changes of having workers idle and so they are used in a better way.

When using workers' schedule provided by Optimization model 2, the gap between the builders’ utilization in ILOG and the one provided for the best simulation results has been reduced from previous sections to a percentage about 8%.
Dealing with breaking operations for low PA factors the broken Kg and the breakers’ utilization percentages are higher when workers’ schedule provided by Optimization model 2 is used. This is due to the same reason explained for building operations.

On the other hand, for high PA factors, since there are more building ULDs which miss their flight, builders do not have much building work to perform and then they can perform breaking operations. As a result of this, the broken Kg using Optimization model 1 or 2 are very similar. Besides, taking into account the fact that the manpower capacity in the simulation model is higher when Optimization model 2 is used, the breakers’ utilization for this workers’ schedule decreases.

Simulation results for breaking operations when PA factors are between 50 and 70 % are considerably lower than for the other PA factors. The reason for this could be, as explained in Section 7.2.3, that for low PA factors, more building ULDs are sent to WS because they have enough time to be processed on time. Consequently breaking ULDs, since they are sorted in the same queue, have to wait longer there than if more building ULDs are missed. So breaking ULDs have less changes of being sent to WS.

In order to analyze how much this fact affects the breaking operations a release mechanism which sorts building and breaking queues separately could be applied.
When comparing breakers’ utilization in the simulation model to the one in ILOG, it can be seen that the best results for breakers’ utilization obtained by the simulation model are 10% lower than the ILOG’s utilization.

### 7.5.2 Optimization outcome

In this stage, as it was done in the previous one, after running the Optimization model 2 to provide the new workers’ schedule, its outputs were compared with the ones provided by the initial Optimization model 1 to check the changes’ effects.

In order to do that, first of all, a numerical comparison of the workers’ schedules provided by both Optimization models 1 and 2 was carried out. *Table 7.6* shows, for each optimization model, the manpower cost, the manpower utilization and the total manpower capacity for the whole week.

<table>
<thead>
<tr>
<th></th>
<th>Optimization model 1</th>
<th>Variation (%)</th>
<th>Optimization model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>COST (cost units)</td>
<td>11.793</td>
<td>6.0%</td>
<td>12.505</td>
</tr>
<tr>
<td>Optimization model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>utilization (%)</td>
<td>Build</td>
<td>99.44%</td>
<td>-0.2%</td>
</tr>
<tr>
<td></td>
<td>Break</td>
<td>97.70%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Total manpower capacity</td>
<td>Build</td>
<td>793.512</td>
<td>5.1%</td>
</tr>
<tr>
<td>at the terminal (Kg)</td>
<td>Break</td>
<td>557.136</td>
<td>8.2%</td>
</tr>
</tbody>
</table>

*Table 7.6* Comparison of the numerical results for Optimization models 1 and 2. The table is showing results of manpower costs, its utilization and its capacity.

As seen in the previous *Table 7.6*, Optimization model 2 is about 6% more expensive than Optimization model 1. This is reasonable due to: the workers’ handling capacity (Kg per hour) in the optimization model was reduced around 9% (1/16 of the time), consequently Optimization model 2 scheduled a higher number of workers for the whole period (5 full time and 10 part time more workers) which means that, as seen in the table, the total manpower capacity for the whole period (Kg) increases for both building, around 5 %, and breaking, around 8%. The results in a higher manpower cost.

It has to be mentioned that even with this reduced handling capacity, the maximum number of workers at the same time scheduled by Optimization model 2 is 32 workers, and only for 5 hours during the whole period. This means that the limitation of the maximum number of workers at the same time in the optimization model can be reduced to 32 at least.
Besides, as it can also be seen in the previous Graph 7.25 and Graph 7.26 both builders’ and breakers’ utilization obtained in the Optimization model 1 and 2 are very similar which makes sense since both optimization models aim at finding the optimal workers’ schedule which profits the workers as better as possible.

Secondly, a graphical representation along the studied period of how workers’ schedule provided by both Optimization models 1 and 2 performs concerning building and breaking operations is presented in the following Figure 7.6 and Figure 7.7.

Graphs do not show all the simulation length but only some periods, this is done in order to obtain a more understandable graph. However, Figure 15.19 and Figure 15.20 and, which include the whole simulation length, can be found in the Appendix 15.8.

The following Figure 7.6 and Figure 7.7 show how the workers’ schedule provided by Optimization model 2 performs concerning building and breaking operations. The manpower capacity scheduled by the Optimization model 1 is also drawn in the graph.

![Demand leveling - Building operations](image)

Figure 7.6 Graph showing the performance of workers’ schedule provided by Optimization model 2 for building operations. It also shows the manpower capacity provided by Optimization model 1.

The manpower capacity at the terminal scheduled by Optimization model 2 (red area) is higher than the one scheduled by Optimization model 1 (discontinuous grey line) as it can be seen clearly in the previous figure (green circle). This is reasonable since the workers’ handling capacity was reduced in the optimization model.
Figure 7.7 Graph showing the performance of workers’ schedule provided by Optimization model 2 for breaking operations. It also shows the manpower capacity provided by Optimization model 1.

Two facts can be taken out from the previous Figure 7.7. First of all, regarding the total manpower capacity at the terminal during each period it can be said that, also for breaking operations, it is higher (green circle) when using workers’ schedule provided by Optimization model 2, as it happened for breaking operations.

Secondly, regarding the delay between the broken Kg curve by ILOG and the broken Kg curve by ProModel, as it can be seen in the graph, generally the peak and peak off hours in ILOG and in ProModel are more or less at the same time. However, it could happen that ILOG and ProModel process Kg one before or after the other one (blue circle). Note that, this delay is a consequence of the building operations in the way that, ILOG processes building Kg after ProModel does. Consequently, the extra building capacity to perform breaking operations is available in ILOG before than in ProModel.

7.5.3 Conclusions

After analyzing the comparison between Optimization model 1, the initial one, and Optimization model 2, some conclusions can be summarized as follows.

Firstly, concerning ULDs on time, results when using workers’ schedule provided by Optimization model 2 are better than when using Optimization model 1 for any PA factor. Higher number of ULDs on time means higher number of customers satisfied with the service so Optimization model 2 seems to provide a better workers’ schedule to perform at the Spirit Air Cargo terminal.
Secondly, concerning building operations, percentages of builders’ utilization and built Kg are always higher when using workers’ schedule provided by Optimization model 2. However, for high PA factors, both percentages are decreasing dramatically. In order to solve that a release mechanism which releases the ULDs with a lower percentage of parcels available in case the workload at WS is lower than the one workers can handle could be applied.

Thirdly, concerning breaking operations, percentages of broken Kg are higher when using Optimization model 2 for any PA. On the other hand, when analyzing percentages of breakers’ utilization only for low PA factors Optimization model 2 performs better than Optimization model 1.

Besides this, simulation results for both broken Kg and breakers’ utilization when PA factors are between 50 and 70 % are considerably low no matter which optimization model is used. This could be due to the fact that building and breaking ULDs are sorted in the same queue.

When comparing workers’ utilization in the simulation model to the one in ILOG, if Optimization model 2 is used, ILOG’s builders’ utilization is 8% higher than the best ones in the simulation model, and breakers’ utilization, 10% higher. These results improve the ones obtained when Optimization model 1 is used.

The analysis of the optimization model’s response when its arrival curve and its workers’ handling capacity were changed shows that the optimization and simulation results were the expected ones.

Finally, it was decided that Optimization model 2 is better than Optimization model 1 not only because it performs better regarding ULDs on time but also because it works closer to the simulation model do to the fact that they use the same arrival curve and the new workers’ handling capacity includes the workers breaks already included in the simulation model. Optimization model 2 also provides a workers’ schedule which is able to achieve higher percentages of built and broken Kg as well as higher workers’ utilizations’ percentages.
7.6 Stage 3. Optimization model 3. Capacities

Taking into account the results of the previous section, it can be said that even after reducing the workers’ capacity set in the initial optimization model to the one used in the Optimization model 2 some ULDs miss their flight. This amount of missed Kg involves lower utilizations in the simulation model than in ILOG.

With the aim of reducing the amount of missed Kg a new optimization model, Optimization model 3, was built changing the workers’ handling capacity once more.

The second step on changing both building and breaking capacities was to reduce them again, this time in the same proportion as missed kg. Workers in the simulation model are not able to process all the kg they are supposed to, this may be due to several reasons:

- Transportation time
- There is not enough work for all workers available because:
  - There are not enough ULDs at WS
  - ULDs are waiting for parcels to be built
  - WS are blocked with ULDs waiting for parcels and new ones cannot get to them.

Due to these uncertainties, the effective capacity of workers in the simulation model is proved to be smaller than the one set in the optimization one due to the fact that workers cannot work all the time because of the external factors explained before. So it has to be reduced somehow. Since all the listed time wastes are difficult to measure, the reduction was decided to be done according to the percentage of missed kg in the simulation with PA factor equal to 65%, the same used in the new ILOG curve 6 hours before the departure time. In this case, 5,28% of building kg and 11,83% of braking kg are missed.
The changing capacity step is presented in the following Figure 7.8:

![Figure 7.8 Diagram showing the change in the capacity from the previous Optimization model 1 to 2 one.](image)

Capacities used in Optimization model 3 and in the simulation model can be then summarized in the following Table 7.7:

<table>
<thead>
<tr>
<th></th>
<th>Building capacity</th>
<th>Breaking capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization model 2</td>
<td>831,55 Kg/h</td>
<td>825,32 Kg/h</td>
</tr>
<tr>
<td>Simulation model</td>
<td>927 Kg/h</td>
<td>954 Kg/h</td>
</tr>
</tbody>
</table>

Table 7.7 Builders and breakers capacity used in the Optimization model 2

7.6.1 Simulations and optimization results

Optimization model 3 was run and the new worker’s schedule was obtained. Shifts were then designed to use them in ProModel and run the same group of simulations than in previous stages.

Simulations where ULDs were released to WS according to Policy B combined with PA release mechanism were run. PA factor was set to values from 50 up to 100%.

When applying shifts designed by Optimization model 3 in the simulation model, no improvements, regarding ULDs on time, built and broken Kg and workers’ utilization, were achieved. So it is not considered worthy to present the results on this section; however the graphs showing a comparison of Optimization model 2 and 3 can be found on Appendix 15.6 and Appendix 15.9 and a summary of them is given as follows.

Dealing with the percentage of ULDs on time the simulations’ results obtained show that there are very small differences between the two workers’ schedules provided
by Optimization model 2 or 3. Percentage of ULDs on time is only about 1% higher when Optimization model 2 is used.

The workers’ handling capacity was reduced even more in the optimization model and as a consequence a higher number of workers needed to be scheduled by Optimization model 3. Accordingly, manpower capacity at the terminal is even higher than the one scheduled by Optimization model 2.

Taking into account the fact that percentages of built and broken Kg are very similar for both workers’ schedules and for any PA factor, the workers utilization when using Optimization model 3 is always lower than using Optimization model 2.

Moreover, since the manpower capacity at the terminal scheduled by Optimization model 3 is even higher than the one scheduled by Optimization model 2, its cost is also higher.

Finally, taking into consideration all the results, it was decided to rule out the workers’ schedule provided by Optimization model 3 and to keep on using Optimization model 2’s workers’ schedule in the next stages simulations.

