Time-window based Truck Appointment System with Adaptive Slot management and Real-Time Truck Information

A case study for the loading operations in a Chemical Plant

VASILEIOS SKOULAS

Master Thesis

Time-window based Truck Appointment System with Adaptive Slot management and Real-Time Truck Information

A case study for the loading operations in a Chemical Plant

by

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Preface

This thesis is the last step towards obtaining my Master of Science in Transport, Infrastructure, and Logistics at Delft University of Technology. It is the result of hard work and dedication in solving a real-world problem in the field of logistics, which is of great importance for society as well as an interest of mine since the beginning of my studies.

Firstly, I would like to thank Prof. Lori Tavasszy for providing me with a state-of-the-art and captivating thesis research topic that aligned with my academic interests and professional aspirations. His responsiveness, critical reflections and guidance helped me towards the successful completion of this thesis. Furthermore, I would like to thank Dr. Ron van Duin for his supervision, insightful feedback and comments on the academic side of the research. Furthermore, I would like to thank Ir. Mark Duinkerken who through our discussions, critical remarks and his expertise on optimization models assisted me during the course of this project. Last but not least I would like to express my gratitude towards Dr. Vanga Ratnaji who was always available to guide me through the research process, discuss problems that occurred and give practical insights on the case study.

Finally, I want to thank my family and friends for their unconditional support and motivation throughout this academic journey in TU Delft and for the completion of my master thesis.

Vasileios Skoulas
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Executive Summary

Long truck queues, parked trucks on the roadside, and congestion around logistic sites, like container terminals and chemical plants, is a common sight (Wibowo & Fransoo, 2020). However, these queues outside the gates of the logistics sites come with many negative externalities for both terminal operators and trucking companies as well as for the environment and the population living in the surrounding areas. Consequently, to face these problems a few solutions have been proposed in the literature which can be classified into three large categories which are the terminal's expansion, the improvement of the terminal's efficiency and the management of truck arrivals. From these categories, the Truck Arrival Management (TAM) has gained the most attention and specifically the Truck Appointment System (TAS) is the most researched and implemented system of this category, as it is a relatively low-cost solution which has already been implemented in many container terminals since the early 2000s. TAS aims to control trucks arrival rate with the objective to smooth out truck arrivals and maintain gate congestion under a certain level or unlikely to happen and thus reduce congestion and emissions around terminals (Chen et al., 2013; Sharif et al., 2011; Wibowo & Fransoo, 2020). However, practical experience shows that TAS performance is not uniform and in its typical form has a few drawbacks, like its inflexibility (strict schedule) and low resilience against disruptions. Thus, new research on the field focuses on improving TAS's robustness and efficiency especially against disturbances while at the same time increasing the compliance of the trucking companies to the TAS with the use of new approaches and technologies. Furthermore, the vast majority of research on the TASs is focused on container terminals, despite the fact that other types of terminals, like chemical plants and bulk terminals, face the aforementioned issues as well. Hence, further research is required in these types of terminals, especially in order to capture the special characteristics of these terminals. Consequently, the focus of this research is on the development of a new TAS, with the use of truck specific time-windows and real-time truck information, for the loading operations in a Chemical Plant.

Based on the problem description and the identified research gaps, the Main Research Question is formulated as follows:

"What is the effect of a Time-Window based Truck Appointment System (TAS) on the performance of the loading facility at a chemical plant for the different stakeholders?"

The Chemical Plant used as a case study in the present thesis is located in the Antwerp region of Belgium. The inbound logistics (supply), for this plant, are performed through marine transportation, while the outbound logistics (delivery to the final customers) are performed through road and rail. However, in the present research, only the road outbound logistics are considered. Further, the focus of this research is limited to the loading operations of the chemical plant and the road transportation of the finished products to the customers, yet the final delivery of the products to the customers is out of the scope of this research. These components form the system boundary for this research. For each truck arriving at the plant, from their arrival at the plant's gates until their departure from the plant, there is a strictly defined path, that each truck follows during which different tasks are completed at each step. The main tasks of this path are the truck entrance through the Plant's Gates, the announcement of the truck's arrival at the plant, and the check of their documents which is carried out at the Documents Check Point (DCP), the weight of the truck at the Scale, the loading process of the truck at the Loading Bays, the weight of the truck at the Scale after the loading has been completed, the completion of the paperwork at the DCP and finally the exit of the truck from the Plant's Gates. The Stakeholders for this project are the Chemical Plant, the Trucking Companies (carriers), and the Authorities, which have different interests and objectives – often contradictory. The KPIs that are used in this research are the Gate Waiting Time, the Slot Utilization, and the Finish Time (Makespan), with the first one being important for the Carriers and the Authorities and the last two being important for the Chemical Plant.

In this Chemical Plant, a typical TAS has already been implemented. However, as it is a typical TAS with fixed slots, it has a few drawbacks as they are described in the literature and are also highlighted in the case of the currently implemented TAS. These disadvantages are the strict schedule that puts a lot of pressure on the truck drivers to arrive on time, the low resilience of the current system against disruptions and the sub-optimal rescheduling of delayed trucks by the slot manager which mandate better solutions. Hence, a new TAS with the use of time-windows, real-time information, and trucks' Estimated Time of Arrival (ETA) at the plant is proposed in order to resolve the aforementioned drawbacks of the typical TAS. In more detail, in the system proposed here, a time-window is assigned to each truck, with an indicative arrival time in the middle of the time-window. Additionally, the duration of the time-windows is longer than the actual service time. Consequently, there is an overlap between some time-windows. For this reason, an assured service start time and an assurance probability are given to each truck, which show the maximum waiting time for a truck that arrived during its assigned time-window before its loading process starts and with what probability. Consequently, the actual trucks service sequence might be different from the one that was reserved. To determine the actual loading sequence an Optimization model is developed, which is run every "Y" minutes with updated information on the actual and Estimated Time of Arrival of the trucks and creates the adjusted schedule for the loading operations.

Consequently, the Optimization model required for the adaptive slot management, based on real-time information of trucks position, and expected arrival time at the plant, is developed. In more detail, the objective of this optimization model is to schedule the trucks' loading sequence and loading bay assignment, based on their expected arrival times and promised service time, while minimizing the total cost. The total cost consists of two parts, the total waiting cost, resulting from the weighted average of all trucks waiting time, and the penalty cost of not servicing on-time trucks during their assured service start time (AST).

For the assessment of the proposed TAS design, a Simulation model of the system under study is created using Discrete Event Simulation. The main characteristics of the real system, which have been briefly described previously, form the base for the development of this model. These main characteristics/ operations of the system are modeled with different simulation modules together with their interactions and form the Simulation model of this research. Furthermore, the integration of the developed Optimization model in the Simulation model is required, as this rescheduling model is a critical component of the proposed TAS design. Moreover, for the evaluation of the proposed TAS performance, a Base Case Scenario is defined. This scenario forms the base for the fair comparison between the Current and the Proposed TAS designs. Also, the parameters for the Current and the Proposed TAS configurations are determined. These two TAS configurations (designs) are compared based on the Base Case scenario, under the same conditions, and according to their outputs and the obtained KPIs values, the effect of the proposed TAS on the objectives of the different stakeholders is evaluated. Finally, it is noted that both TAS designs are simulated for a 6-month period, during which 6630 trucks are generated for each TAS configuration, Current and Proposed.

From the comparison of the results of these two TAS configurations, it can be deduced that the Proposed TAS performs significantly better compared to the currently in use TAS. The biggest improvement compared to the current system is noticed in the trucks' Gate Waiting Time (KPI 1), as a reduction of around 94.5% in the mean waiting time is achieved, from 91.63 to 5.02 minutes. This KPI is primarily important for the Carriers and the Authorities. In addition, the Makespan (KPI 3), which is important for the Chemical Plant, shows an improvement of around 10%, in comparison to the system used in practice. However, the Slot Utilization (KPI 2), which is important for the Chemical Plant, appears to be the same for both systems. The values, mean and standard deviation (in the parenthesis), of all KPIs for both TAS designs are presented in Table 1 below. Finally, it is noted that in the proposed TAS design, there is not a trade-off on the performance of the different KPIs, meaning that the improvement of one does not result in a deterioration of the others.

	Current		**Proposed**	
KPI 1 – Gate Waiting Time [min]	91.63 (110.92)		5.02 (41.17)	
KPI 2 – Slot Utilization	Theoretical	Actual	Theoretical	Actual
	0.655 (0.093)	0.325 (0.050)	0.654 (0.102)	0.330 (0.054)
KPI 3 – Makespan [min]	1689.63 (280.55)		1530.97 (276.86)	

Table 1: KPIs Analysis between Current and Proposed Design. Mean value and standard deviation in the parenthesis (N=6630 trucks)

In conclusion, based on the preliminary results of this research, a significant improvement on system's performance between the proposed and the current TAS systems can be noticed, with only exception the loading bays utilization, which seems to be the same for both systems. Moreover, it can be concluded that a less strict TAS, compared to the typical one, can improve significantly the system's performance. In addition, these results dictate that some of the severe problems logistics terminals face due to congestion and trucks arrival uncertainty, can be notably improved with the proposed design. Specifically, the remarkable reduction of trucks' average waiting time has a positive effect on the reduction of truck queues length at the plant's gates, as well as the number of trucks waiting with their engines idling in the parking area. Also, congestion around logistics sites can be reduced as the number of trucks waiting on the roadside and in queues will be diminished. Additionally, the reduction of trucks' waiting times increases their Utilization, as their turn-around time is decreased, and reduces their fuel consumption, as they wait for shorter time with their engines idling. Moreover, the environmental footprint of the loading facility –estimated indirectly from the trucks Gate Waiting Time (KPI 3)– is expected to be significantly improved. Indeed, trucks waiting outside the plant's gate or in queues in order to get into the plant are considered in the literature to have a significant contribution on the terminal's environment footprint. Thus, as air pollution and congestion are expected to be reduced the livability of the terminal's surrounding area will be improved. Lastly, the flexible start-times, of the proposed TAS design, improve significantly the system's resilience against the trucks' arrival time-uncertainty. However, more experiments and a small-scale testing of the proposed system in practice would be useful for further confirmation of the obtained results.