7.7 Stage 4. Release Policy B2

As concluded in previous Section 7.5.3, simulation results for breaking operations when PA factors are between 50 and 70% are considerably lower than for the other PA factors. This could be due to the fact for those PA factors, more building ULDs are sent to WS because they have enough time to be completely processed before their departure time. Consequently breaking ULDs have to wait longer in the queue do to the fact that they are sorted together with building ULDs, as a result, they have less changes of being sent to WS.

In order to evaluate which is the impact of sorting building and breaking ULDs in the same queue two new release policies were designed. Since they are based on the previous Policy A and B with some modifications, the new policies are called Policy A2 and Policy B2. Note that a new policy based on the previous Policy C was not designed do to the fact that it was ruled out in previous sections.
**Policy A2 and B2** work in the same way as the previous **Policy A and B** but they sort the building and breaking ULDs into two different queues. As a result of this, their **Queueing** and the **Priority to be picked up by the crane** methods were modified.

*Table 7.8* summarizes the tested policies on the simulations:

<table>
<thead>
<tr>
<th>Release Policies</th>
<th>Queueing</th>
<th>Priority to be picked up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slack</td>
<td>FIFO (ok to rel. time)</td>
</tr>
<tr>
<td>A</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>C (ruled out)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>A2</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

*Table 7.8* Overview of the different release policies tested in the simulations. The release and order mechanisms used in each policy are marked by the crosses.

Since in previous sections it was decided to run all the simulations of the feedback process using **Policy B**, in order to evaluate the effects of sorting building and breaking ULDs separately, only **Policy B2** was used to run the simulations in this section.

However, also in previous sections, it was concluded that **Policy A** achieves higher percentages of ULDs on time, workers' utilization and built and broken Kg than **Policy B**. Consequently, **Policy A** has to be taken into consideration when deciding the optimal configuration at the terminal. This is the reason why **Policy A2** was also designed.

Since **Policy B2** was the one used to run the following simulations, the changes in its Queueing and Priority to be picked up methods are presented as follows.


**Policy B2** uses a queuing method called **FIFO OktoRelease B2** and it sets the priority to be picked up by using the **Lowest OktoRelease B2** method. **Policy B2**, as it will be explained further in this section, needs to be combined always with Conwip release mechanism for breaking operations and besides it can be combined with any of the other release mechanism for building operations.
- **Queuing method: OktoRelease time B2**

   It is based on the Queuing method used by Policy B, FIFO of the Ok to release time (See Section 7.2.2) but instead of having only one queue where building and breaking ULDs are mixed, it sorts the ULDs into two queues in AnyULDstorage.

- **Priority to be picked up method: Lowest OktoRelease time B2**

   Policy B2 uses the time when a ULD becomes ready to be released to WS to set the priority for the crane.

   At a certain moment there might be up to three ULDs waiting to be moved to the WS in the release locations: the first ULD of the queue in EmptyULDstorage, the first ULD of the build queue and the first one of the break queue in AnyULDstorage.

   In case the WIP level at breaking WS is lower than the workload that breakers can handle, the first ULD of the break queue in AnyULDstorage is always picked up first and sent to WS. Otherwise, the moment when each of them became ready to be released is compared and the one with lowest one is picked up first and sent to WS. This is why Policy B2 needs to be always combined with Conwip release mechanism.

   **Policy B2 works as follows:**

   The ULDS are in the storages waiting there to become ready to be released according to the release mechanisms which are being currently used. When the ULDs are ready to be sent to the WS, they are sorted into two different queues using FIFO depending on their OktoRelease time. Then, if the WIP level at breaking WS is lower than the workload breakers can handle, the first ULD of the break queue is always picked up first and sent to WS. Otherwise, its OktoRelease Time is compared with the one of the first ULDs in the other queues in order to decide which one has the highest Priority to be picked up by the crane.

   When the ULD arrives to Usinairside or DDincoming, as in Policy B, all of them are sent straight to storages, so no checks or queues are done in these locations.
Chapter 7 Simu. and results discussion

### Priority to be picked up

- **Lowest (OK to rel. time)**: H,(7)2loc.
- **Not first to be picked up**: WS

### Build Queuing

- **FIFO (OK to release)**: Build Queuing

### Release Mechanisms

**Release Mechanism (Conwip)**
- **Build Queuing (FIFO)**: OK to release

### ULD storage

- **ANY/EMPTY ULD storage**

### Build Break

- **WIP level < Breakers can handle**: Build Break

### Priority to be picked up

- **Lowest (OK to rel. time)**: 2loc.

### Release Policies

1. **Priority to be picked up**
2. **First to be picked up**
3. **WAIT**

### Release Locations

- **Any/Empty ULD storage**
- **UsinAir / DD incoming**

**Figure 7.9** Diagram showing the different phases of this release order policy "POLICY B2" but in this case with building and breaking ULDs queuing separately for both types of the release locations Any/Empty ULD storage and UsinAir side / DD incoming.

Previous **Figure 7.9** shows step by step the different phases of this release policy for both types of the release locations **Any/Empty ULD storage** and **UsinAir side / DD incoming**.

#### 7.7.1 Simulations results

Since in the previous stage it was concluded to rule out Optimization model 3, workers’ schedule provided by Optimization model 2 was used to run the simulations in order to test this new policy.

Simulations where ULDs were released to WS according to **Policy B2** combined with PA release mechanism for building operations and Conwip release mechanism for breaking operations were run. PA factor was set to values from 50% up to 100% and Conwip factor was set to 1. This value was chosen not only because it performed the best...
results when running simulations combining all Conwip factors (from 0.5 to 10 with intervals of 0.5) with every PA factor, but also because it seems to be the most realistic one (WIP level equal to the workload which scheduled workers can handle).

Regarding the percentage of ULDs on time the simulations’ results obtained releasing the ULDs according to Policy B combined with PA and Policy B2 combined with PA and Conwip (breaking ULDs) are drawn on the following Graph 7.27.

Graph 7.27 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 2 and releasing the ULD to WS according to Policy B or B2.

The previous graph shows that percentages of ULDs on time when releasing according to Policy B2 are always a little bit higher than when releasing according to Policy B. However, the differences are very small, between 2 and 3%.

Graph 7.28 and Graph 7.29 show the comparisons between the builders’ utilization and built Kg and breakers’ utilization and broken Kg.

The fact of sorting the building and breaking ULDs into two queues, having breaking ULDs a higher priority to be picked up by the crane does not seem to affect highly building operations. Percentages of built Kg are very similar when releasing according to Policy B and B2. Concerning builders’ utilizations, the differences for any of the PA factors are also very small, around 1 or 2 %, as it happened for built Kg.
On the one hand, when comparing the builders’ utilizations obtained in the simulation model to the one in ILOG, it can be seen that for low PA factors the differences are about 6%. On the other hand, for high PA factors, builders’ utilizations in the simulation model decrease drastically. This could be due to the fact that ULDs are sent to WS too late and even if there is available manpower they do not have enough time to be completely processed on time.

As it can be seen in the previous graph, both broken Kg and breakers’ utilizations are higher when releasing according to Policy B2. This improvement of breakers’ utilizations makes the simulation utilizations closer to the ILOG’s one. In this case the gap between them is only about 5% for the best simulation results.
The simulation results show that sorting building and breaking ULDs into two different queues improves considerably percentage of broken Kg and breakers’ utilizations when PA factors are low. The higher the PA factors are, the smaller improvements are since when the ULDs were sorted into the same queue the results were already good do to the fact that more building ULDs are missed.

7.7.2 Conclusions

After analyzing the simulations’ results in order to evaluate which is the impact of having building and breaking operations sorted in the same queue, it can be said that a great improvement has been achieved using the new release policy Policy B2.

Dealing with building operations, releasing according to Policy B2, having breaking ULD a higher priority to be picked up by the crane, does not affect highly building operations. For low PA factors, builders’ utilizations are only 6% lower than the one in ILOG. However, for high PA factors, they decrease drastically.

Finally, percentages of both broken Kg and breakers’ utilizations are higher when releasing according to Policy B2. With this improvement, breakers’ utilizations are only about 5% lower than ILOGs one.

To sum it up, it was decided to keep on releasing the ULDs according to Policy B2 it achieves good percentages of workers’ utilization while maintaining the high percentage of ULDs on time.

7.8 Stage 5. Release mechanism. PA depending on WIP level at WS

As concluded in the previous stage, percentages of built Kg for high PA factors is very low, probably because ULDs are sent too late to WS and then many of them miss their flight. Consequently, the builders’ utilization also decreases.

A release mechanism which releases the ULDs with a lower percentage of parcels available in case the work load at WS is lower than the one workers can handle was defined. In this way, some demand leveling was introduced to the simulation model, like
it did already exist in the optimization one, so improvements regarding the workers’ utilization were expected.

This new release mechanism called *Parcel availability depending on WIP* presented as follows:

**Parcel availability depending on WIP level at WS**

A variant of the first *Parcel Availability* release mechanism was defined. *Parcel Availability depending on WIP level at WS* is working as PA one but with a small difference: the percentage of parcels needed to start building a ULD depends now on the WIP level at WS.

In the simulation model ULDs are released only when percentage of parcels available is the one set by the old *Parcel availability factor* times the new *Parcel Conwip factor*. This new factor takes a certain value depending on parameter A, which measures how lower is the current load at WS compared to the one current workers can handle times the *Conwip factor*. Once the value of A is found, the values of the *Parcel Conwip Factor* are assigned according to the table and the formulation presented on Figure 7.10.

![Figure 7.10 Diagram of Parcel Availability Release mechanism depending on WIP level at WS](image)

For instance, if the current work load at WS is 0.7 times the Total number of Kg workers can handle times the *Conwip Factor* (previously defined), then the *Parcel Conwip Factor* takes a value equal to 0.75, which means that ULDs will be released to WS as soon
as they have a number of parcels equal to Parcel availability Factor times 0,75. In this way, ULDs will be released sooner.

The advantage of this mechanism is that it releases ULDs according to the workload level, so if WIP is low the ULD is sent to the WS sooner that it would be sent by the normal Parcel Availability mechanism. In this way, the ULDs have less chances of missing their flight. Besides, it makes sense sending ULDs to WS as soon as there are free WS and workers available, when there are some parcels to build the ULD, even if there are not as many as the Parcel availability factor requires.

A disadvantage could be the long build and break durations. Since the ULDs are sent sooner than with the normal Parcel Availability mechanism they spend more time at WS waiting for the parcels to arrive and this might cause that at some moment the ULD can not be sent to WS because they are all full.

### 7.8.1 Simulation results

In this section, a comparison of how performs Policy B2 combined with both PA and PA depending on WIP level release mechanisms was done. Note that Policy B2 needs to be combined also with Conwip release mechanism for breaking operations.

PA factor was set to values from 50 upt to 100% and the same Conwip factor for building and breaking operations, was set to 1. This value was chosen not only because it performed the best results when running simulations combining all Conwip factors (from 0,5 to 10 with intervals of 0,5) with every PA factor, but also because it seems to be the most realistic one (WIP level equal to the workload which scheduled workers can handle).

Results of the percentage of ULDs processed on time are presented on following Graph 7.30, where the effects of the new policy can be checked:

Policy B2 combined with PA depending on WIP performs better than Policy B2 combined with PA due to the fact that the one which depends of the WIP level send the ULDs earlier to WS so they have more chances to be finished on time.
Graph 7.30 Graph showing the percentage of ULDs processed on time depending on PA factor. The simulations results for Policy B2 releasing by PA and PA depending on WIP setting Conwip factor to 1 and for any PA factor are showed.

When releasing with PA depending on WIP, an important fact to point out is that the percentage of ULDs processed on time does not depend a lot on the PA factor and all the outcome values are high enough for any of them.

Regarding builders’ utilization and percentage of built Kg over the total demand, the following comparison of how every release mechanism, PA or PA depending on WIP, works was done, as it can be seen on Graph 7.31:

Graph 7.31 Graph showing the builders’ utilization and the number of kg built depending on PA factor. The simulations results for Policy B2 releasing by PA and PA depending on WIP setting Conwip factor to 1 and for any PA factor are showed

On previous graph, it can be easily seen how the results from simulations where the ULDs are released by PA depending on WIP do not depend highly on the PA factor. Note that there is an important difference form simulation results when releasing by PA itself, where results are very dependent on the PA factors.
Regarding the comparison between the performances when releasing by PA or by PA depending on WIP, the percentage of built Kg and builders’ utilization is equal or higher for the second release mechanism. This is due to the fact that PA depending on WIP releases the ULDs earlier when workload at WS is lower than the previously established one, so in this way building demand can be spread over more periods before the departure time. As a result a better leveling is achieved for any PA factor.

The same graph can be done for breaking process:

![Graph 7.32 Graph showing the breakers’ utilization and the number of Kg broken depending on PA factor. The simulations results for Policy B2 releasing by PA and PA depending on WIP setting Conwip factor to 1 and for any PA factor are showed.](image)

Regarding breaking operations, as seen on Graph 7.32 breakers’ utilization and broken Kg results do not depend of the PA factor, which make sense since breaking operations are carried out in the same way for any PA factor value. When releasing according PA depending on WIP, percentages of broken Kg and breakers’ utilizations are a bit higher.

### 7.8.2 Conclusions

Regarding percentages of ULDs on time workers’ utilization and also built and broken Kg, the results when Policy B2 is combined with PA depending on WIP do not depend highly on PA factor. They are most of the times better and other times as good as those provided by Policy B2 combined with PA release mechanism.

The fact that results do not depend on PA factor makes the ULDs’ release more flexible and suitable for a larger number of situations, which is also and advantage,
especially in a market such as the air cargo one, which is framed in a changing environment. This is why it was decided to choose Policy B2 combined with PA depending on WIP release mechanism as the one which can utilize the resources more efficiently in practice while achieving a good customer service level.

Comparing the simulations’ results provided when using workers’ schedule provided by Optimization model 2 and releasing the ULDs according to Policy B2 combined with PA depending on WIP release mechanism with the ones obtained in Stage C, where workers’ schedule provided by Optimization model 1 was used and the ULDs were released according to Policy B combined with PA release mechanism, it can be said that a great improvement has been achieved. Percentages of ULDs on time are about 6% higher while workers’ utilization increases about 6% in case of builders and about 5% in case of breakers.

7.9 Last stage. ULDs’ release at the Spirit Air Cargo terminal and leveling

The final aim of this Master Thesis was to optimize the operations of the Spirit Air Cargo Terminal finding the best configuration which achieves cost reductions while maintaining customer service levels and, at the same time, fully utilizes the manpower resources.

Best configuration refers to the combination of workers’ schedule, release policy and release mechanism that provides the highest percentages of ULDs on time and so most of the customers are satisfied with the service.

As concluded on the last Section 7.8, the best results concerning ULDs on time are achieved when:

- Workers are scheduled by Optimization model 2, which is based on the initial one but with a new arrival curve which is the same as in the simulation model and with a new workers’ handling capacity which was reduced in order to include the time the workers are taking a break.
- ULDs are released according to release Policy B2 which sorts the building and breaking ULDs into two queues according to their Ok to release and uses Ok to release time to set the priority to pick them up with the crane.
- Policy B2 works combined with PA depending on WIP release mechanism which sends the ULDs to WS depending on the PA factor which is varying according to the current WIP level at WS.

Taking into account these results and the fact that Policy A was considered as the best release policy at The Spirit Air Cargo terminal (Section 7.2), simulations where ULDs are released according to Policies B2 and A2 combined with PA depending on WIP release mechanism were run in other to compare which one is the best to release the ULDs at the terminal after all the changes.

Simulations were run setting PA factor to values from 50 up to 10% and Conwip factor to 1. Workers’ schedule provided by Optimization model 2 was used.

Graph 7.33 shows the comparison of the performances releasing according to Policy B2 or A2 regarding ULDs on time.

Even though, results for Policy A2 and B2 are very similar, since the differences between them are, generally, about 2% higher for Policy A2 the decision was to chose Policy A2 combined with PA depending on WIP using the workers’ schedule provided by Optimization model 2 as the best configuration for The Spirit Air Cargo terminal.
Once decided which is the best configuration for the terminal, in order to analyze if it performs a good leveling on the demand, for both building and breaking operations the following Figure 7.11 and Figure 7.12 were drawn. The graphs show, besides the data already mentioned in previous sections, the capacity of the staff currently scheduled in The Spirit Air Cargo terminal (discontinuous dark green line) and the customers’ demand in kg (black line).

Graphs do not show all the simulation length but only some periods, this is done in order to obtain a more understandable graph. However, Graph 15.16 and Graph 15.17 and, which include the whole simulation length, can be found in the Appendix 15.10.

Both building and breaking demands, which is here not presented in ULDs but in kg, are very irregular along the simulation length. Peak and peak-off hours can easily be distinguished. In order to get a good workers’ utilization it is necessary to level somehow the demand, so workers are not so idle in peak-off hours and can then process in advance demand due to rush hours.

The following Figure 7.1211 analyzes leveling for building operations:

As it can be seen on the previous Figure 7.11 building demand is uneven and with outstanding peaks. Since currently no leveling is applied at The Spirit Air Cargo terminal, the staff is not able to cover the demand any time. It can be seen also that Spirit capacity is overdimensioned for peak-off hours, meaning builders are idle most of the time, and their capacity is not enough to cover the demand in peak hours.
New workers’ schedule provided by the Optimization model 2 offers a capacity which is more adapted to the demand and current policy to release ULDs provides some leveling so built Kg in the simulation model tend to meet workers capacity and built Kg on ILOG, which means workers’ utilization is improved and consequently not so many builders have to be scheduled, so cost can be reduced. The objective is to obtain a curve of the built Kg in the simulation model as close as possible to the optimization one; however, since in ILOG all of the demand is processed and in ProModel some kg are missed, the area that built Kg in the optimization model draws is bigger.

The following Figure 7.12 analyzes leveling for breaking operations:

![Figure 7.12 Graph showing the demand leveling achieved for breaking operation by the simulation model.](image)

The graph can be analyzed in a similar way than the previous one for building. The achievements regarding leveling and workers’ utilization are almost the same. However, for breaking processes broken Kg in the simulation model are farther from the ones broken in the optimization one.

In summary, improvements regarding leveling and workers’ utilization have been achieved, which mean the chosen policy for the simulation model is working in the right way, even though it can still be improved.
8 Global conclusions

The Spirit Air Cargo Terminal at Kastrup airport is a complex dynamic system characterized by a high level of uncertainty and non-stationarity. This Master Thesis has integrated the optimization model for manpower scheduling and the simulation model for cargo operations to find the best unit load devices (ULDs) release mechanism to utilize the manpower resources fully. It can be concluded that in order to provide an efficient manpower scheduling an intelligent release mechanism is required.

Since ULDs are released by combining a certain release policy with one or more release mechanisms based on the coordination between simulation and optimization models, different combinations of different release policies and release mechanisms have been tested in a realistic and non-deterministic environment. This allows finding the best configuration for the ULDs release which interacts as well as possible with the workers’ schedule to achieve good workers’ utilization while maintaining the customer service level.

Policy A2 seems to be the best policy to release the ULDs at the Spirit Air Cargo terminal. It separates the ULDs for building and breaking into two different queues. Each queue sorts ULDs according to their Lowest Processing Time and ULDs that needs the least time to be built and/or broken down will be placed in the first position in the queue. In addition, Policy A2 uses Lowest Slack as the criterion to set priorities about which ULD is the first to be picked up by the crane. Slack refers to the time left for a ULDs after being processed and until its departure time.

The best release mechanism for building operations is to release ULDs according to the Parcel availability curve (PA) depending on WIP (work in process). It consists in sending ULDs to workstations depending on the PA factor which depends on the current workload level (WIP) at workstations. When releasing the ULDs according to PA depending on WIP release mechanism, the results are insensitive to changing environment such as uneven demands and variable cargo demand. In addition, PA depending on WIP also provides good demand leveling, which matches the demand leveling mechanism in the optimization model. In this way, the workers’ utilization can be improved, especially during peak-off hours, and there are more chances to cover all of the demand in peak periods.
The best release mechanism for breaking operations is Conwip. It uses the concept of CONstant Work In Progress which means maintaining constant workload at the workstations. The level of workload, in this project, is measured based on the number of workers in each period.

The best configuration for the releasing ULDs is to combine Policy A2 with PA depending on WIP for building operations and with Conwip for breaking operations. It can utilize manpower resources efficiently in practice, only about 5% lower than the optimal solution generated by the optimization model while maintaining a good customer service level, with 97.56% of the ULDs on time.

Furthermore, the simulation results can also provide the basis for validating the optimization model [20] and revising some parameters such as worker handling capacity and the arrival pattern. It can be concluded that the model [20] based on the revised parameters can be applied to actual manpower planning at the air cargo terminal with the suitable handling capacity that can be derived based on simulation results.
9 Further work

Regarding global conclusions some further work can be done in the following aspects.

Firstly, a smarter release mechanism can be found to provide better manpower utilization and customer service levels if both the workload level at workstations and the size of the ULD are considered before the ULD is released.

Secondly, real data from the Spirit Air Cargo Terminal and its own curve for parcels arrival should be obtained in order to test the best release mechanism in the simulation model. In this way the best combination of PA and Conwip factors can be defined based on the reality of the Spirit Air Cargo terminal. PA factor refers to the required percentage of parcels available at the terminal to release the ULD to workstations and Conwip factor to the workload level at workstations which allow releasing ULDs.

Finally, if the best release mechanism is tested using the real data from the cargo terminal, the handling capacity in the optimization model should be updated and new worker schedules can be generated, which should be the real worker schedules the Spirit Air Cargo Terminal can be used in practice. Also more iterations between the simulation model and the optimization model could be carried out to find the optimal worker schedules by updating the workers’ handling capacity in each iteration.
10 Acknowledgments

Firstly, I would like to thank my supervisors Martin Grunow, Peter Jacobsen and Aiying Rong for giving us the opportunity of doing this project, for constantly inspiring us and helping us to move forward.