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List of Abbreviations

Abbreviation	Explanation
ABM	Agent-Based Modeling
AST	Assured Service Start Time
B-PSFFA	B-Pointwise Stationary Fluid Flow Approximation (Method)
CT	(Service) Completion Time
d1	Currently used TAS, with fixed slots
d2	Proposed TAS, with time-windows
DC	Penalty Cost for not Serving on-time trucks during the promised service time
DCP	Documents Check Point
DES	Discrete Event Simulation
ETA	Estimated (Expected) Time of Arrival
FCFS	First-Come-First-Served
FTMAAS	Freight Traffic Management As A Service
FT	Finish Time
GHS	Greenhouse Gases
GPS	Global Positioning System
GWT	Gate Waiting Time
HFS	Hybrid Flowshop Scheduling
IDTs	Improper Documents
KPI	Key Performance Indicator
L	Session Length
MILP	Mixed Integer Linear Programming
MTO	Make to Order
NIST	National Institute of Standards and Technology
NL	Number of Loading Bays
NLT	Number of Late Trucks
NO_x	Nitrogen Oxides
NR	Number of Reschedules (per truck)
NTBG	Number of Trucks Waiting Before the Gate
Pa	Assurance Probability
PM	Particulate Matter
S_l	Service Duration at loading bay l
SO_x	Sulfur Oxide
Std	Standard deviation
SU	Slot Utilization
TAM	Truck Arrival Management
TAS	Truck Appointment System
TEU	Twenty-foot Equivalent Unit
TL	Maximum Waiting Time for all trucks
VDTW	Vessel Dependent Time-Window
WIP	Work In Progress
WTBG	Waiting Time Before the Gate
WTPD	Waiting Time due to Process Delay
X	Appointment (session) Time

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Chapter 1: Introduction

1.1 Background

Long truck queues, parked trucks on the roadside, and congestion around logistic sites, like container terminals and chemical plants, is a common sight (Wibowo & Fransoo, 2020). However, these queues outside the gates of the logistics sites come with many negative externalities for both terminal operators and trucking companies as well as for the environment and the population living in the surrounding areas.

Terminals are affected by these externalities due to the reduction of their site productivity and the increased risk of accidents, as the traffic is getting higher (CEFIC & ECTA, 2013a; Wibowo & Fransoo, 2020; Chen et al., 2013). While, trucking companies (carriers) are affected by the reduced efficiency or utilization rate of their trucks, the increased fuel consumption and the higher risk of accidents (Neagoe et al., 2021). The environment is affected by the increased emissions of the trucks, which usually have their diesel engines idling while they are waiting in queues (Sharif et al., 2011). In this way, air pollution and greenhouse gases (GHS) are generated. Moreover, some of these air pollutants, produced by the trucks' idling diesel engines, account for a major portion of the total emissions of these pollutants on local and regional level. Such pollutants are particulate matter (PM), nitrogen oxides (NO_x) and sulfur oxide (SO_x) which are considered as a very serious health concern for the population living and working nearby (Giuliano and O'Brien, 2007; Chen et al., 2013; Sharif et al., 2011). The health concerns, due to the increased polluting emissions, and the disruptions from the increased traffic congestion are the two major externalities for the population living nearby (Heilig et al., 2017). Finally, it is important to point out that air pollutants are major contributors to the port's environmental footprint (Heilig et al., 2017), and at a higher level these disruptions, like congestion and queues, can have both an economic and environmental impact on whole supply chains (Heilig et al., 2017).

There are several causes for these long queues and the congestion around the logistic sites. To start with, trucks go to the logistics sites at their own convenient time without any prior notice to the terminal operator. This behavior is caused by the shippers' demands/ schedule and the ship schedules, in the case of ports (Sharif et al., 2011). However, this rational behavior creates long truck queues and traffic, as the number of trucks arriving at the logistics site (demand) exceeds the site's capacity (supply), both for the gates and the servicing equipment and infrastructure (Sharif et al., 2011). In addition, in the case of the Truck Appointment System (TAS), which is one of the most widely researched and used method for facing these externalities, and is explained in detail later, trucks still come early in the morning creating long queues at the gate of the sites regardless their appointment time. This happens due to the fact that the success of the afternoon appointments largely depends on the successful completion, with no major delays, of the morning appointments, an experience from practice that trucking companies have (Huynh et al., 2016). Thus, by doing so the trucking companies try to minimize the risk of getting delayed or being rescheduled to the next day (Huynh et al., 2016). In addition, as Huynh et al. (2016) mention, these delayed appointments create inconvenience and reduce the productivity of the trucking companies, which makes them less motivated to adhere to the appointed slot time. Moreover, disruptions, like traffic jams and bad weather, can occur during trucks operations, which can cause significant delays on truck's arrival time at the logistics site, resulting in a deviation between the scheduled (appointment time) and the actual truck arrival time (Li et al., 2016). But, in most cases of TAS, with fixed slots, if a truck is late then it loses its slot and must book a new available slot (Li et al., 2016). This is another reason that trucking companies prefer to have their trucks waiting outside the logistics sites rather than losing their assigned time slot – they actually try to reduce the probability of losing the time slot –, as the next available time slot for booking might be after a few hours or even the next day. Furthermore, when using a TAS the truck arrival delays can propagate and create even more delays and further reduce equipment's utilization. This occurs as the scheduled time during which the delayed truck was expected to be served the equipment remains idle and when the truck arrives, as its service will start later than the scheduled time, thus it will probably overlap with the next truck's service time creating even larger delays and queues (Li et al., 2016).

In order to face these problems of the long queues, congestion, reduced efficiency of operations, and high air pollution around logistics sites a few solutions have been proposed. These solutions can be classified into three large categories, the first one is to expand the terminal's gates, the second one is to increase the gate and servicing capacity, while the third one is to manage the rate of trucks arrival (Chen et al., 2013; Motono et al., 2016). The expansion of gates and site capacity has serious drawbacks and is not always possible. The main disadvantages of this solution are the high investment cost, the long preparation and completion time, the possibly land unavailability, and the long planning horizon, as it is a strategic decision that increases the risks involved. On the other hand, managing trucks' arrival rate is generally easier and cheaper to be implemented and thus several different methods have been proposed (Chen et al., 2013). The most common truck arrival management (TAM) method is the Truck Appointment System (TAS), which seems to be one of the most effective systems and for which a broad range of research and practical applications can be found in the literature (Neagoe et al., 2021). The aim of the TAS is to control the truck arrivals so that the gate congestion is kept under a certain level. In more detail, in such a system the terminal operator announces some opening hours and entry quota within each hour based on which the trucking companies can book the entry slots that they prefer before their actual arrival at the terminal, this is usually done through a web-based information system (Chen et al., 2013; Wibowo & Fransoo, 2020). Other TAM methods that can be found in the literature are the time-dependent road/ toll pricing, where the toll prices vary depending on the time of the day (Chen et al., 2011) and the installation of webcams showing the site's gates aiming to inform truckers in real-time for the traffic condition at the gates (Sharif et al., 2011). Moreover, another important stakeholder, apart from the terminal operators and carriers, are the governments and provinces which have the power, through regulations and incentives or disincentives, to influence the trucks' arrival pattern and parking locations, especially during peak hours (Neagoe et al., 2021). Finally, it is important to point out that the vast majority of research and consequently the available literature on this topic is focused on container terminals and research about the implementation of TAS in chemical plants is very limited.

1.2 Problem Definition

Despite the wide implementation of the Truck Appointment System in practice and the aforementioned advantages that its implementation has, literature indicates that its performance is not uniform and that some characteristics of the typical TAS can be restrictive and decrease its efficiency and performance (Chen et al., 2013; Li et al., 2016). These attributes are briefly described below.

- The typical TAS is very *restrictive* for trucking companies as the system does not account for any typical disruptions, like congestion which can delay the trucks arrival to the terminal and consequently they lose their appointment and have to schedule a new one. This high inflexibility of the typical TAS appointments is also a major disincentive for the trucking companies to adhere to their booked timeslots.
- Disruptions (delays), on both trucks' and terminal's side, can affect the performance of the logistics site as their equipment is idling for some time and later overtime work might be needed. This shows the *low resilience* of the system *against typical disruptions* (Li et al., 2016).
- It should be noted that in most of the available literature on the TAS, the planning of the available entry quotas and their booking from the trucking companies are made in a fully *deterministic environment*, while in practice both terminals and trucks experience disruptions which affect the effectiveness and the applicability of the implemented TAS.
- The *reduced reliability of the appointment times*, especially in the evenings, when truckers can encounter long delays is another significant drawback of TAS.
- For the proper design of a TAS different methods, terminal's local conditions and site operations should be taken into account. Thus, there is not a universal design formula, which means that for each terminal the TAS should be designed case-specifically (Chen et al., 2013; Wibowo & Fransoo, 2020).
- The TAS has been extensively researched on container terminals, which leaves a large gap in the literature for research in other logistics sites, like chemical plants (Neagoe et al., 2021; Wibowo & Fransoo, 2020).

1.3 Research Gap

Regardless of the extensive use of TAS in practice and the benefits that come from its implementation, literature indicates that in its typical form, TAS has some significant drawbacks, as they have already been explained in Section 1.2 and are more extensively described in Section 2.3. In addition, as literature review shows, the TAS has mainly been researched for container terminals, thus there is a big literature gap for its application and in other logistics sites, like chemical plants (Neagoe et al., 2021; Wibowo & Fransoo, 2020). Further, the planning of the entry quotas in a TAS and their booking is made in a fully deterministic environment, while in practice many unpredictable disruptions can occur which can affect both the effectiveness and the applicability of the developed TAS schedule. Thus, the need of considering the stochasticity of the real world in the new studies on the field is obvious. Also, the successful implementation of a TAS is severely affected by its acceptance and compliance by the carriers. Moreover, it is important to point out that Wibowo & Fransoo (2020) found, by comparing the historic data of trucks performance in 52 chemical plants across Europe, that there is no significant difference in the performance between chemical plants that used TAS and those that did not.

Thus, the literature gaps that the present research aims to fill are the implementation of a TAS in a chemical plant and the proposal of its extension with relaxation of some of its typical and strict constraints, along with the use of new technologies in order to improve system's performance against disruptions and overcome some of the main shortcoming of a typical TAS. In more detail, the use of a TAS in chemical plants is a topic significantly understudied in the literature, as the vast majority of research has been on containers terminals and for chemical plants the study on TAS implementation is very limited. The importance of researching further the TAS in different logistics sites and especially in the chemical industry derives from the fact that for the implementation of such a system there is no universal formula and each terminal's specific characteristics and conditions must be considered, as Chen et al. (2013) and Wibowo & Fransoo (2020) have indicated. In addition, the introduction of a new TAS, in which some of its typical and strict constraints are relaxed, aims at increasing trucking companies' acceptance towards TAS and achieving higher level of adherence to their booked slots while at the same time minimizing some of the shortcomings of the typical TAS, as they are described in the literature. Finally, the use of new technologies, like GPS and real-time information, and approaches aims at exploring the possibilities of proposing a leading-edge system, which can maintain a high level of resilience against common disruptions and can improve terminal's performance.

1.4 Objective and Research Questions

1.4.1 Objective

The goal of this research is to design a time-window based Truck Appointment System (TAS) with the use of real-time information and adaptive slot management. The idea of the proposed model is based on the typical TAS, but with the relaxation of some of its typical and strict constraints and with the use of new technologies – like the GPS and utilization of real-time information.

The proposed system is an extension of the typical TAS, with fixed timeslots, along with rescheduling of the trucks service sequence, based on real-time information about their expected arrival time at the plant. In this design, all trucks can be rescheduled, not only the late ones, with the objective to improve system's utilization level, improve trucks' service level and reduce their waiting times and thus queues. It is important to point out that for the implementation of the proposed system, the position of the trucks heading to the plant is considered to be known in real-time as well as their Expected Arrival Time at the plant. The proposed system is expected to reduce the inflexibility of the typical TAS slots for the truckers, and at the same time to increase the resilience to disruptions of the site's operations. The inflexibility of the typical TAS is expected to be improved for the truck drivers, as in the current system they could only arrive earlier than their appointment time, so that they would not miss it. While, in the proposed system, truck drivers can arrive earlier or later than their appointment time, as long as their arrival is during their assigned time-window, this gives them a two-way flexibility – earlier or later arrivals. Thus, the system's resilience against disruptive scenarios is expected to be improved. To the best of our knowledge there is no other research using truck specific time-windows in a TAS. Also, a case study of the proposed TAS will be carried out for a chemical plant, an industry in which literature is lacking and research shows that the use of TAS does not show any significant improvement in system's performance (Wibowo & Fransoo, 2020). Finally, a comparison between the currently used typical TAS, and the proposed TAS will be carried out and their effect on the different stakeholders' objectives will be assessed.

1.4.2 Main and Sub-Research Questions

Based on the problem description and the aforementioned objectives, the Main Research Question is formulated as follows:

"What is the effect of a Time-Window based Truck Appointment System (TAS) on the performance of the loading facility at a chemical plant for the different stakeholders?"

In order to answer the main research question, the following sub-research questions are developed.

Sub-Research Question 1: *"What is the state-of-the-art towards traffic management around logistics sites?"*

Aim of this sub-research question is the in-depth research of this problem in the literature. It should be noted that in this work the term traffic management reflects the measures for handling the problem of long queues of parked or waiting trucks around or at the gates of logistics sites and the congestion caused by them. In more detail, through this sub-research question it is intended to describe the problem and identify its causes and the proposed solutions in literature, and more importantly to reveal the state-of-the-art approaches and methods in dealing with it.

Sub-Research Question 2: *"What is the current situation of the loading operations in the chemical plant under study?"*

Aim of this sub-research question is the understanding of the operations, procedures and specific characteristics of the loading operations at the chemical plant (system) studied here. The knowledge obtained by answering this question is vital for designing a promising TAS.

Sub-Research Question 3: *"Which are the characteristics of the current TAS?"*

This sub-research question focuses on the TAS currently used by the Chemical Plant. In more detail, it aims at identifying the operation and the characteristics of the currently used TAS design, by the chemical plant, and at highlighting this design's limitations and drawbacks. This information is an important input for developing a new and improved TAS.

Sub-Research Question 4: *"Which are the components and the structure of a new and improved TAS with the use of time-windows and real-time information?"*

The aim of this sub-research question is the description of the proposed new TAS with the use of time-windows and real-time information.

Sub-Research Question 5: *"How is the real-time rescheduling model designed and which parameters are taken into account in the optimization?"*

The aim of this sub-research question is double, initially it is aimed to define and justify the model's requirements and assumptions. Then, the description of the parameters and the variables considered in the development of the proposed rescheduling optimization model is outlined, followed by the mathematical formulation of this rescheduling optimization model.

Sub-Research Question 6: *"How can the loading operations of the Chemical Plant be modelled?"*

The aim of this sub-research question is the explanation of the chosen modelling method, namely Simulation, for the representation of the actual system used as a case-study in this research. Further, it is aimed to define the model's boundaries, justify model's assumptions, and finally describe the whole simulation model. Moreover, it is described the way that the integration of the optimization model, required for the proposed TAS design, is performed in the simulation model.

Sub-Research Question 7: *"What is the effect of the proposed Truck Appointment System on the objectives of the different Stakeholders compared to the one used currently in practice?"*

The aim of this sub-research question is to evaluate the effectiveness of the proposed TAS, in comparison to the current one, for the different stakeholders. Also, the robustness of the proposed TAS performance is tested with the execution of Sensitivity Analysis.

1.5 Research Methodology

In this section, an overview of the methodology used in this study to answer the aforementioned sub-research questions is presented. The used methodology is summarized in a research framework, developed based on Sargent's (2001) work, which is depicted in Figure 1.1. It is noted that in this figure, the Problem Domain (Real World) and the Model Domain are presented with different colors. Based on this framework, the research methodology is explained.

The research framework starts with the Real-World Problem, which for this work is the long queues of parked or waiting trucks around or at the gates of logistics sites and the congestion that is caused due to them. Then, an extensive literature review regarding traffic management, with a special focus on congestion and long truck queues, around logistics terminals is performed, to obtain a good understanding of the problem, its causes, and the state-of-the-art solutions proposed in the literature.

Subsequently, the description of the System used as a case-study, namely the chemical plant, and its operations is performed. In more detail, both quantitative and qualitative data is presented about the process times, the daily throughput, the number of delayed trucks, process sequence, etc. of the chemical plant. With this analysis, a good understanding of the system's current situation is obtained. Then, the two different TAS, the Current and the Proposed, are presented. For the Current TAS, its main characteristics, limitations, and drawbacks are highlighted. Regarding the proposed TAS, which uses time-windows and new technologies for the execution of adaptive slot-management, its design requirements are established. Also, the main components of this system, and their interactions are presented and explained.

Following the Conceptual Model for the Proposed TAS is formulated. In this step, the Assumptions and the Simplifications (model abstraction) of the Real World for both the Optimization and Simulation models are established. In more detail, regarding the development of the optimization's conceptual model, initially, a literature review is carried out about existing schedule optimization models with the use of time-windows. Based on the findings of this research and the characteristics of both the proposed TAS's and the chemical plant's under study, the mathematical formulation of the optimization for the proposed TAS is developed. Then, the optimization model, the optimization objective(s), the decision variables, and the parameters are described and explained. Regarding the simulation's conceptual model, the System Description forms the base for its creation. This conceptual model represents the loading operations of the chemical plant under study and is used for the comparison between the proposed design and the one currently in use. This is achieved with the integration of the developed optimization model into this simulation model. In more detail, the developed conceptual model for the simulation is based on a previously developed conceptual model, created for the same chemical plant, and it is available for use, still, some updates are needed. This model represents the loading operations of the terminal, with a dedicated block for each process.

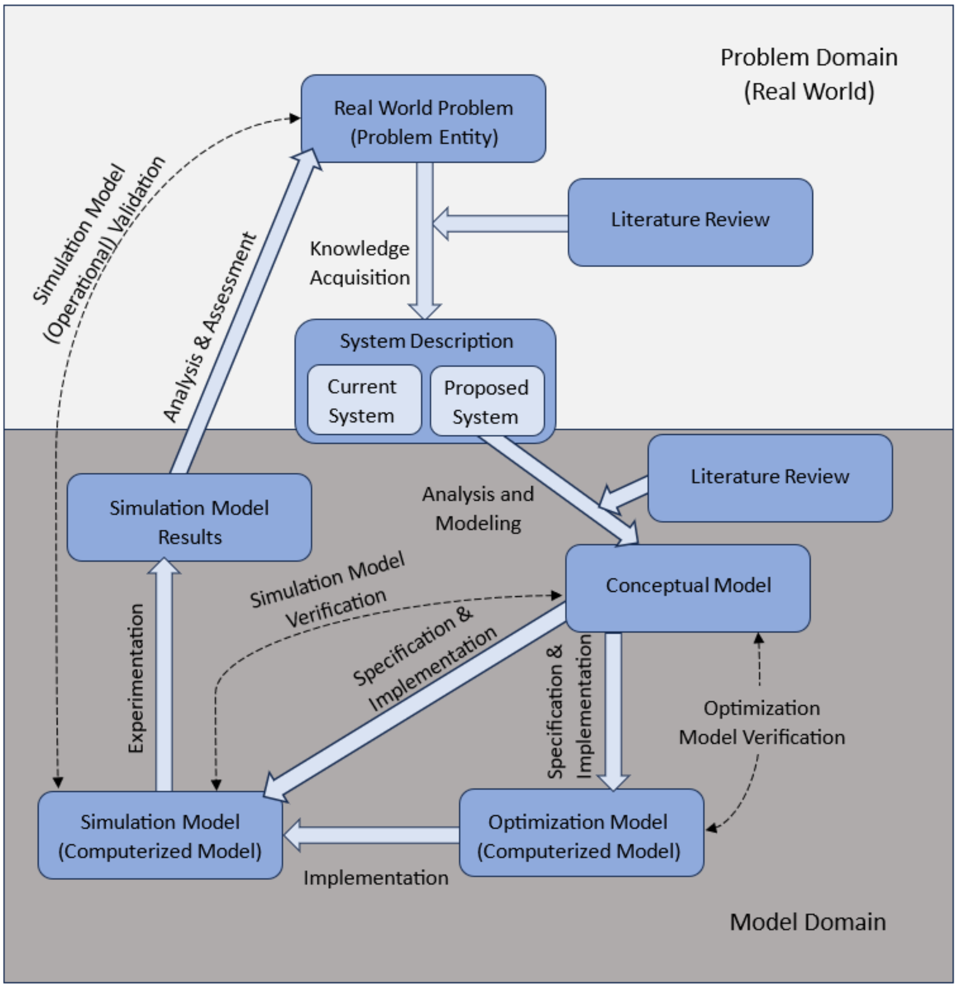


Figure 1.1: Research Framework based on Sargent (2001)

Succeeding, the Optimization and Simulation models' characteristics are specified, and they are implemented on computer software, creating the Computerized Models. In more detail, the values of the Optimization's model parameters are specified and then the mathematical model, developed as part of the Conceptual Model, is coded in a programming language. Also, verification of the computerized optimization model is executed. The Simulation Model of this research is based on a previously developed Simulation model – which is the implementation, in computer software, of the base conceptual model, which was mentioned prior and was also used to create this work's conceptual model. Thus, this simulation model, which was created for previous research on this chemical plant, is used as the base for developing this research's model, according to the developed conceptual model for this work. However, some modifications and updates are required on the base model. Part of these updates is the integration of the computerized Optimization Model into this Simulation model. The Simulation model represents the loading operations of the terminal, with a dedicated simulation block for each of the different service steps, while considering both the process times and the travel time between them. Moreover, the verification and validation of the developed computerized simulation model are performed.