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11 References


12 Table of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Simulation Optimization model</td>
<td>22</td>
</tr>
<tr>
<td>2.2</td>
<td>Illustration of the coordination between the simulation model and optimization model in this project.</td>
<td>23</td>
</tr>
<tr>
<td>3.1</td>
<td>Illustration of the Spirit Air Cargo terminal</td>
<td>26</td>
</tr>
<tr>
<td>3.2</td>
<td>Main processes involved in air cargo handling when it comes to build ULDs from booking to take-off [23]</td>
<td>27</td>
</tr>
<tr>
<td>5.1</td>
<td>Overview of the simulation model</td>
<td>35</td>
</tr>
<tr>
<td>5.2</td>
<td>Data used as a order schedule in the simulation model</td>
<td>37</td>
</tr>
<tr>
<td>5.3</td>
<td>Sheet of &quot;order sequencing test&quot; excel file where all the results are sumarized</td>
<td>37</td>
</tr>
<tr>
<td>5.4</td>
<td>Equation showing how calculations of the new capacity were done</td>
<td>39</td>
</tr>
<tr>
<td>5.5</td>
<td>Parcel availability curve [16].The horizontal axis gives the time in minutes (72 hours) before cut-off departure time (the latest time the cargo must leave the terminal without delaying the flight departure). The vertical axis shows the percentage of available parcels as a function of time</td>
<td>43</td>
</tr>
<tr>
<td>5.6</td>
<td>Diagram of Parcel Availability Release mechanism</td>
<td>44</td>
</tr>
<tr>
<td>5.7</td>
<td>Diagram of Latest time release mechanism</td>
<td>45</td>
</tr>
<tr>
<td>5.8</td>
<td>Diagram of Expected Production time release mechanism</td>
<td>46</td>
</tr>
<tr>
<td>5.9</td>
<td>Diagram of CONWIP release mechanism</td>
<td>47</td>
</tr>
<tr>
<td>5.10</td>
<td>Diagram showing the different phases of this release policy “POLICY A” for both types of the release locations Any/EmptyULDstorage and Usinairside / DDincoming</td>
<td>51</td>
</tr>
<tr>
<td>6.1</td>
<td>Coordination between simulation and optimization models</td>
<td>53</td>
</tr>
<tr>
<td>7.1</td>
<td>Diagram showing the different phases of this release - order policy “POLICY B” for both types of the release locations Any/EmptyULDstorage and Usinairside / DDincoming</td>
<td>68</td>
</tr>
<tr>
<td>7.2</td>
<td>Diagram showing the different phases of this release - order policy “POLICY C” for both types of the release locations Any/EmptyULDstorage and Usinairside / DDincoming</td>
<td>70</td>
</tr>
<tr>
<td>7.3</td>
<td>Graph showing the performance of workers’ schedule provided by Optimization model 1 for building operations. It also shows the manpower capacity provided by Optimization model 1</td>
<td>95</td>
</tr>
<tr>
<td>7.4</td>
<td>Graph showing the performance of workers’ schedule provided by Optimization model 1 for breaking operations. It also shows the manpower capacity provided by Optimization model 1</td>
<td>95</td>
</tr>
<tr>
<td>7.5</td>
<td>Diagram showing the change in the capacity from the previous Optimization model 1 to 2</td>
<td>99</td>
</tr>
<tr>
<td>7.6</td>
<td>Graph showing the performance of workers’ schedule provided by Optimization model 2 for building operations. It also shows the manpower capacity provided by Optimization model 1</td>
<td>104</td>
</tr>
<tr>
<td>7.7</td>
<td>Graph showing the performance of workers’ schedule provided by Optimization model 2 for breaking operations. It also shows the manpower capacity provided by Optimization model 1</td>
<td>105</td>
</tr>
<tr>
<td>7.8</td>
<td>Diagram showing the change in the capacity from the previous Optimization model 1 to 2 one.</td>
<td>108</td>
</tr>
<tr>
<td>7.9</td>
<td>Diagram showing the different phases of this release - order policy “POLICY B2” but in this case with building and breaking ULDs queuing separately for both types of the release locations Any/EmptyULDstorage and Usinairside / DDincoming</td>
<td>112</td>
</tr>
<tr>
<td>7.10</td>
<td>Diagram of Parcel Availability Release mechanism depending on WIP level at WS</td>
<td>116</td>
</tr>
</tbody>
</table>
Figure 7.11 Graph showing the demand level achieved for building operation by the simulation model.

Figure 7.12 Graph showing the demand level achieved for breaking operation by the simulation model.

Figure 15.1 The data provided in Master file with transcript of ULD movements.
Figure 15.2 Data provided in Flight schedules with departing and arriving ULDs.
Figure 15.3 Overview of the simulation model.
Figure 15.4 Logic that determines if a worker has work to do on the WS and on which ULD has to work first.

Figure 15.5 WS breaking activity where every 2 minutes if the ULD is finished or missed is checked.
Figure 15.6 Builder working on the most urgent ULD.
Figure 15.7 Builder working on the most urgent ULD.
Figure 15.8 Building and breaking process. Checking if the ULD is ready every five minutes.
Figure 15.9 Representation of where the breaks have been inserted into full-time shifts.
Figure 15.10 Representation of where the breaks have been inserted into part-time shifts.
Figure 15.11 Part of the code generated in Excel for the parcel availability curve. The left part is the time interval and the right part is the percentage of parcels available at the terminal.

Figure 15.12 Data used as a order schedule in the simulation model.
Figure 15.13 Data input for workers.
Figure 15.14 Output for KPI - middle part.
Figure 15.15 Output for KPI - right part with ability to track single ULDs movements.
Figure 15.16 Sheet of "order sequencing test" excel file where all the results are summarized.
Figure 15.17 Graph showing the performance of workers’ schedule provided by Optimization model 1b for building operations. It also shows the manpower capacity provided by Optimization model 1b.
Figure 15.18 Graph showing the performance of workers’ schedule provided by Optimization model 1b for breaking operations. It also shows the manpower capacity provided by Optimization model 1b.
Figure 15.19 Graph showing the performance of workers’ schedule provided by Optimization model 1 for breaking operations. It also shows the manpower capacity provided by Optimization model 2.
Figure 15.20 Graph showing the performance of workers’ schedule provided by Optimization model 1 for breaking operations. It also shows the manpower capacity provided by Optimization model 2.
Figure 15.21 Graph showing the performance of workers’ schedule provided by Optimization model 2 for breaking operations. It also shows the manpower capacity provided by Optimization model 3.
Figure 15.22 Graph showing the performance of workers’ schedule provided by Optimization model 2 for breaking operations. It also shows the manpower capacity provided by Optimization model 3.
Figure 15.23 Graph showing the demand levelling achieved for breaking operations by the simulation model.
Figure 15.24 Graph showing the demand levelling achieved for breaking operation by the simulation model.
13 Table of Tables

Table 5.1 New builders and breakers capacities used to make the workers’ utilization calculations 39
Table 5.2 Slack for each ULD depending on its attribute ................................................................. 49
Table 7.1 Default values for the WS release mechanisms .............................................................. 57
Table 7.2 Overview of the different release policies tested in the simulations. The release and order
mechanisms used in each policy are marked by the crosses ............................................................ 70
Table 7.3 Builders and breakers capacity used in the original Optimization model 1 and 1b in the
simulation model ........................................................................................................................ 90
Table 7.4 Comparison of the numerical results for Optimization models 1 and 1b. The table is
showing results of manpower costs, its utilization and its capacity ................................................ 93
Table 7.5 Builders and breakers capacity used in the Optimization model 2 and in the simulation
model ............................................................................................................................................. 99
Table 7.6 Comparison of the numerical results for Optimization models 1 and 2. The table is showing
results of manpower costs, its utilization and its capacity .............................................................. 103
Table 7.7 Builders and breakers capacity used in the Optimization model 2 ............................... 108
Table 7.8 Overview of the different release policies tested in the simulations. The release and order
mechanisms used in each policy are marked by the crosses ............................................................ 110
Table 15.1 Examples of the number of workers on each shift currently at the terminal ................ vii
Table 15.2 Different kinds of ULD states within the simulation model ........................................ xviii
Table 15.3 Comparison of the numerical results for Optimization model 1 and Optimization model
1st part of 2. Table showing the results of manpower costs, its utilization and its capacity ........... xxxii
Table 15.4 Comparison of the numerical results for Optimization model 1st part of 2 and
Optimization model 2. Table showing the results of manpower costs, its utilization and its capacity .... xxxiii
Table 15.5 Comparison of the numerical results for Optimization models 2 and 3. The table is
showing results of manpower costs, its utilization and its capacity ............................................. xxxv
14 Table of graphs

Graph 4.1 Parcel Availability curve for the outbound cargo defined for the optimization model

Graph 7.1 Graph of the number of ULDs on time and builders and breakers’ utilization depending on the PA factor

Graph 7.2 Graph of the number of ULDs on time and builders and breakers’ utilization depending on the Expected production time factor

Graph 7.3 Graph of the number of ULDs on time and builders and breakers’ utilization depending on the Latest release time

Graph 7.4 Graph of the number of ULDs on time and builders and breakers’ utilization depending on the Conwip factor

Graph 7.5 Graph comparing the Policy A performances using Lowest or Highest Processing time to give the Priority to be piked up by the crane to ULDs

Graph 7.6 Graph showing the percentage of ULDs processed on time depending on the Parcel Availability factor. The simulations results for the three policies A, B and C are showed

Graph 7.7 Graph showing for each release policy (A, B and C) the builders’ utilization obtained from the simulations compared with the builders’ utilization of the optimization model. Also the built kilograms are showed. Everything depending on the PA factor

Graph 7.8 Graph showing for each release policy (A, B and C) the breakers’ utilization obtained from the simulations compared with the breakers’ utilization of the optimization model. Also the broken kilograms are showed. Everything depends on the PA factor

Graph 7.9 Graph showing the % of ULDs on time and built and broken Kg for any PA factor

Graph 7.10 Graph showing the % of builders’ utilization for any PA factor. It is showed also the % for the time the builders are idle, taking a break or moving around the terminal

Graph 7.11 Graph showing the % of breakers’ utilization for any PA factor. It is showed the % for the time the breakers are idle, taking a break or moving around the terminal

Graph 7.12 Graph showing the build WS occupation. It can be seen the % of time that the WS is empty, with one ULD but without builder working on it and with 1 or 2 builders working on the ULD

Graph 7.13 Graph showing the build WS occupation. It can be seen the % of time that the WS is empty, with one ULD but without builder working on it and with 1 or 2 builders working on the ULD

Graph 7.14 Graph showing the building and breaking total process duration and one only at WS

Graph 7.15 Graph showing the time which the ULD is waiting for the crane to get to the WS or to leave them

Graph 7.16 Graph showing the number and duration of blockings at building and breaking WS

Graph 7.17 Graph showing the percentage of ULDs processed on time depending on the Conwip factor when releasing according to Policy B combined with PA and Conwip

Graph 7.18 Graph showing the builders’ utilization obtained from the simulations compared with the builders’ utilization of the optimization model when releasing according to Policy B combined with PA and Conwip

Graph 7.19 Graph showing the builders’ utilization obtained from the simulations compared with the builders’ utilization of the optimization model when releasing according to Policy B combined with PA and Conwip
Graph 7.20 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 1 and simulation using the workers’ schedule provided by Optimization model 1b (bnb). ........................................................................................................................................................ 91

Graph 7.21 Comparison of builders’ utilization and Built Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and simulation using the workers’ schedule provided by Optimization model 1b (bnb). ........................................................................................................................................................ 91

Graph 7.22 Comparison of breakers’ utilization and Broken Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and simulation using the workers’ schedule provided by Optimization model 1b (bnb). ........................................................................................................................................................ 92