Finally, Experiments, based on the developed Simulation model, are conducted for the different TAS designs, and their outputs are acquired. Based on these results analysis, the effectiveness of the proposed TAS, in comparison to the current TAS, for the different stakeholders as well as for the plant's greenness is assessed. In addition, the effect of some design parameters on the proposed system's performance is examined.

1.6 Scientific and Societal Relevance

The scientific relevance of this research has been extensively discussed in Sections 1.2 and 1.3, but it can be briefly described as the study of the TAS implementation in a different logistical site – chemical plant, apart from the container terminals on which the vast majority of research has been carried out. Also, the proposal of a new TAS, which mitigates some restrictions of a typical TAS, as they are described in the literature, aims at increasing trucking companies' acceptance towards TAS and consequently the improvement of its and terminal's efficiency. In addition, the use of new technologies and approaches, explores the possibilities of proposing a leading-edge system which can maintain a high level of resilience against common disruptions and improve terminal's performance. Moreover, the use of truck specific arrival time-windows in a TAS is something that to the best of the authors knowledge has not been researched again. Finally, and as it has already been mentioned the outcome of this research is expected to diminish some externalities of the current TAS and in more detail reduce the congestion around the chemical plant and thus the environmental pollution.

The societal relevance of this study, is strongly connected to the expected reduction of the plants' operations externalities from the implementation in practice of the typical TAS. In more detail, congestion is a significant problem around the logistical sites, also caused by trucks arriving earlier than their booked slot and waiting along the route to the plant. This increased congestion significantly disturbs the livability of the surrounding areas. Moreover, this increased congestion and the long truck queues outside the logistic sites, where trucks usually wait with their engines idling, are major contributors to the increased noise and air pollution. Especially, the air pollution apart from being catastrophic for the environment it is also dangerous for the humans' health and due to its nature can affect large areas around the logistic sites. Thus, diminishing these aforementioned externalities of logistic sites is very important for both the people and the societies around such locations, but also for the local and regional authorities.

1.7 Thesis Structure

The rest of this thesis report is structured as follows. In Chapter 2, an extensive literature review on this topic is given. Then, in Chapter 3 a more detailed description of the chemical plant used as a case-study is given. Also, in this chapter a brief stakeholders' analysis is presented and the Key Performance Indicators (KPIs) are defined. Next in Chapter 4, the currently in use TAS and the proposed TAS are described. Chapter 5 consists of a detailed description of the methodologies used in this research, apart from the literature review. These methodologies are the Mixed Integer Linear Programming and Simulation, and for each of these two methodologies the developed models, the input data along with their validation and verification is presented. Succeeding, in Chapter 6 the Base Case Scenario along with the Current and Proposed TAS configurations are determined. Moreover, in this chapter the Comparison between the Current and the Proposed TAS designs is performed followed by the Sensitivity Analysis. Lastly, the obtained results are discussed and reflected, and the research limitations are highlighted. Finally, in Chapter 7 the conclusions for this research are drawn followed by the recommendations for future scientific research.

Chapter 2: Literature Review

This chapter aims at answering sub-research question 1. Consequently, a literature review is conducted in order to identify the previous research on the logistics field regarding facing congestion, long truck queues and disruptions in general around logistics sites. In order to perform this literature review, Scopus, ScienceDirect and Google Scholar were used to find relevant publications, to this research. All these are online bibliographic databases of scientific publications. The key words used for this research are “truck”, “congestion”, “long queues”, “ETA”, “real-time information”, “delay arrival”, “Chemical Plant”, “terminal”, “loading operations”, “time-window”, “TAS” and “model”. These terms were used in different combinations and with the use of Boolean Operators in order to obtain more targeted results. Furthermore, backward snowballing was applied in cases where intriguing topics related to this work were found and when further exploration of a topic with limited available literature was required.

The main findings of this literature review are presented in this chapter. Also, different knowledge gaps in the literature are identified and the contribution of this work in scientific knowledge is depicted. In more detail, in Section 2.1 an overview of the congestion and long truck queues problem at logistics sites is given followed by the description of its causes in Section 2.2. Then in Section 2.3, the solutions proposed in the literature in order to face this problem are presented succeeded by an in-depth review on the TAS and the introduction of the state-of-the-art research approaches on the field. In Section 2.4, the methods applied in the literature in order to deal with this problem are presented. While, in Section 2.5 some literature gaps are identified and the contribution of this research in the literature is defined. Finally, in Section 2.6 the chapter summary is presented along with the answer to the first sub-Research Question.

2.1 Problem Overview

Congestion and long truck queues inside and outside logistic sites is a commonly observed circumstance (Wibowo & Fransoo, 2020). Motono et al. (2016), defined landside congestion for a marine container terminal as: “a state where trailers take additional waiting time in the queue either at the destination terminal gate or on the access road to the gate”. These long truck queues and congestion which occur at the gate of the logistics terminals, especially during peak hours, have significant negative effects on terminals’ operations, on trucking companies (carriers) and the population living nearby. For terminals, traffic and queues usually reduce their efficiency, increase trucks’ service time as well as the idling time of the handling equipment (Azab et al., 2019; Chen et al., 2013; Li et al., 2016). In addition, these truck queues are considered as a critical source of emissions, due to the big number of idling diesel engines of the trucks. Resulting in significantly increased greenhouse emissions associated with terminals’ operation (Azab et al., 2019; Chen et al., 2013; Neagoe et al., 2021; Sharif et al., 2011; Talley & Ng, 2016). It is important to point out at this point, that also congestion occurring inside the terminals’ premises has the aforementioned negative effects on terminals’ operations, in addition to the higher risk of occurring an accident (Neagoe et al., 2021). For trucking companies, the effects of congestion, in and around logistics terminals, are the increased trucks’ turnaround time, which reduces their utilization and thus operators’ earnings, the augmented fuel consumption, the higher risk of accidents, the greater time losses and the increased greenhouse emissions (Neagoe et al., 2021; Talley & Ng, 2016). For the population living in the surrounding areas, the effects of the long truck queues and congestion, in and around the terminals, are the increase of air pollution and the reduction of roads accessibility, which lead to reduced livability of those areas (Heilig et al., 2017). Air pollution in such cases is increased due to the trucks' diesel engines which are usually still operating while the trucks are waiting in queues or congestion (Azab et al., 2019; Sharif et al., 2011). Moreover, some of the diesel engines emissions are accountable for a significant portion of these emission types in local and regional level. The major ones are the particulate matter (PM), nitrogen oxides (NOx) and sulfur oxide (SOx) which are considered a very serious health concern (Giuliano and O'Brien, 2007; Chen et al., 2013; Li et al., 2016; Sharif et al., 2011). Also, it is important to point out that due to the nature of these pollutants, depending on the wind's direction, they can affect the residents of a great geographical area. Finally, looking at the bigger picture, all these obstructions and delays of terminals and trucks can have a significant impact on the whole supply chain. As for supply chains congestion is a disruption that leads to increased inventory, warehousing, and transportation costs and augments its environmental impact (Neagoe et al., 2021).

Consequently, the reduction of queues and congestion inside and around the terminals is in the interest of both the terminal's operator and the trucking companies (private sector), but also of the public sector, who has to protect the population living in the surrounding areas and the environment (Chen et al., 2013). Also, the increasing interest for the reduction of the environmental footprint of logistics terminals, as part of the supply chain in which air pollutants are the biggest part of their footprint, leads in this direction and amplifies the need for proposing solutions (Heilig et al., 2017; Neagoe et al., 2021). Thus, there is a lot of research on this field, aiming to find solutions to these problems, so that the logistics terminals and trucking companies can maintain a high resilience despite all the frequently occurring disruptions like delayed trucks, no-shows of trucks, equipment breakdowns and road congestion (Li et al., 2016).

2.2 Problem Causes

In this section, the literature review findings regarding the causes of the aforementioned problem, as described in Section 2.1, are presented. Also, some interesting observations regarding this problem are made.

A number of different causes are identified in the literature as the root of the long queues and congestion around and inside the logistics terminals. To start with, a very common cause of this problem in practice is the arrival of trucks at the terminal at their earliest convenient time without any prior information to the terminal operator. Their arrival time is mainly set by the truck driver's shifts start time, shippers demands and special conditions of the terminal, like the arrival time of a ship for a container terminal or the opening hours. In this way, and due to this rational behavior of trucks; a non-uniform arrival pattern of trucks occurs which leads to peaking traffic hours at terminals (CEFIC & ECTA, 2002; Guan and Liu, 2009; Sharif et al., 2011; Wibowo & Fransoo, 2020). This can also be explained from an economic point of view as it is a function of supply (terminal resources) and demand (number of trucks), where in specific times (peak-hours) demand is significantly higher than capacity (Sharif et al., 2011). Another cause of this problem are the disruptions that occur either during trucks' trip to the terminal or to terminal's equipment and operations. For trucks, these disruptions can be bad weather conditions, traffic congestion, road accidents, breakdowns etc. which make the arrival time at the logistics terminal deviate from the scheduled one –especially for cases where appointment systems are used. While for terminals, such disruptions can be equipment breakdowns and bad weather conditions. These disruptions can significantly affect the smooth execution of the scheduled operations and consequently lead to reduced terminals' handling capacity and productivity and at the same time increase the waiting time for service and thus the queues (Li et al., 2016). Motono et al. (2016) identified as another cause that trucks carry improper documents (IDTs) for the goods that they get from or leave at the terminal. Specifically, they estimated that the number of trucks carrying improper documents was 12.7% and 10% of all arrival trucks in Nagoya port and Hakata port respectively. The trucks carrying IDTs require significantly more time at terminal's gate, compared to the ones which carry the proper documents, resulting in a substantial reduction of gates handling capacity. Moreover, in cases where a Truck Appointment System (TAS) is used in a terminal, research has shown that terminals' inability to fulfil on time the afternoon appointments is a main reason for their reduced performance and the increased traffic and congestion (Huynh, Smith, and Harder, 2016). This is explained by the fact that the ability of a terminal to offer on-time service on the afternoon appointments is strongly connected to the adherence or not to the schedule of the morning appointments. Trucking companies are aware of this, and especially as delays or cancelations of their afternoon appointments create inconvenience for them, reduce their productivity and increase their costs, thus they are not much motivated to stick to their booked slot (Huynh, Smith, and Harder, 2016). Consequently, trucks prefer to arrive early and wait before terminal's gate hopping that they will find an empty slot and get served earlier or at least get served on-time – not miss their slot. However, this behavior results in long queues and congestion around the terminals (Azab et al., 2019). Finally, one more cause of this problem is the multi-service congestion, which can occur inside and around terminals, and occurs when users of two or more services, which are provided at the same node or link, interfere with each other so that finally all of them end up experiencing congestion and long queues. The effect of this congestion can be propagated and to other nodes or links as far as they are connected (Talley & Ng, 2016).

Lastly, some interesting remarks, found in the literature, regarding this problem are presented. To begin with, Neagoe et al. (2021) indicate that congestion has a limited impact on the turnaround times when the terminal operates below its capacity as it has quite some flexibility to absorb the variability of the truck arrivals. However, when demand approaches terminal's capacity then the effect of the congestion has a significant impact to terminal's operations and in extreme cases it can even bring them to a halt. Also, research has shown that the First-Come-First-Served strategy (FCFS), that it often applied in many terminals is not one of the most efficient strategies, especially regarding the trucks' turnaround-time (Li et al., 2016). Moreover, some research state that terminal operators may not really have the incentive to alleviate the problem of congestion and long queues as they perceive it as a way to succeed and maintain high utilization level of their equipment and infrastructure which actually makes congestion even worse (Neagoe et al., 2021; Wibowo & Fransoo, 2020). Finally, Azab et al (2019) and Wibowo and Fransoo (2020) both notice that there is a conflict of interest among the stakeholders, and especially between terminal manager and the carriers.

2.3 Proposed Solutions

In order to deal with this problem of long queues and congestion around logistics terminals, which comes with many externalities as it has been discussed before, a lot of research has been carried out, especially the last two decades, with many different solutions to have been proposed. These solutions can be classified in to three categories which are the terminal's expansion, the improvement of terminal's efficiency and the management of truck arrivals rate.

Terminal Expansion

Gate expansion and investment in additional equipment and infrastructure is one solution in order to handle this problem. Aim of this approach is to expand terminal's handling capacity and consequently to face this issue. However, the applicability of this proposal is limited as it is a strategic level decision and thus it requires a lot of time until it is actually implemented, secondly the land and monetary resources are not always available and finally by increasing the gate capacity and allowing an excessive number of trucks in terminal's premises this might lead into yard congestion, resulting again in a reduced handling capacity (Guan and Liu, 2009; Neagoe et al., 2021).

Terminal's Efficiency Improvement

The improvement of terminal's efficiency can be achieved through different ways, namely the use of technology, the extension of terminal's operating hours and the reduction of the improper documents that trucks carry. To start with, technology can be used in order to improve terminal's operational efficiency and consequently reduce the long queues and congestion. This can be done with the automation of procedures on an operational and tactical level and by increasing the documents processing and handling speed (Heilig & Voß, 2016). Another option is the extension of terminal's working hours, so that its handling capacity is increasing without requiring new investments (Huynh et al., 2016; Neagoe et al., 2021). Finally, the elimination of improper documents that trucks carry is proposed by Motono et al. (2016) as an effective measure in order to face landside congestion, especially when the gate service time differs significantly between trucks that carry proper and improper documents.

Truck Arrival Management (TAM)

The third category is the management of truck arrivals, for which the majority of research has been carried out, and which can be divided in three sub-categories namely, the use of web cameras, the implementation of (financial) incentives or disincentives and the implementation of a truck appointment system. To start with, the utilization of web cameras is proposed by Sharif et al. (2011) as a measure to reduce truck queueing at terminals by providing to trucking companies livestreaming video of terminal's gate cameras, accessible through the internet. The assumption behind this proposal is that dispatchers of trucking companies and truck drivers will utilize this provided information to their advantage by dispatching the trucks when the queues at the terminal's gate are small instead of sending them there and waiting outside the gate in long queues. Another proposed measure is the introduction of incentives or disincentives in order to change trucks arrival pattern. This can be achieved by implementing a time dependent road/toll pricing (Li et al., 2016). Specifically, Chen et al. (2011) suggested a method in order to define the desirable pattern of time varying tolls which lead to an optimal truck arrival pattern. A case in practice where this strategy was used is the Pier Pass Program which was designed in order to reduce the gate congestion during peak hours at the container port (terminal) of Long Beach at Los Angeles. Pier Pass Program charged a $40 per-TEU fee for trucks that entered ports' gates during its peak hours (Talley, 2009). Finally, the third and most research sub-category is the Truck Appointment System (TAS), for which several different variants have been proposed.

Truck Appointment Systems (TASs)

TAS controls trucks arrival rate with the objective to smooth out truck arrivals and maintain gate congestion under a certain level or unlikely to happen (Chen et al., 2013; Sharif et al., 2011; Wibowo & Fransoo, 2020). Chen et al. (2013) defined TAS as the system where "a terminal operator announces opening hours and entry quota within each hour through a proprietary web-based information system though which truckers can choose and book their entry hour as they prefer", but necessarily before their actual arrival (Wibowo & Fransoo, 2020). It is expected that with the implementation of a TAS, congestion and long queues around logistics terminals will be reduced significantly and consequently a vast number of idling truck hours will be saved, as the truck arrivals will be spread out more evenly during terminals operating hours (Chen et al., 2013). Huynh and Walton (2008) proposed a method in order to define per time window the maximum number of trucks a terminal can serve according to its available resources, equipment and personnel. In addition, Huynh and Walton (2011) suggested that TAS can be improved even more by assigning a different appointment time for each truck, meaning that it is preferable not all the appointments, for all bays, to have the same starting time. Another advantage of the TAS is that operators can configure the offered appointments in a way that the trucks arrival rate is at the required level at which terminals resources are used effectively and efficiently and at the same time timely service is offered for the truck drivers (Sharif et al., 2011). Further, it has been proposed that offering more appointments slots during off-peaking hours compared to the peak-hours it can significantly reduce truck congestion (Zehendner & Feillet, 2014). Also, in literature a vessel dependent time windows (VDTWs) methodology is suggested. This methodology is designed for 24-hours operating marine container terminals, and its aim is to control truck arrivals. Trucks are grouped and different time-windows are assigned per group, then the time-windows arrangement and duration are optimized with the objective to minimize the system's total cost (Chen et al., 2013). In this methodology two-time windows are assigned to each vessel, one for delivering the containers and one for collecting them from the port (Chen et al., 2013). Moreover, many papers point out the importance of considering the interests of the various parties, affected by the implementation of TAS system, while creating it. This is very important as the successful implementation of a TAS system strongly depends on the acceptance and the benefits that all involved parties gain from its use (Huynh, Smith, and Harder 2016). Specifically, Phan and Kim (2015) proposed a negotiation process for the TAS, so that apart from terminal's operator interests, also carriers' interests and inconvenience are taken into account for the system's design. Similarly, Jula et al. (2006) had proposed a cooperative time window system, in which terminal operator and carriers communicate in order to create the optimum time windows while considering the objectives and constraints of both parties. Likewise, Azab et al. (2019) developed a simulation-based optimization model in order to obtain the collaboratively optimal schedule for truck arrivals at the terminal, while considering the terminal's yard and gate operations as well as the trucks inconvenience resulting from the deviation between their preferred and assigned appointment time. Furthermore, Wibowo's and Fransoo's (2020) research aims to identify the optimal TAS configuration from a multi-stakeholder perspective for chemical plants. Finally, it is important to point out that the research of Wibowo and Fransoo (2020) indicates that there is no benefit from implementing a TAS when site traffic is lower that 50%, as the effort to implement such a system is higher than its benefits.

Drawbacks of the typical Truck Appointment System

Nevertheless, from all these alternatives, TAS is the solution that has gained the most attention and research, for two reasons firstly as it is a relatively low-cost solution and secondly as it has already been implemented in many container terminals since the early 2000s (Sharif et al., 2011; Wibowo & Fransoo, 2020). As it has already been mentioned, aim of TAS is to control trucks' arrival distribution in order to reduce congestion and emissions around terminals (Li et al., 2016). However, practical experience shows that TAS performance is not uniform (Chen et al., 2013; Li et al., 2016). This is supported from the findings of Giuliano and O'Brien (2007) which show that the application of a TAS at the Port of Vancouver was successful, while for the port of Long Beach at Los Angeles the implementation of TAS did not result in any significant improvement regarding congestion, long queues and emissions. Similarly, the data collected by Wibowo and Fransoo (2020), for trucks performance in 52 chemical plants in Western Europe, shows not significant difference in the performance between plants that used TAS and those which did not. Giuliano and O'Brien (2007) point out in their research as causes of these problems the lack of specific guidelines regarding the TAS in U.S.A. and the unproper design of TASs. Also, in literature different studies suggest that for the successful development and implementation of a TAS, the consideration of terminal's local conditions is a key success factor (Chen et al., 2013; Guan and Liu,2009). This is explained by the fact that terminals are very different, they serve different kind of products, they have different operating hours – some operate 24-hours while others specific hours a day–, their processes and equipment are different etc., so the copy of a successful TAS solution of one terminal and its implementation in a different one does not necessarily mean that it will be successful too. Furthermore, in cases where terminals have implemented TAS some trucking companies still tend not to adhere to their booked appointments and prefer to arrive earlier and wait before plant's gates. A few reasons justify this behavior and these are the inability of the terminals to serve on-time the afternoon appointments, the inconvenience caused to the trucking companies by unsuitable appointments designated to them, the extremely competitive environment that trucking companies work in and the very strict schedule determined by the TAS (Azab et al., 2019; Van Den Brink, 2023; Huynh, Smith, and Harder, 2016). Moreover, the planning of the available entry quotas for the TAS and their booking from the trucking companies are typically made in a fully deterministic environment, considering only regular maintenance of the terminal's equipment and assuming punctual truck arrivals. However, in practice both terminals and trucks experience unpredictable disruptions such as terminal equipment breakdowns, deviation between the appointed and actual arrival time of trucks and no-show ups of trucks, all of which affect both the applicability of the created schedule and the effectiveness of the implemented TAS as terminal's utilization is reduced, truck turnaround times increase and the need for rescheduling rises (Van Den Brink, 2023; Nasiri et al., 2022; Vanga et al., 2022). Finally, Li et al. (2016) study notices that the congestion and long queues around terminals is a significant and complex problem which severely affects the whole system's performance and environment footprint. And despite the identification of this problem's significance in the industry, still the scientific research proposing practical guidance is very limited.