Graph 7.23 Parcel Availability curve for the outbound cargo defined for the optimization model... 98

Graph 7.24 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 1 and simulation using the workers’ schedule provided by Optimization model 2 .......................................................................................................................................................... 100

Graph 7.25 Comparison of builders’ utilization and Built Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and simulation using the workers’ schedule provided by Optimization model 2 .......................................................................................................................................................... 101

Graph 7.26 Comparison of breakers’ utilization and Broken Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and simulation using the workers’ schedule provided by Optimization model 2 .......................................................................................................................................................... 102

Graph 7.27 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 2 and releasing the ULD to WS according to Policy B or B2. ................................................................. 113

Graph 7.28 Comparison of builders’ utilization and Built Kg obtained from simulations using the workers’ schedule provided by Optimization model 2 and releasing the ULD to WS according to Policy B and B2. .......................................................................................................................................................... 114

Graph 7.29 Comparison of breakers’ utilization and Broken Kg obtained from simulations using the workers’ schedule provided by Optimization model 2 and releasing the ULD to WS according to Policy B and B2. .......................................................................................................................................................... 114

Graph 7.30 Graph showing the percentage of ULDs processed on time depending on PA factor. The simulations results for Policy B2 releasing by PA and PA depending on WIP setting Conwip factor to 1 and for any PA factor are showed .......................................................................................................................................................... 118

Graph 7.31 Graph showing the builders’ utilization and the number of kg built depending on PA factor. The simulations results for Policy B2 releasing by PA and PA depending on WIP setting Conwip factor to 1 and for any PA factor are showed .......................................................................................................................................................... 118

Graph 7.32 Graph showing the breakers’ utilization and the number of Kg broken depending on PA factor. The simulations results for Policy B2 releasing by PA and PA depending on WIP setting Conwip factor to 1 and for any PA factor are showed .......................................................................................................................................................... 119

Graph 7.33. Performances comparison when releasing according to Policy B2 and A2 combined with PA depending on WIP release mechanism .......................................................................................................................................................... 121

Graph 15.1 Graph showing the percentage of ULDs prosseced on time depending on the Conwip factor. The simulations results for the three policies A, B and C are showed .......................................................................................................................................................... xxvii

Graph 15.2 Graph showing for each release policy (A, B and C) the builders’ utilization obtained from the simulations compared with the builders’ utilization of the optimization model. Also the built kilograms are showed. Everything depending on the Conwip factor .......................................................................................................................................................... xxvii
Graph 15.3 Graph showing for each release policy (A, B and C) the breakers’ utilization obtained from the simulations compared with the breakers utilization of the optimization model. Also the broken kilograms are showed. Everything depending on the Conwip factor.......................................................... xxviii
Graph 15.4 Graph showing the build WS occupation. It can be seen the % of time that the WS is empty, with one ULD but without builder working on it and with 1 or 2 builders working on the ULD ......... xxix
Graph 15.5 Graph showing the break WS occupation. It can be seen the % of time that the WS is empty, with one ULD but without builder working on it and with 1 or 2 breakers working on the ULD ......... xxix
Graph 15.6 Graph showing the building and breaking total process duration and one only at WS xxix
Graph 15.7 Graph showing the time which the ULD is waiting for the crane to get to the WS or to leave them ...................................................................................................................................................... xxx
Graph 15.8 Graph showing the number and duration of blockings at building and breaking WS....xxx
Graph 15.9 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 1 and Optimization model 1st part of 2.......................................................... xxxi
Graph 15.10 Comparison of builders’ utilization and built Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and Optimization model 1st part of 2 .................. xxxi
Graph 15.11 Comparison of breakers’ utilization and broken Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and Optimization model 1st part of 2 .................. xxxi
Graph 15.12 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 1st part of 2 and Optimization model 2.......................................................... xxxii
Graph 15.13 Comparison of builders’ utilization and build Kg obtained from simulations using the workers’ schedule provided by Optimization model 1st part of 2 and Optimization model 2........................... xxxii
Graph 15.14 Comparison of breakers’ utilization and broken Kg obtained from simulations using the workers’ schedule provided by Optimization model 1st part of 2 and Optimization model 2........................... xxxiii
Graph 15.15 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 2 and simulation using the workers’ schedule provided by Optimization model 3 .......................................................... xxxiv
Graph 15.16 Comparison of builders’ utilization and Built Kg obtained from simulations using the workers’ schedule provided by Optimization model 2 and simulation using the workers’ schedule provided by Optimization model 3.......................................................... xxxiv
Graph 15.17 Comparison of breakers’ utilization and Built Kg obtained from simulations using the workers’ schedule provided by Optimization model 2 and simulation using the workers’ schedule provided by Optimization model 3.......................................................... xxxiv
Optimization of a Cargo Terminal

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APPENDIX

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15 Appendix

15.1 Optimization model. Formulation and notation

15.1.1 Indices and sets

\[ q \in Q \] Type of work \( Q = \{p, f\} \), part and full time. Constrain 12 in the model uses \( q \) and \( p \) referring at type of work.

\[ Q \] Set of different work types, part and full

\[ t \in \{1, \ldots, T\} \] Period \( t \) is defined from \( t - 1 \) to \( t \)

\[ s \in S \] Shifts are defined by their starting times

\[ S \] Set of part time and full time shifts for the whole planning horizon

\[ E_{q,t} \] Set of all shifts for type \( q \) workers which include period \( t \).

\[ E_{p,1} = \{142, 143, 144, 1\} \quad E_{f,1} = \{138, 139, 140, 141, 142, 143, 144, 1\} \]

15.1.2 Parameters

\( a \) Manpower consumption for building up one kilogram of cargo

\( b \) Manpower consumption for breaking down one kilogram of cargo

\( c_{s,q}^{\text{build}} \) Cost of shift \( s \) for type \( q \) build up workers

\( c_{s,q}^{\text{break}} \) Cost of shift \( s \) for type \( q \) break down workers

\( d_t \) Demand (kg) for the outbound cargo at the end of period \( t \).

\( e_t \) Demand (kg) for the inbound cargo at the end of period \( t \).

\( l_q \) Maximum number of shifts for type \( q \) workers each day

\( r_q \) Shift length (hours) for each type \( q \) of work

\( L(j) \) Percentage of cargo arriving up to time \( t - j \) that account for the cargo demand for the flights departing at the end of period \( t \)

\( B \) Number of periods in a day

\( D \) Number of days in the planning horizon

\( M \) Large positive value

\( N \) Manpower capacity of all WS
\[N_{q}^{\text{build}}\] Maximum number of type \( q \) build up man-shifts over the planning horizon

\[(\#\text{workers/shift*shifts} \text{ for the planning horizon})\]

\[N_{q}^{\text{break}}\] Maximum number of type \( q \) break down man-shifts over the planning horizon

\[(\#\text{workers/shift*shifts} \text{ for the planning horizon})\]

\[T\] Number of periods in the planning horizon \( T = B \cdot D \)

\[\tau\] Maximum number of periods during which the outbound cargo can be built up

\[\omega\] Maximum number of periods during which the inbound cargo must be broken down

\[\eta\] Maximum share of build up and break down workload performed by part time workers

### 15.1.3 Decision variables

\[g_{s,q}^{\text{build}}\] Number of type \( q \) build up workers in shift \( s \)

\[g_{s,q}^{\text{break}}\] Number of type \( q \) break down workers in shift \( s \)

\[h_{s,q}\] Binary variable indicating if a shift \( s \) exists for type \( q \) workers

\[u_{t+j,t}\] Break down quantity (kg) in period \( t + j \) for the inbound cargo arriving at the end of period \( t \). \((j = 1,\ldots,\omega)\)

\[v_{t}\] Total break down quantity (kg) in period \( t \)

\[x_{t-j,t}\] Build up quantity (kg) in period \( t - j \) for the outbound cargo departing at the end of period \( t \). \((j = 0,\ldots,\tau - 1)\)

\[y_{t}\] Total build up quantity (kg) in period \( t \)

### 15.1.4 MIP model

\[
\text{Min} \sum_{s \in S} \sum_{q \in Q} (c_{s,q}^{\text{build}} g_{s,q}^{\text{build}} + c_{s,q}^{\text{break}} g_{s,q}^{\text{break}})
\]
\[
\sum_{j=0}^{\tau-1} x_{t-j,t} = d_t \quad t = 1, \ldots, T
\]  
(2)

\[
\sum_{j=k}^{\tau-1} x_{t-j,t} \leq L(k)d_t \quad t = 1, \ldots, T, k = 1, \ldots, \tau - 1
\]  
(3)

\[
\sum_{j=0}^{\tau-1} x_{t+j,j} = y_t \quad t = 1, \ldots, T
\]  
(4)

\[
\sum_{j=1}^{\omega} u_{t+j,t} = e_t \quad t = 1, \ldots, T
\]  
(5)

\[
\sum_{j=1}^{\omega} u_{t-j,t} = v_t \quad t = 1, \ldots, T
\]  
(6)

\[
ay_t \leq \sum_{q \in Q} \sum_{s \in S, q} g_{s,q}^{\text{build}} \quad t = 1, \ldots, T
\]  
(7)

\[
ay_t + bv_t \leq \sum_{q \in Q} \sum_{s \in S, q} g_{s,q}^{\text{build}} + g_{s,q}^{\text{break}} \quad t = 1, \ldots, T
\]  
(8)

\[
\sum_{q \in Q} \sum_{s \in S, q} g_{s,q}^{\text{build}} + g_{s,q}^{\text{break}} \leq N \quad t = 1, \ldots, T
\]  
(9)

\[
\sum_{s \in S} g_{s,q}^{\text{build}} \leq N_{\text{build}}^q \quad q \in Q
\]  
(10)

\[
\sum_{s \in S} g_{s,q}^{\text{break}} \leq N_{\text{break}}^q \quad q \in Q
\]  
(11)

\[
\sum_{s \in S} r_p (g_{s,p}^{\text{build}} + g_{s,p}^{\text{break}}) \leq \eta \sum_{s \in S} \sum_{q \in Q} r_q (g_{s,q}^{\text{build}} + g_{s,q}^{\text{break}})
\]  
(12)

\[
\sum_{s \in S} h_{s,q} \leq D \cdot l_q \quad q \in Q
\]  
(13)

\[
g_{s,q}^{\text{build}} \leq M h_{s,q} \quad q \in Q, s \in S
\]  
(14)

\[
g_{s,q}^{\text{break}} \leq M h_{s,q} \quad q \in Q, s \in S
\]  
(15)

\[
h_{s,q} = h_{s+jr_q,q} \quad q \in Q, s = 1, \ldots, r_q, j = 1, \ldots, l_q - 1
\]  
(16)

\[
h_{s,q} = h_{s+jB_q,q} \quad q \in Q, s = 1, \ldots, B, j = 1, \ldots, D - 1
\]  
(17)

\[
x_{t-j,t} = x_{T+t-j,t} \quad \text{if} \quad t - j \leq 0, t = 1, \ldots, T, j = 1, \ldots, \tau - 1
\]  
(18)

\[
x_{t,t+j} = x_{t, \text{mod}(t+j,T)} \quad \text{if} \quad t + j \geq T + 1, t = 1, \ldots, T, j = 0, \ldots, \tau - 1
\]  
(19)

\[
u_{t-t-j} = u_{t,T+t-j} \quad \text{if} \quad t - j \leq 0, t = 1, \ldots, T, j = 1, \ldots, \omega
\]  
(20)
\[ u_{t+j,t} = x_{\text{mod}(t+j,T)}, t \quad \text{if} \quad t + j \geq T + 1, t = 1, \ldots, T, j = 0, \ldots, \omega \quad (21) \]
\[ x_{t-j,t} \quad y_t \geq 0, t = 1, \ldots, T, j = 0, \ldots, \tau - 1 \quad (22) \]
\[ u_{t+j,t} \quad v_t \geq 0, t = 1, \ldots, T, j = 1, \ldots, \omega \quad (23) \]
\[ g_{s,q}^{\text{build}}, g_{s,q}^{\text{break}} \geq 0 \quad \text{and integer, } q \in Q, s \in S \quad (24) \]
\[ h_{s,q} \in \{0, 1\} \quad q \in Q, s \in S \quad (25) \]

(1) Objective function which minimizes the manpower costs over the planning horizon
(2) Cumulative build up quantities in the previous $\tau$ periods up to period $t$ which should satisfy the demand at the end of period $t$
(3) Connection between the cumulative build up quantities prior to $t$ and the arrival pattern of the outbound cargo. This constraints guarantee that cargo is actually available when the build up occurs.
(4) Total built up cargo during period $t$
(5) The inbound cargo must be broken down within $\omega$ periods.
(6) Total broken down cargo during period $t$
(7) Left hand side: Manpower requirements for build up operations
Right hand side: Number of build up workers in each period
(8) Left hand side: Manpower requirements for build up and break down operations
Right hand side: Number of build up and break down workers in each period
(9) Only a limited number of workers can work simultaneously at the WS.
(10) Enforce the limits on the availability of different types of build up workers over the planning horizon.
(11) Enforce the limits on the availability of different types of break down workers over the planning horizon.
(12) Ensure that the share of build up and break down workload performed by the part time workers does not exceed a given maximum
(13) Enforce the limits on the number of shifts for different types of work.
(14) Build up workers can be assigned to a shift only when that shift exists.
(15) Break down workers can be assigned to a shift only when that shift exists.
(16) It is applied only if the shifts are non-overlap for different types of workers.
(17) Shifts schedules repeat from day to day.
(18)-(21) Boundary conditions for build up and break down quantities and generate a cyclic shift schedule.
(22)-(25) Define variable domains.
15.2 Simulation Model

The simulation software used to build the simulation model is PRO-MODEL 4.2, which is discrete event simulation software, used for planning, designing and evaluating warehouses, logistics and other operational and strategic situations.

15.2.1 Data sources

The data inputs are obtained from the previous project by Spirit Air Cargo Handling and meetings with its managers. This data is presented in the following paragraphs:

Master file with transcript of ULD movements

This file shows all the registered ULD movements in the system during the period 4.9.06- to 9.9.06 and its the corresponding time, ULD type and Flight Company.

Flight schedules with departing and arriving ULDs

This file shows the departure/arrival time and the weight of the ULD, as well as the flight company and the flight number.
**Personnel schedules**

This file shows the shifts and number of workers per shift that are currently working on the ULD production at the Spirit Air Cargo terminal.

<table>
<thead>
<tr>
<th>Day</th>
<th>Shift</th>
<th>Full builders</th>
<th>Full breakers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7-15</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>15-23</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td>23-7</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>7-15</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>15-23</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>23-7</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 15.1 Examples of the number of workers on each shift currently at the terminal

**Production information 2006 for Spirit Air Cargo Handling**

This file shows production information and the distribution of import/export and transfer cargo for each week over couple of years, and the production distribution of the weekdays, as well as the trend in the production.

The manipulation processes, based on the files explained before, to get the data ready to use it as input in Pro-Model is explained in detail on Chapter 6 of the previous project report [11]. The final excel file version which includes all the data that ProModel needs to run the simulation is presented on Section 15.2.6.

15.2.2 Simulation model build-up

The aim of this section is to give a basic description of the simulation model building.

There are two possible modeling alternatives, push or pull approach. The pull approach consists in using an existing flight schedule to generate the total inbound and outbound cargo volume for each aircraft, in terms of number of ULDs and number of kilos in a ULD.

It has been decided to use the pull approach, enabling to design and compare different release policies. Since ProModel does not work with a pull approach this has been simulated by assigning a departure time to each ULD. The ULDs are then being
“pulled out” according to departure time.

Locations. Routing and processing there.

Locations in ProModel can be physical or just for simulation purposes. Routing is the definition of the different ways a ULD can move in the model. Processing is done when an entity enters a location and it will be described further on in the definition of each location.

1. Truck arrival & Departure Select one of TD01..06 for ULD arrivals into the terminal. They are selected in the order TD06..01 according to current utilization, that was found out in the Excel file provided by Spirit Air Cargo Handling.

2. Truck Docks (TD) For ULDs going into the model the crane PET01 is used to move the ULDs to conveyer for transporting them into terminal. Output data is written for each ULD going out from the model the.

3. USIN Landside For ULDs going into model: Forwarding to conveyer. For the ULDs going out from the model: Forwarding to TD.
4. **Euro pallet store** There is no physical location for the Euro pallet store.

5. **Meeting point for Breakers** Location where the Breakers are waiting until they find work to do in the workstations. The logic that determines on which ULD has to work a worker is showed on Section 5.3.

   It runs in the interval 16..30 to find the WS which has the ULD with highest priority with parcel availability and less than 2 workers. If there are two ULDs with the same departure time, then the one with the least load left to break is chosen. All data is saved in the array `currentWorkStationContents` to get an overview over all the WS at the same time and to make it easier to compare values in-between WS.

6. **Meeting point for Builders** It is working as the breakers one with the exceptions that it runs in the interval 1...15 and those builders also have the ability to break so they are looking for breaking work to do too. This activity is performed only if there’s currently no build activity that needs to be done.

![Figure 15.4 Logic that determines if a worker has work to do on the WS and on which ULD has to work first](image-url)
7. Conveyers They are forwarding from air- to landside and vice versa depending on the ULD destination.

8. General arrival Is the location where all ULDs arrive into the model and the following attributes are assigned to them. Afterwards, the routing to origin is done.

- **uldType** The current ULD type
- **uldNumber** The Unique ID of this ULD
- **flightCompany** The owning flight company
- **destination** ULDs destination
- **departureTime** Flight departure time
- **cumulativeWeight** The sequences total weight after this ULD
- **PercentOfTotalOrder** This ULD + previous ones weight of total sequence.
- **origin** 1: TD, 2: empty ULD store, 3: DD
- **buildBreak** 0: Complete, 1: Brake down to 0 kg and then fill up to targetULDload, 2: Brake down to targetULDload from current ULDLoad, 3: Fill up from current ULDLoad to targetULDLoad, 4: Missed flight ULD

Note that in the simulations ULDs with the attribute **buildbreak** equal to 1 are first broken down to 0 kg, then its **buildbreak** attribute turns to be equal to 3 with currentULDLoad equal to 0. Also an important assumption when designing the simulation model is that when a ULD needs to be first broken and after built, it can not go from the breaking WS directly to the building WS, it has to pass first trough the storages.

- **arrivalTime** Arrival time
- **targetULDLoad** The final load of this ULD, then it is ready to be shipped.
- **loadOfTotalOrder** The load of the whole sequence.
- **previousULDsTotalLoads** The load of the previous ULDs in the sequence.

9. Workstations

The workstations are divided into workstation lines with the following simplifications:

- Workstation 01 – 10 ☰ Workstation line 1 (Break)
- Workstation 11 – 20 ☰ Workstation line 2 (Build/break)
- Workstation 21 – 30 ☰ Workstation line 3 (Build)
Since workstation line 2 is a mixed line, workstations 11-15 are used for break operation and workstations 16-20 are used for build operation.

**a) Break Workstations** They are the workstations for performing break operations. As soon as the ULD arrives its values are assigned to the `currentWorkstationContents` array.

When the ULD is at WS the breaking activity can be performed by both builders and breakers. The subroutines `breaking` and `builderBreaking` are used to update current numbers of parcels in the ULD. The activity in the WS is shown in the following *Figure 15.5*.

![Figure 15.5 WS breaking activity where every 2 minutes if the ULD is finished or missed is checked](image)

**b) Build Workstations** Workstations for performing build operations. They are almost the same as the ones for break with only minor differences. The building operation can be only performed by builders and the subroutine `building` is the one used here.

10. **USIN airside** Forwarding from Air- to landside or vice versa. The routing carried out there will be explained on *Section 5.3*

11. **Any ULD storage** Storage for partly or totally built (ready to depart) ULDs. The processing and routing carried out in the storages will be explained on *Section 5.3*
12. **Empty ULD storage** Storage for empty ULDs. The processing and routing carried out in the storages will be explained on *Section 5.3*

13. **Dolly Docks (DD)** The ULDs coming from the airplanes are delivered into the terminal through *DDincoming*. The routing carried out there will be explained on *Section 5.3*. The ULDs going out from the model are delivered out to the airplanes (*DDoutgoing*) and the output data is written for each ULD.

14. **Airside arrival & Departing** Select one of DD08..14 for delivering a ULD into the terminal. DD01...07 are used for delivering the ULDs to the airplanes.

15. **Turn Table (TT)** The link between the WS lines and the crane that takes the ULDs to the storages. They are not simulated as turntables which turn a ULD in the right orientation but as a passage where only one ULD can appear at the time.

*Entities.*

The entities are the items that the system processes. The ones used in the model are:

- **ULD** ULDs being shipped to, from and within the terminal
- **BuildersForklift** The builders’ forklift which facilitate the simulation of the builders’ movements.
- **BreakersForklift** The breakers’ forklift which facilitate the simulation of the breakers’ movements. Further details will be found later on in this section.

*Resources.*

The resources are the items moving the entities around the terminal in the simulation. They can be the personnel or the equipment.

The main equipment used in the model is cranes and forklifts. The details about their movements are explained on the next subsection. Their speed can be defined.

**PET01** Crane used for transporting ULDs between the truck doors on the landside of the terminal.
PET02-03 Cranes used for transporting ULDs between TT and ULD storage on the airside of the terminal.

TV01-03 Forklifts for moving ULDs from the turntables to the WS or vice versa.

The personnel are the workers who build/break down the ULDs:

**Breaker** Worker who breaks down ULDs.

**Builder** Worker who is able to both break down and build up ULDs.

The model has been designed so that there can never be more than two workers on the same WS at the same time. In this way, most of the ULD processing is done by pairs of workers.

*Resources and entities combination.*

ProModel has presented some limitations when creating some parts of the simulation model. They are the following ones:

- *Create workers that work on the most urgent ULD on the workstations which depends of four different factors.*

In ProModel a resource can be sent to work on an entity that has the highest or lowest number of only ONE of its attributes. But in the case of the most urgent ULD it is needed to look at many factors to finally decide which ULD is the most urgent.