New Research on the field

Consequently, the new research on the field focuses on improving TAS's flexibility, robustness and efficiency especially against disturbances, or similarly the stochasticity of the real world, while at the same time increasing the compliance of the trucking companies to the TAS with the use of new approaches and technologies. Currently, in most of the available literature in the Truck Arrival Management (TAM) field, disturbances are faced with either proactive approaches, where a master schedule is created in advance with some slack in order to account for the disruptions and usually it is not adjusted after its creation, or/and reactive approaches, where the initial schedule is updated when a truck arrives late at the terminal which also result in sub-optimal schedules as the planner has a myopic view of the system while rescheduling (Larbi et al., 2011; Nasiri et al., 2022). Some state-of-the-art approaches found in the literature in order to deal with these problems include the combination of two different TAM systems, the collaborative optimization of the TAS schedule and the utilization of real-time information with the use of new technologies. To start with, Van Den Brink (2023) proposed a TAM system, for the external trucks of a bulk liquid terminal in Rotterdam, which is a combination of the typical TAS and the Drop and Swap system. The results of this study showed that the proposed system, compared to the typical TAS, increases the number of trucks that can be unloaded but it also increases the trucks turnaround time. Another approach, which aims at increasing trucks' compliance to the TAS is the collaborative or joint optimization of the TAS schedule. Wibowo and Fransoo (2020) present a model in order to define the optimum slots length for a TAS in a chemical plant, while considering the perspectives of all the different stakeholders, namely trucking companies, site manager and social planner. The findings of this research suggest firstly that the implementation of TAS in chemical plants can significantly improve their performance, and secondly that the main advantage of the joint optimization is the redistribution of the benefits from the TAS usage to all stakeholders and thus the alleviation of some of the inconveniences caused by its use, especially for the trucking companies. Likewise, Azab et al. (2019) introduce a simulation-based optimization model to collaboratively schedule the appointments of the external trucks for a TAS in a container terminal while considering the stochasticity of the operation and the costs related to the trucking companies and the container terminal. The outcomes of their research suggest that the proposed appointment system can reduce the trucks turnaround times on average 29% and the maximum queue length on an average 38%. Also, it is highlighted the importance of the trucking companies to adhere to their booked slots, despite any inconveniences that they may encounter from it, as the deviation of even one trucking company can lead to delays not only for that company but for all. This is explained from the fact that when a trucking company schedules only for its own benefit, and is not adhering to the booked slot, it cannot create a more efficient schedule than the proposed one as it does not have information for the overall schedule of the terminal. However, this high sensitivity of the proposed system to trucks deviation from the original schedule is its main drawback. Also, it is worth pointing out that the proposed system was tested against hypothetical instances from the literature and not real data. Finally, the utilization of real-time information for the trucks rescheduling is another approach which has gained very recently quite some attention in the research of logistics field, especially after the start of the Freight Traffic Management As A Service (FTMAAS) project (Freight Traffic Management as a Service, 2020). Aim of the FTMAAS project is to create information value chains from data, by connecting and integrating real-life logistics and traffic management systems. One of its use cases focuses on the accurate estimation of truck arrival times based on real-time information and the use of this estimation for dynamic rescheduling (Freight Traffic Management as a Service, 2020). The research from

Larbi et al. (2011) examines the value of information obtained from the knowledge of the arrivals of the incoming trucks in the cross-docking operations under three different levels of available information, namely full information – sequence of inbound trucks is fully known –, partial information – the sequence of the next Z inbound trucks is known – and no information – information of the inbound trucks sequence is obtained when they arrive at the terminal –. The findings of this research suggest that there is significant benefit when having and utilizing full information on the truck arrivals compared to the case when this information is not available. Also, it is noted that distant future information, from a point onwards, does not further improve the obtained solution. In the same logistics field, of cross-docking operations, Nasiri et al. (2022) proposed a predictive-reactive rescheduling system which considers the available information about the deviation of the inbound trucks arrival times. The rescheduling is done in predetermined intervals during which the information of the incoming trucks is updated. Regarding the use of real-time information in TAS, two studies were found, both of which are part of the FTMAAS project. To start with, Prakoso (2021) presented a predictive model which incorporates the use of real-time ETA information for optimizing the TAS's schedule and which is also very beneficial when rescheduling is required. A Machine Learning technique was used for the estimation of the trucks arrival time, based on the integrated real-time information of logistics operations and traffic systems as well as historical data of trucks arrivals. Also, in this work the added value from the integration of the logistics and traffic systems for the trucks rescheduling is examined. It is important to note that in this study only delayed trucks are allowed to be rescheduled. The outcomes of this research suggest that the utilization of the information obtained from the integration of the logistics operations and the traffic systems for the (re)scheduling of a TAS can enhance the operational efficiency of terminal's loading operations. Vanga et al. (2022), proposed an extension of Prakoso's (2021) work where the obtained real-time information is still utilized for the (re)scheduling of a TAS but in which there is the flexibility of all trucks to be rescheduled, not only the delayed ones but also the ones that arrive on-time, with the aim of minimizing the trucks average waiting time. Also, in this study the value of real-time truck arrival information and its effect on an appointment management system is investigated too. The results of this research demonstrate again the benefits of using the real-time information as system's overall performance is improved, measured by Key Performance Indicators (KPIs), compared to the case where no information is available.

2.4 Applied Methods

In this section, the various methods used in the literature in order to handle the aforementioned problems are presented. These methods, found in the literature, can be grouped into four large categories the Queueing models, the Optimization models, the Simulation models and a combination of Optimization and Simulation Models.

Queueing Models

Queueing models, Motono et al. (2016) developed a multi-server queueing model, based on the queueing theory, for their research. Also, Guan and Liu (2009) used a multi-server queueing model in order to assess the congestion around the gate of a terminal. In addition, Chen et al. (2011) point out that even though several studies have used stationary queueing models in order to model terminals gate operation, this approach is not appropriate and non-stationary queueing models should be used. This is explained by the nature of these queues at terminal gates as the trucks arrival rate varies significantly from hour to hour and many times also gates service rate might change over time, so terminal gates are a typical non-stationary queueing system (Guan and Liu, 2009). For modeling a non-stationary queueing system, fluid-based approximation models are used. These models compared to the stationary queueing models, have a remarkable improvement in the approximation accuracy and at the same time their computational time remains reasonable (Chen et al., 2013; Wibowo & Fransoo, 2020). Besides, Chen et al. (2011) created and used a non-stationary queuing model in order to optimize a time-varying toll fees system. Furthermore, Wibowo and Fransoo (2020) developed an improved version of the B-Pointwise Stationary Fluid Flow Approximation (B-PSFFA) method, which is a fluid flow approximation method for solving a non-stationary queueing system, in order to solve the joint-optimization model for a TAS in a chemical plant. Finally, it is important to point out that queueing models are popular among researchers for modelling logistic sites and compared to the simulation models they are usually simpler, they produce good quality results and without a big number of repetitions needed (Wibowo & Fransoo, 2020).

Optimization Models

Optimization models are another commonly used method. Wibowo and Fransoo (2020) created a joint-optimization model in order to define the optimal TAS by taking into account the interests of the various stakeholders in the chemical industry. Also, Chen et al. (2013) applied an optimization model in order to define the optimal vessel dependent time-window per vessel with the objective of minimizing the total system cost. In this research, also a sensitivity analysis of the solution regarding the different cost factors was conducted. Further, Zehendner and Feillet (2014) developed a mixed-integer linear programming optimization model, which aims at determining the optimal number of entry quotas in a TAS. Besides, Prakoso (2021) developed a probabilistic slot rescheduling optimization model, with the use of the expected value in order to incorporate the stochastic variables, for the TAS in a chemical plant. The aim of this model is to optimize the trucks rescheduling process with its objective being the minimization of the expected cost, which consists of the cost resulting from the deviation between the new (updated) and the initial schedule and the cost of rescheduling. Additionally, Nasiri et al. (2022) formulated two Optimization models for a cross-docking system, the first one was developed in order to obtain the initial schedule for the facility while the second one was created to perform the optimization of the rescheduling process with the use of the available information of the delayed trucks. The objective of the second model is to minimize the deviation from the initial schedule. Lastly, for solving these optimization models either linear/ integer solvers are used or heuristic methods like conventional Genetic Algorithms and Simulation Annealing (Chen et al., 2013).

Simulation

The most commonly used method is simulation, either discrete event or agent-based simulation. To start with, Motono et al. (2016) used simulation, along with a multi-server queueing model in order to assess the effect of the improper documents to the congestion at terminal gates. Discrete-event simulation is considered to be a very good method for researching about congestion and long queues around logistics terminals as it is easy to create different scenarios, conduct sensitivity analysis and obtain a good understanding of the system and how different measures affect it (Neagoe et al., 2021). Which is different compared to the optimization, where the optimization objective is the main outcome and goal of the analysis process (Neagoe et al., 2021). In addition, discrete event simulation models are very powerful tools when dealing with uncertainty and stochasticity of the system, which is the case for a terminal, as nearly every factor is stochastic (Huynh, 2009). Thus, Neagoe et al. (2021) used in their research a discrete simulation model in order to perform different scenarios analysis, for different congestion management initiatives. Also, Li et al. (2016) created a discrete event simulation model in order to assess the performance of different disruption response strategies and to conduct sensitivity analysis. Furthermore, Van Den Brink (2023) developed a discrete event simulation model in order to evaluate the performance of his proposed TAM system. Regarding the use of agent-based simulation, it is a relatively new method which has not yet been used widely in the truck logistics field. Agent-based simulation focuses on agent level and the interactions between them; thus, it can capture better the behavior of a system in a micro scale compared to the discreet event simulation, but it tends to have higher computational times (Becker et al., 2006). Sharif et al. (2011) applied agent-based simulation in their research in order to assess the effect of depots management, without collaboration between them, when giving them real-time gate queueing information, through web-cameras, of the gates congestion and the expected trucks waiting time before terminal's gates. Finally, it is important to point out that simulation is considered as a very good tool for the creation of tangible solutions (Neagoe et al., 2021).

Combination of Optimization and Simulation

The fourth category is the combination of Optimization and Simulation. Azab et al (2019) developed a collaborative optimization model for trucks appointment scheduling in a container terminal. However, the value of some of the optimization's model input parameters are obtained from the output of a discrete event simulation model that they also created. Moreover, Vanga et al. (2022) proposed a rescheduling optimization model for a TAS in the chemical industry with the use of real-time information. Nevertheless, in order to assess the performance of the proposed optimization model they developed a discrete event simulation model, which represents the loading operations of the studied chemical plant. With the integration of the optimization model in this simulation model the evaluation of the proposed rescheduling system was made possible.

2.5 Research Gap

In this section, initially a few literature gaps regarding the TASs are discussed. Then the gaps that this research aims to answer are presented.