For the build ULD, it first has to control if there is a ULD at WS $i$, if it is, then it has to control if there is less than 2 workers there. If this is true, the parcels have to be available for packing into the ULD that is matched in the *ParcelAvailability* subroutine. All these factors tell the worker that he might go here but it does not tell him if this is the most urgent ULD. This is done in a while loop that finally finds the most urgent ULD. The checking procedure has been shown on *Figure 15.7*. Then the builder (in this case the resource) should be sent to the right WS and that gives another problem.
ProModel can not send a resource through a specified route to a location. This can only be done by an entity. Therefore, an entity (in this case: a forklift) is attached to the resource (the worker) so that the forklift moves the worker around.

- **Create workers who should be used for a few minutes (to simulate that the worker builds or breaks) and during this time they should also update the load of the ULD they are working on Figure 15.6.**

The problem is then that since workers are resources, and a resource in ProModel can not change the value of a variable itself, the ULD load can not be upload by the worker but it has to be done by the forklift. It is also needed to send the ULD to the storages when it is finished. This is solved with the array `currentWorkStationContents`, which is updated also by the forklift. Every minute it is read by the ULD and transferred to its ULD load attribute.

*Path network.*

Path networks are designed to define the resource’s movement. One single path network can be used by one or more resources.

- **PET01_PATH** Path network used for PET01 running next to the TD
- **PET02_03_CRANE_PATH** Path network for the PET02 and PET03, non-crossing cranes serving the ULD storage, TT, USIN_AIR and DD.
- **TV01_PATH** Path network for the crane TV01 serving TT01 and WS01-10.
- **TV02_PATH** Path network for the crane TV02 serving TT01 and WS11-20.
- **TV03_PATH** Path network for the crane TV03 serving TT01 and WS21-30.
- **WorkStationsPATH** Path network for connecting workers with WS.
- **TruckNET** Path network for trucks arriving and departing TD.
- **AirPlaneNET** Path network for trucks arriving and departing TD.

*Attributes and variables.*

Attributes in ProModel are local variables defined for every single entity, in this case, single ULDs. Variables in ProModel are global and defined for the whole model.
Subroutines and macros.

Subroutines and macros are used in the model to reduce writing redundant codes as much as possible. A subroutine is called with in-parameters (integer or real) and it returns a value (integer or real). Macros cannot do that, they are called to check a certain part of the simulation code.

- **Subroutines**

  **ParcelAvailability** To obtain the current percentage of parcels available in the terminal according to the parcel availability curve.

  **ULDvisuality** To set the right colour to the ULD, depending on if it is the most urgent or not, and the right ULD load icons for the model.

  **ULDBeingBuilt** For a ULD being built at a WS.

  **Building** The builder carrying out the building operations of ULDs at a WS.

  **ULDBeingBroken** For a ULD being broken at a WS.

  **Breaking**. The breaker carrying out the breaking operations of ULDs at a WS.

  **BuilderBreaking** The builder carrying out breaking operation at a WS because there is no building work to do.

The workers, to carry out the building and breaking operations, are working in a way that they check if the ULD is finished every 5 minutes in order to know if they have to keep on working or the ULD is done and can be sent to the storages. The checking procedure is shown in Figure 15.7. If building or breaking the kilograms missing to finish the ULD takes less than 5 minutes the workers are working on it only during the time they need to finish it. In case the cargo missing to finish the ULD until its TargetULDLoad takes more than 5 minutes, the worker is building or breaking during five minutes and then it checks again if the cargo missing takes more or less than 5 minutes.

```
Build/Break during:
  • If time to break down to Target ULD load < 5 min  ➔ Time to break down to Target ULD load
  • IF not ➔ 5 min
```

*Figure 15.8 Building and breaking process. Checking if the ULD is ready every five minutes.*
TraceReport This subroutine is used for writing tracing data in order to trace every ULDs movement through the model. All movements are written to the sheet trace of the output Excel file order sequencing.

GoToTurnTable Allocating a ULD to a certain WS by checking availWSinLine variables, which inform about which WS are available in the required line.

- Macros

DDincoming Macro for handling incoming ULDs. This macro can release the ULDs to WS, to landside or to ULD storage.

DDoutgoing Macro for handling outgoing ULDs in the airside.

FourtyMinuteRule Working name for rule with which the ULDs are released to the WS certain time before the scheduled departure. This amount of time is defined with the variable FourtyMinuteFactor.

ParcelAvailabilityRule Macro for the parcel availability rule. ULDs are released as soon as all the parcels required are available to build this certain ULD. The percentage of parcels required to release the ULD to WS is defined by the variable ParcelAvailabilityFactor.

ParcelConwip Macro also for the parcel availability rule but some differences with the previous one. In this case the Parcel availability factor, which defines the parcels needed to send the ULD to the WS, depends on the WIP (work in processes) level at the WS.

TakeCareOfMissedULDs Macro for handling ULDs which have missed the flight (there is not enough time to finish the ULD before the departure time). They are sent to the location missedFlightULDStore.

ConwipRuleForStorages Conwip rule for ULD storages. The way it works will be explained on Section 5.3

ConwipRule Conwip rule for the locations USIN_AIR and the incoming DD. It will also be explained on Section 5.3.

BreakRule Taking care of ULDs that needs to be broken so that they don’t have to queue with those ones that only need to be built and need to go through release mechanisms.
Arrivals

An arrival in ProModel defines location, quantity, first time, occurrences and frequency for the entities arrival in the simulation.

The arrival time for the ULDs coming into the model is done according to the Order Schedule imported from the Excel file. Since all ULDs arrive to the model in the first second of simulation, as soon as they get there they are coded in order to make them wait until their arrival time, defined in their attribute Arrivaltime set in the GeneralArrival.

15.2.3 Shifts

All the workers’ individual shift files are defined in ProModels Shift Editor to make builders and breakers work according to shift plans. Shifts for full-time workers are 8 hours long and the ones of part-time workers are 4 hours long. Also breaks have been inserted into the shift. In the case of 8 hours shift, the lunch break is 30 minutes and it has been spread out along the two hours in the middle of the shift, with four different starting times. For 4 hours shifts the break takes 15 minutes and it has been spread out along half an hour in the middle of the shift, so there are two different starting times. See Figure 15.9 and Figure 15.10.

Figure 15.9 Representation of where the breaks have been inserted into full-time shifts

Figure 15.10 Representation of where the breaks have been inserted into part-time shifts

The breaks are spread out in order to avoid all the workers to have breaks at the same time, as it might have a negative influence on the effectiveness of ULD processing.
15.2.4 Parcel availability curve

In order to enable the simulation model to check how many parcels are available for building ULDs at a certain time before flight departure the parcel availability curve has been defined in ProModel. The software can handle distributions but since it does not work in the desired way (input: real or integer, output: percentage value) the subroutine Parcel Availability was created for this purpose. Microsoft Excel has been used to generate the code in an easy way where intervals of 5 minutes have been defined as it can be seen:

```
if ( timeBeforeDeparture > 1370 and timeBeforeDeparture <= 1380) then return 34
if ( timeBeforeDeparture > 1360 and timeBeforeDeparture <= 1370) then return 35
if ( timeBeforeDeparture > 1350 and timeBeforeDeparture <= 1360) then return 35
```

Figure 15.11 Part of the code generated in Excel for the parcel availability curve. The left part is the time interval and the right part is the percentage of parcels available at the terminal.

The output of this curve is the percentage of parcels of the total order which are available to be built at a certain time. This issue is explained with more detail on Section 5.3.

15.2.5 Color code

<table>
<thead>
<tr>
<th>Empty</th>
<th>ULDload &lt; targetULDLoad</th>
<th>ULDload = targetULDLoad</th>
<th>Timeframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td>&gt; 200 minutes to departure</td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
<td>&gt; 100 minutes to departure</td>
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<tr>
<td>Red</td>
<td></td>
<td></td>
<td>&lt; 100 minutes to departure</td>
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<tr>
<td>MissedULD</td>
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</tbody>
</table>

Table 15.2 Different kinds of ULD states within the simulation model
In order to get a clear overview while simulating, a color code for the ULDs has been defined. In this way it is easy to see which ULDs are the busiest ones and if they are full, empty or missed. They are ordered according to the previous table.

15.2.6 Data, Input and Output

An excel file called “order sequencing test.xls”, which includes the following information, has been created.

- Input data that ProModel needs to run the simulations.
- Data that ProModel saves and reads continuously during the simulations.
- The updated Output for KPI results.

All the arrays explained in the following sections are read or saved from or to this excel file.

Final data input

Arrays

**ULDinput** (Sheet: Order Schedule) Array used for data input. It has been constructed based on several data sources already explained on Section 15.2.1. A detailed explanation of the procedure carried out to get this final Excel file can be found on Section 6 of the previous report [11]

![Figure 15.12 Data used as a order schedule in the simulation model](image)

As it can be seen in columns B and C on *Figure 15.12*, orders are groups of ULDs with the same departure time, due to the fact that they belong to the same flight. The
Figure also shows which percentage of freight a single ULD means for the order, the cumulative Kg per each order and the initial and target load for each ULD.

The output of the Parcel availability curve is a percentage of the total order, so to calculate the percentage of cargo available for a single ULD it is needed to use not the percentage the ULD means for the order but the cumulative percentage. In this way, it is possible to know when to start building each of the order’s ULDs.

**numberOfWorkers** (Sheet: *Number of workers*) Number of builders and breakers per hour over the whole simulation period. It is not really used by ProModel since shifts have been defined previously, but it is used as an input in order to analyze Conwip theory, where the number of workers every hour is required to make some calculations. Conwip Theory will be explained on Section 5.3.

![Figure 15.13 Data input for workers](image)

**currentWorkStationContents** (Sheet: *WS Lines*) Array that saves the current contents of the workstations, with the following column indexes:

- **B**: WS number
- **C**: Activity that can be performed at this WS (1 = break; 3 = build)
- **D**: Number of Workers Currently at WS
- **E**: DepartureTime - estimatedTimeToFinishULD
- **F**: currentULDLoad
- **G**: TargetULDLoad
- **H**: Is there a ULD at WS?
Data output

Arrays

Since ProModel’s Statistics module is not good enough for the purpose, an overview of all necessary data that has been exported as is presented below.

Tracearray (Sheet: trace) Array used for tracking every single ULDs movement pattern within the terminal.

outputForKPI (Sheet: Output for KPI) Array used for data output. It is possible to divide it in three parts:

- **Output for KPI – ULD Statistics on hour basis**

  The following data can be read:

  - B Hour in the model
  - C Built Kg during given hour
  - D Broken Kg during given hour
  - E Number of missed ULDs during the given hour.
  - F Available number of WS at the shift between two hours.
  - G Total Kg that all builders currently working can handle.
  - H Total Kg that all breakers currently working can handle.
It has to be mentioned that the data exported from ProModel to columns C and D can be in some cases inaccurate. This is due to the fact that the number of kilograms the workers have already built or broken is updated every five minutes; as a consequence, the kilograms processed during the last five minutes of each hour are counted in the next hour. This is the reason of some incoherencies when the manpower capacity and the kilograms processed of an hour are compared. Incoherencies such the number of kilograms built or broken during one hour is higher than the kilograms all the scheduled workers can handle. The update frequency was reduced in order to solve the problem; however, the simulations turned to be very slow so it was decided to keep updating it every 5 minutes.

- Output for KPI – ULD which have left the terminal

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Figure 15.14 Output for KPI - middle part

- K
  - Planned departure time
- L
  - Departure time from terminal in model
- O
  - On Time or Missed for flight
- Q
  - Build (3), break (1,2), transfer cargo (0) or done (0) (has been processed in terminal).
- R
  - Initial ULD load when entering terminal
- S
  - Target ULD load when leaving terminal
- T
  - This ULDs % in weight of the total order sequence for a flight
- U
  - Kg that needs to be built before departure
- V
  - Estimated time to build
- W
  - Kg that needs to be broken before departure
X Estimated time to break

Y Shortest total processing time if two workers work at the same ULD all the time.

Y Arrival time

- **Output for KPI – Single ULDs movements**

In the right part of the Output for KPI it is possible to track one single ULD movement through the terminal and its timing using the array Tracearray. In addition, the number of ULDs on time is counted as a result of column O in the previous Figure 15.14

![Figure 15.15 Output for KPI - right part with ability to track single ULD movements](image)

**Other output data**

Other output data is taken in order to analyze results in a better way. Some other sheets are created to summarize the data in the same Excel file, called “order sequencing test.xls”.

**Workers’ utilization** Excel sheet where workers’ utilization per hour and its average are calculated using the data from the sheets NumberofWorkers and OutputforKPI in the same Excel file.

Workers’ utilisations are calculated as an average of the number of kg workers can handle each hour and the kilograms built and broken that hour. It is also taken into account when builders extra capacity, meaning the one that is not used for building up processes, is used to do breaking operations. The value of builders and breakers utilization is the average of its utilization every hour.
Statistics Some of the statistics which ProModel gets as a result of each simulation are exported also to the excel file in order to process them and get other results:

- Workers: % time working, % time taking a break, % time moving around the terminal and % time idle.
- Workers at the workstation: % time which there is no worker in the WS, % time which there is a ULD on the WS and one worker working on it, % time which there is a ULD on the WS and two workers working on it.
- Workstations: % time which there is no ULD on the WS % time which there is a ULD on the WS.
- Blockings: number of blockings (the ULD cannot be released to the WS because they are all full, with a ULD on it) during the whole simulation period and their average duration.

Results This sheet is done with the only intention of summing up all the desired outputs of each simulation. It can be seen in Figure 15.16.

The first table shows the percentage of ULDs on time and the time while the ULD has to wait for the crane. *Wait for the crane 1* is the average time (min) that ULDs are waiting for the crane to go from the storage until the turn table, in order to get to WS, and *Wait for the crane 2* is the average time a ULD is waiting for the crane in the turn table to go to the next destination (Storages, \( D_{Outgoing} \) or \( Usinairside \) for truck departure) after being processed in the WS. These times have been calculated based on the *Trace array* sheet already explained before.
The second table shows firstly the percentage of workers’ utilization taken from the sheet *Workers’ utilization*. Secondly, the percentage of kilograms built and broken above the total number of kg that were to be processed in order to make all the ULDs on time is presented. Finally, the duration (min) of building and breaking procedures which is calculated based on the *Trace array* sheet already explained before. The building procedure is measured in two different ways. The first timing is since the ULD becomes ready to be released to the WS until the time when it arrives to the next location after the building process (Storages, *DDoutgoing* or *Usin airside* for truck departure). The second one is just measuring the time the ULD spends on the WS, like the one for the breaking procedure.

The third table shows the percentage of time that workers are working, moving themselves around the terminal, taking a break or just idle looking for more work that needs to be done. Besides it shows the number of blockings and its average duration.

The last table shows the percentage of time with no worker and no ULD at WS, with ULD but no worker and with one and two workers processing a ULD.

15.2.7 *Assumptions and simplifications in the simulation model building*

- In the simulation model no flights are cancelled or delayed.
- Only general cargo is considered (no dangerous, fragile, temperature controlled, radioactive or high value cargo is included).
- All the ULDs are 10ft ULDs (no 20ft are simulated)
- No cooler / freezer ULDs, which need a special storage location, are simulated
- Currently at Spirit Cargo terminal extra high priority ULDs are processed in a special WS for that purpose. This is not simulated here.
- Parcels arrive smoothly according to the parcel availability curve, as described on Section 15.2.4.
- ProModel considers that a ULD which has been released to the WS with less than 100% of parcel availability stays there until the rest of the parcels arrive and it can be completely built.
• ULDs that have to be both built and broken cannot change from a Breaking WS to a Building WS station directly, they have to go to the storage in between and wait to be released to build.

• In the simulation model, ULDs which have been considered missed, which means that they do not have enough time to be processed before its departure time, will never be processed. This is not how it really works in the Terminal, where ULDs are processed and then delivered with delay.
15.3 **A, B and C policies’ comparison (Simulations with WIP check)**

Graph 15.1 Graph showing the percentage of ULDs processed on time depending on the Conwip factor. The simulations results for the three policies A, B and C are showed.

Graph 15.2 Graph showing for each release policy (A, B and C) the builders’ utilization obtained from the simulations compared with the builders’ utilization of the optimization model. Also the built kilograms are showed. Everything depending on the Conwip factor.
Graph 15.3 Graph showing for each release policy (A, B and C) the breakers’ utilization obtained from the simulations compared with the breakers utilization of the optimization model. Also the broken kilograms are showed. Everything depending on the Conwip factor.
15.4 *Stage C. Accurate analysis of Policy B (Simulations with WIP check)*

**Building WS occupation**

Graph 15.4 Graph showing the build WS occupation. It can be seen the % of time that the WS is empty, with one ULD but without builder working on it and with 1 or 2 builders working on the ULD.

**Breaking WS occupation**

Graph 15.5 Graph showing the break WS occupation. It can be seen the % of time that the WS is empty, with one ULD but without builder working on it and with 1 or 2 breakers working on the ULD.

**Building - Breaking process duration**

Graph 15.6 Graph showing the building and breaking total process duration and one only at WS.
Optimization of a Cargo Terminal

Appendix

Graph 15.7 Graph showing the time which the ULD is waiting for the crane to get to the WS or to leave them.

Graph 15.8 Graph showing the number and duration of blockings at building and breaking WS.
15.5  **Stage 2. Optimization model 2. Arrival curve and capacities**

15.5.1  **First part of Optimization model 2 (Arrival Pattern)**

Graph 15.9  Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 1 and Optimization model 1st part of 2

Graph 15.10  Comparison of builders’ utilization and built Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and Optimization model 1st part of 2

Graph 15.11  Comparison of breakers’ utilization and broken Kg obtained from simulations using the workers’ schedule provided by Optimization model 1 and Optimization model 1st part of 2
| COST (cost units) | Optimization model 1 | Variation (|/|%) | Optimization model 1st part of 2 |
|------------------|----------------------|--------------|-------------------------------|
|                  | 11.793               | -0.5%        | 11.730                        |
| Optimization model utilization (%) | Build 99.44% | 0.2% | 99.68% |
| Break 97.70% | -0.3% | 97.45% |
| Total manpower capacity (Kg) | Build 793.512 | -2.8% | 771.264 |
| Break 557.136 | 4.1% | 580.032 |

Table 15.3 Comparison of the numerical results for Optimization model 1 and Optimization model 1st part of 2. Table showing the results of manpower costs, its utilization and its capacity

15.5.2 **Second part of Optimization model 2 (Capacity-breaks)**

Graph 15.12 Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 1st part of 2 and Optimization model 2

Graph 15.13 Comparison of builders’ utilization and build Kg obtained from simulations using the workers’ schedule provided by Optimization model 1st part of 2 and Optimization model 2
Graph 15.14 Comparison of breakers’ utilization and broken Kg obtained from simulations using the workers’ schedule provided by Optimization model 1st part of 2 and Optimization model 2

<table>
<thead>
<tr>
<th></th>
<th>Optimization model 1st part of 2</th>
<th>Variation (DHSZ)</th>
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<tr>
<td>COST (cost units)</td>
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<tr>
<td>Optimization model utilization (%) Build</td>
<td>99.68%</td>
<td>-0.5%</td>
<td>99.20%</td>
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<tr>
<td>Optimization model utilization (%) Break</td>
<td>97.45%</td>
<td>1.3%</td>
<td>98.70%</td>
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<tr>
<td>Total manpower capacity (Kg) Build</td>
<td>771.264</td>
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<td>782.154</td>
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<tr>
<td>Total manpower capacity (Kg) Break</td>
<td>580.032</td>
<td>3.9%</td>
<td>565.248</td>
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</table>

Table 15.4 Comparison of the numerical results for Optimization model 1st part of 2 and Optimization model 2. Table showing the results of manpower costs, its utilization and its capacity.
### 15.6 Stage 3. Optimization model 3. Capacities

![Graph 15.15](image1.png)

**Graph 15.15** Comparison of ULDs on time obtained from simulations using the workers’ schedule provided by Optimization model 2 and simulation using the workers’ schedule provided by Optimization model 3

![Graph 15.16](image2.png)

**Graph 15.16** Comparison of builders’ utilization and Built Kg obtained from simulations using the workers’ schedule provided by Optimization model 2 and simulation using the workers’ schedule provided by Optimization model 3

![Graph 15.17](image3.png)

**Graph 15.17** Comparison of breakers’ utilization and Built Kg obtained from simulations using the workers’ schedule provided by Optimization model 2 and simulation using the workers’ schedule provided by Optimization model 3
<table>
<thead>
<tr>
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<th>Variation (sent2sent)</th>
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<td><strong>COST (cost units)</strong></td>
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<tr>
<td><strong>Optimization model utilization (%)</strong></td>
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<tr>
<td></td>
<td><strong>Break</strong></td>
<td>98.70%</td>
<td>-7.1%</td>
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<tr>
<td><strong>Total manpower capacity (Kg)</strong></td>
<td><strong>Build</strong></td>
<td>782.154</td>
<td>4.0%</td>
</tr>
<tr>
<td></td>
<td><strong>Break</strong></td>
<td>565.248</td>
<td>10.3%</td>
</tr>
</tbody>
</table>

Table 15.5 Comparison of the numerical results for Optimization models 2 and 3. The table is showing results of manpower costs, its utilization and its capacity.
15.7 Stage 1. Optimization model 1b. Builders breaking validation

Figure 15.17 Graph showing the performance of workers’ schedule provided by Optimization model 1b for building operations. It also shows the manpower capacity provided by Optimization model 1.

Figure 15.18 Graph showing the performance of workers’ schedule provided by Optimization model 1b for breaking operations. It also shows the manpower capacity provided by Optimization model 1.
15.8 Stage 2. Optimization model 2. Arrival curve and capacities

Figure 15.19 Graph showing the performance of workers’ schedule provided by Optimization model 1 for breaking operations. It also shows the manpower capacity provided by Optimization model 2.

Figure 15.20 Graph showing the performance of workers’ schedule provided by Optimization model 1 for breaking operations. It also shows the manpower capacity provided by Optimization model 2.
15.9 Stage 3. Optimization model 3. Capacities

Figure 15.21 Graph showing the performance of workers’ schedule provided by Optimization model 2 for breaking operations. It also shows the manpower capacity provided by Optimization model 3.

Figure 15.22 Graph showing the performance of workers’ schedule provided by Optimization model 2 for breaking operations. It also shows the manpower capacity provided by Optimization model 3.
15.10 Last stage. ULDs’ release at the Spirit Air Cargo terminal and leveling

**Figure 15.23** Graph showing the demand levelling achieved for breaking operations by the simulation model

**Figure 15.24** Graph showing the demand levelling achieved for breaking operation by the simulation model