As it can be concluded from the previously conducted literature review, the disruption of truck arrivals along with congestion and queues around terminals is a severe and complex issue which affects the performance and environmental footprint of the logistics terminals (Chen et al., 2013; Li et al., 2016; Sharif et al., 2011). Consequently, quite some research has been carried out in the logistics field in order to handle these problems aiming to develop a method which can maintain a high level of system's resilience against common disruptions, like truck delays and equipment breakdowns. TAS is one of the most commonly used and effective methods in order to deal with this problem of the long queues and congestion, as it has already been mentioned (Neagoe et al., 2021). However, there are still drawbacks and limitations in this method too, as they have been described previously. To start with, as Li et al. (2016) notice that the available literature with practical guidance and solutions on this topic is still limited, albeit that this problem is recognized in the industry. Also, even though a few solutions have been proposed to deal with these problems there is not a general formula which can be replicated and applied successfully in all terminals (Wibowo & Fransoo, 2020). Especially, when designing a TAS the local conditions of the terminal should be taken into account, as each terminal is different from the other (Chen et al., 2013; Li et al., 2016). Hence, for the implementation of an existing in the literature system in a different terminal the consideration of the terminal's specific characteristics and the performance of some modifications on the original system are required. In addition, despite the fact that all kind of terminals face the aforementioned issues, the vast majority of research that has been carried out on this topic focuses on container terminals (Neagoe et al., 2021; Wibowo & Fransoo, 2020). Thus, further research is required in different logistics terminals like chemical plants, bulk terminals, etc., as different types of terminals differ significantly, with regards to their operations, safety standards, procedures etc. (Neagoe et al., 2021; Wibowo & Fransoo, 2020). In more detail, regarding Chemical Plants only four previous research were found that studied the implementation of a TAS in the industry, and notably the two of them are part of the FTMAAS project. Besides, only two of them are scientific papers – Vanga et al. (2022) and Wibowo & Fransoo, (2020) –while the other two are master thesis – Van Den Brink (2023) and Prakoso (2021) –. Moreover, for the implementation of a TAS, the participation of the terminal operator and carriers in the development and implementation of the system is critical for its success (Neagoe et al., 2021). Therefore, the factors that affect the acceptance of a TAS from the trucking companies and their compliance to their booked appointments require further study too. Besides, the planning of the available entry quotas for the TAS and their booking from the trucking companies are typically made in a fully deterministic environment, while in practice both terminals and trucks experience unpredictable disruptions which can affect both the effectiveness and the applicability of the developed TAS schedule. Thus, the need of considering the stochasticity of the real world in the new studies on the field is made clear. Furthermore, based on the historical data collected by Wibowo and Fransoo (2020), for 52 chemical plants in Europe the implementation of a TAS did not show any significant performance improvement between the plants that used one and those which did not. This raises the question of exploring the reasons why the implementation of a TAS in chemical plants does not show any significant performance improvement, compared to the plants that do not use one. Finally, additional research is required in exploring further the potentials of the state-of-the-art approaches and methodologies in designing more resilient systems against disruptions while considering the stochastic nature of the logistics operations. Consequently, it becomes clear that there are quite a few gaps in the literature that need to be further investigated.

However, this research aims at investigating further the implementation of TASs in chemical plants with the design of an effective TAS, which relaxes some of the hard constraints of TAS – especially for the trucks– and uses new technologies, in order to improve system's performance against disruptions and overcome some of the main TAS shortcoming, as they have been described in the literature. Particularly, the study of TAS in the chemical industry was motivated by the very limited available literature regarding this topic on the field. Further, the proposal of a new TAS design which incorporates some flexibility in it is done with the aim of increasing trucking companies' acceptance towards TAS and achieving higher level of adherence to their booked slots. This choice was inspired from the literature findings which indicate that the strict schedule of a TAS is an important factor for trucks to not comply with their booked appointments. Moreover, the use of state-of-the-art technologies and approaches, like the utilization of real-time information obtained from the integration of logistics and traffic systems for the trucks rescheduling through the adoption of new technologies like GPS, is motivated by the aim of this research to propose a leading-edge system which can maintain a high level of resilience against common disruptions and improve the terminal's performance. Additionally, advanced methods, like optimization and discrete event simulation, are implemented complementary to the aforementioned approaches. This is the contribution of this project in the scientific knowledge.

2.6 Chapter Summary

Congestion and long truck queues inside and around logistic terminals, especially during peak hours, are common. However, they have a negative impact on all the involved stakeholders, namely terminal operator, trucking companies (carriers) and the community leaving nearby. Furthermore, in a broader view the resulting obstructions and delays can have a significant impact on the whole supply chain's performance and environmental footprint. Thus, it is in the best interest of all stakeholders to face the abovementioned problems.

A number of different causes have been identified in the literature as the root of the long queues and congestion inside and outside the logistics terminals. Some of these problems causes are the arrival of trucks at the terminal at their earliest convenient time without any prior information to the terminal operator, the disruptions that occur either during trucks' trip to the terminal or to terminal's equipment, the improper documents carried by the trucks, the inability of the terminals to fulfil on time the afternoon appointments – when a Truck Appointment System (TAS) us used– and the multi-service congestion.

Consequently, and due to the severity of these problems there is a lot of research on this field, aiming to find solutions to these problems, so that the logistics terminals and trucking companies can maintain a high resilience despite the frequently occurring disruptions. Many different solutions have been proposed to handle these problems, which can be classified in three large categories, namely terminal's expansion, improvement of terminals efficiency and the management of trucks arrival rate. Regarding the management of trucks arrivals, the implementation of financial incentives or disincentives and the use of truck arrival management (TAM) systems are recommended. Truck Appointment System (TAS) is the most commonly used TAM system for which extensive research has been carried out. Aim of the TAS is to control the trucks arrival rate in order to smooth out truck arrivals, by spreading them more evenly during the day, and maintain gate congestion under a certain level or unlikely to happen. For the successful design and implementation of a TAS, the consideration of terminal's local conditions is a key success factor. Nevertheless, practical experience shows that TAS performance is not uniform, and its implementation is not always successful. Finally, it is worth mentioning that most of the available research on the TAS is made in a fully deterministic environment, while in practice both terminals and truck experience disruptions which affect the effectiveness and the applicability of the implemented TAS.

Thus, the new research on the field focuses on designing improved TASs with higher robustness and efficiency especially against disturbances – the stochasticity of the real world – while at the same time increasing the acceptance and compliance of the trucking companies towards TASs. In order this achieve these new approaches, technologies and methods are studied. Such approaches are the combination of different TAM systems, the collaborative or joint optimization of the schedule, in which the interests of all the stakeholders are considered and aims at increasing trucks acceptance and compliance to the TAS, and the utilization of new technologies and real-time information for trucks rescheduling. Part of this last approach category is also the integration of real-time logistics and traffic systems in order to increase the accuracy of the predictions based on the obtained real-time information. The benefits of using real-time information while rescheduling for a TAS have been proven in the literature, as the operational efficiency of terminal's loading operations can be increased. Regarding the methods used in the most state-of-the-art research are the Optimization, Simulation and a combination of these two. In more detail, for solving the optimization models either linear/ integer solvers are used or heuristic methods. While, for the Simulation models, discrete event and agent-based simulation are the two most applied methodologies with agent-based being able to capture better the system's behavior in a more micro scale compared to discrete event. In conclusion, in this paragraph the 1st the sub-research question is answered as the state-of-the-art techniques used for the traffic management – handling the long queues of parked and waiting trucks and congestion – around logistics sites are described.

Finally, this research aims at investigating further the implementation of TASs in chemical plants and the design of an effective TAS, with the relaxation of some of TAS hard constraints –especially for the trucks– with the use of new technologies, in order to improve system's performance against disruptions and overcome some of the main TAS shortcoming. The literature gaps that this research aims to fill in are the limited literature regarding the implementation of TASs in chemical plants, the proposal of a new and more flexible TAS, with the use of time-windows, in order to increase trucks acceptance and the use of state-of-the-art approach and methodologies, namely use of real-time information, optimization and simulation.

Chapter 3: System Description

Initially, in this chapter, a brief overview of the Chemical Supply Chain is given in Section 3.1. Then, in Section 3.2 the problem that this research aims to handle is briefly described from a case-study perspective. Following, in Section 3.3 the System Boundaries for the system under study are defined. Afterwards, in Section 3.4 the distinct characteristics of Chemical Plants along with the attributes that differentiate them from other logistic sites are identified. Furthermore, in Subsections 3.5.1 and 3.5.2 a detailed description of the chemical plant under study and its loading operations is given, along with the presentation of the factors that affect trucks' arrival time at it. Subsequently, in Section 3.6 the Stakeholder Analysis is performed followed by the Definition of the KPIs used in this research in Section 3.7. Finally, in Section 3.8 the summary of this chapter is made and sub-Research question 2 is answered.

3.1 Petrochemical Supply Chain

As it has already been mentioned in the Introduction, for this research a Chemical Plant, which is located in the Antwerp Region of Belgium, is used as a case study and it is owned by a multinational corporation whose operations cover the whole petrochemical supply chain (Raj, 2019). Thus, it is considered important to give a brief description of the whole petrochemical supply chain, firstly in order to position this research in the whole supply chain and secondly to illustrate the importance of this research at higher level.

In the literature, there is not a universally accepted definition of the supply chain, as Da Silva Lima et al (2016) indicate. Thus, for this study the definition of supply chain used by NIST (2018) is considered a good fit for this project and is the one adopted. NIST (2018) describes the supply chain as "a linked set of resources and processes between multiple tiers of developers that begins with the sourcing of products and services and extends through the design, development, manufacturing, processing, handling, and delivery of products and services to the acquirer". More specifically, the petrochemical supply chain is very complex and unstable as it is significantly affected by the global geopolitical environment, competition, and the price fluctuations (Da Silva Lima et al., 2016). Consequently, there is a constant need for improvement and optimization of all the processes in a supply chain in order to satisfy its customers while at the same time increasing its revenues, minimizing its costs and increasing its flexibility.

The oil supply chain can be classified in three different manners, based on the number of segments in which the supply chain is divided into, two or three, and the activities included at each segment (Sahebi, 2013). For the purpose of this research, the second classification scheme is applied, the same one as Raj (2019) and Prakoso (2021) applied while analyzing the supply chain of this corporation too. In more detail, this scheme divides the oil supply chain in three segments, namely upstream, midstream and downstream (Sahebi, 2013), as it can been seen in Figure 3.1. The upstream segment includes all the activities from the exploration, extraction and transportation of the crude oil to the refinery plants. The midstream segment consists of the all the refining operations for the conversion of crude oil to finished products. Finally, the downstream segment includes the activities related to the transportation, storage, distribution and marketing of the finished products (Sahebi, 2013).

Figure 3.1: Oil Supply Chain – 2nd classification Scheme (Da Silva Lima et al., 2016)

The company under study, as it has already been mentioned, is present in all of these three segments, either directly or indirectly with the use of sub-contractors and third parties doing some of these activities, for instance the transportation. However, the scope of this research is limited to the loading operations of finished goods at the Chemical Plant (refinery) and their distribution or storage. Thus, this study is placed at the end of the midstream and the beginning of the downstream operations of the whole supply chain.

3.2 Problem Description for the Chemical Plant under study

In literature various factors affecting the smooth and efficient execution of the trucks loading operations can be identified. However, for the chemical plant, used as a case study in this research, located in the Antwerp region there are a few site-specific factors, that are described later, which significantly affect the performance of currently in practice TAS and consequently its loading operations too. To start with, currently Antwerp region is facing again, after the pandemic era, severe traffic congestion as it is indicated by the data (TomTom European Traffic Congestion Index, 2023). This was the case and before the pandemic and until 2019, as both Raj (2019) and Prakoso (2021) have demonstrated in their research. In addition, the total amount of freight handled through the port of Antwerp, for both containers and liquid bulk, shows a steadily and significant increase until the beginning of the pandemic, yet this trend is expected to persist in the after covid era (Port of Antwerp Bruges, 2022; Port of Antwerp Bruges, 2023). Consequently, additional pressure is put on the already congested road network of Antwerp and thus congestion and delays are expected to keep increasing. On top of these, construction works have been planned for the Antwerp's Ring Road, which is major gateway for accessing and leaving the plant under study, in order to rehabilitate it. These works are expected to make the current situation even worse as the initial schedule of these works states that they are expected to be completed by 2030 (Vanga et al., 2022; Billion-euro Project: Making the Antwerp Ring Round Again and Bringing It into Harmony with Its Surroundings, 2022; Eib, 2021; Raj, 2019).

As it can be understood all these aforementioned factors create an environment where road congestion and subsequently travel times and delays are expected to be increased even more compared to the current situation. These can have significant impact on the operations of the chemical plant, as delayed arrivals and thus delayed loading of the trucks can result in overflow of finished products resulting in production disturbances or need for extra inventory storage facilities (Raj, 2019). In addition, these delays can also significantly affect the performance of the currently in practice Truck Appoint System (TAS) as more trucks will either arrive delayed or much earlier than their appointment time so they do not miss their booked slot. Furthermore, the current capacity utilization of the plant's loading infrastructure is around

60%-70% of its total daily available capacity (slots), which is 114 slots per day (Raj, 2019). Currently this gives some buffer to the manager of the loading facility, to reschedule delayed trucks, however it can significantly reduce plants' efficiency when demand increases. The data from 2019, which is before the pandemic and the start of the works in the Antwerp's ring road, shows that the percentage of delayed truck arrivals is 20.5% (Raj, 2019). Moreover, the communication lag between the truck drivers and the plant planer, due to the manual operations and the absence of a real-time truck positioning system, add another level of complexity and inflexibility in the current system (Raj, 2019). Thus, the need of developing of a new system, with higher flexibility and resilience against disruptions compared to the currently used TAS, is made obvious. Finally, it is important to point out this research focuses only on the road transportation of finished goods towards the customers.

3.3 System Boundaries

In this section, the System Boundaries of this research are defined. In more detail, in Figure 3.2 below, the operations of the midstream and downstream segments of the company's under study supply chain are presented. The focus of this research is limited to the loading operations of the chemical plant and the road transportation of the finished products to the customers, these form the system boundary for this research which is depicted with the light blue oval shape in Figure 3.2. The actors involved directly in this system are the Chemical Plant's loading facilities (loading operations) and the carriers. Furthermore, it is important to make a few remarks about this system's boundaries. To start with, the transportation operations considered in this study do not reach until the products delivery to the customer, but only until the departure of the trucks from the plant. Also, the trucks arriving to this chemical plant located in the Antwerp region to be loaded, originate from many different countries such as the Netherlands, Belgium and Germany. In addition, as it has already been mentioned previously in this study only the road transportation is considered. Finally, it is noted that further below in this chapter a detailed description of all the components and processes of the studied system (terminal) is given.

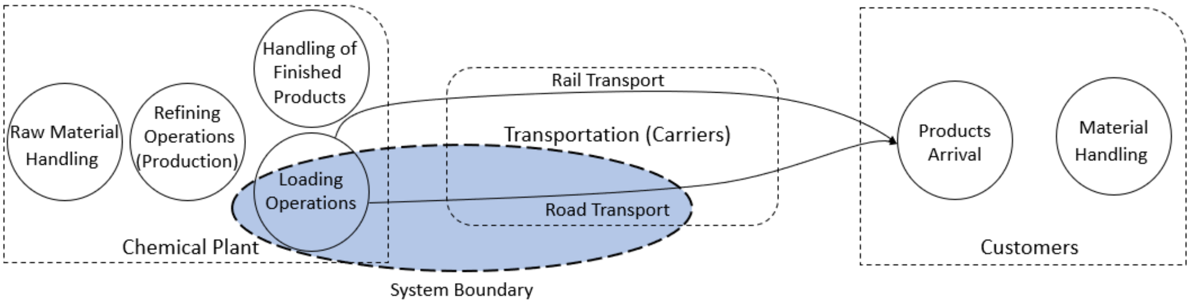


Figure 3.2: Boundaries of the System under study (Depicted with the light blue oval shape)

3.4 Chemical Plants distinct characteristics

Chemical plants have some distinct characteristics which make them unique and significantly differentiate their operations and procedures from other logistics sites (Wibowo & Fransoo, 2020). To start with, the operations in chemical plants are strictly regulated by high safety standards and procedures (CEFIC & ECTA, 2013a; CEFIC & ECTA, 2013b). In addition, every truck before getting into the plant has to pass a document checkup in order to assure the legitimacy of its operation and confirm that the truck meets the safety standards requirements of the plant (Wibowo & Fransoo, 2020). Also, the loading time in chemical plants is significantly longer than other logistics sites and it varies from 30 to 90 minutes. This time variation is caused by the different product properties and types as well as the from the different ordered quantities (CEFIC & ECTA, 2009). Moreover, chemical plants usually operate for a limited time during the day, normally they are open for 8-12 hours per day, in contrast to other logistics sites which have more extended operating hours, which in some cases operate even 24 hours per day (CEFIC & ECTA, 2002). Further, Wibowo and Fransoo (2020) point out that the traffic congestion problem in chemical plants is caused not only from the special characteristics of this logistics site, but also from the behavior of the carriers and the site manager. This happens as these aforementioned parties have different goals and objectives which usually are conflicting, thus a multi-stakeholder approach in order to deal with the congestion and long queues problem is recommended (Wibowo & Fransoo, 2020). Additionally, in chemical plants, similarly to container terminals, truck arrivals usually show two peaks during the day. Finally, as the chemical plant is a very big and complex system, equipment failures can happen unpredictably at the gates, the loading bays or weighting equipment (scale) which can result in unforeseen delays and consequently increase both plant's and trucks' idling time (Wibowo & Fransoo, 2020).

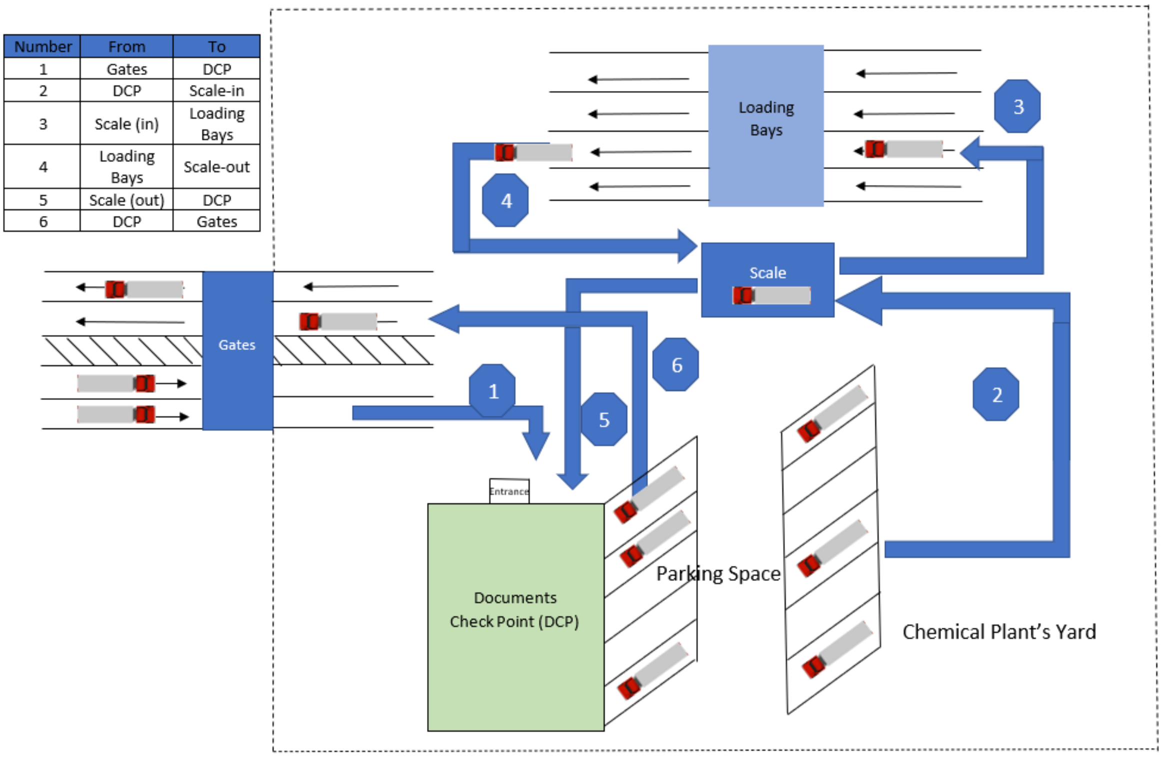
3.5 Chemical Plant Presentation – Case Description

In this section, initially a description of the specific characteristics of the studied Chemical Plant along with a detailed description of its loading operations are given. Then, in Subsection 3.5.2 the factors affecting trucks on-time arrival at the plant, according to the truck drivers, are presented.

3.5.1 Chemical Plant and Loading Operations Description

In this research a chemical plant located in the Antwerp region of Belgium is used as a case study. The inbound logistics (supply), for this plant, are performed through marine transportation, while the outbound logistics (delivery to the final customers) are performed through road and rail. However, in this research only the road outbound logistics are considered. This, choice was made for two reasons, firstly transportation with trucks accounts for the vast majority of outbound shipments. And secondly, the fact that trucks and rail cargo carriages are not allowed to be serviced at the same time at the plant for safety reasons, even if they are in different loading bays, as their interaction in plant premises significantly increases the risks of accidents. Consequently, rail carriages are serviced during the night, after the plant has closed for the trucks and only a limited number of loading bays are compatible with servicing rail carriages.

In this paragraph, a detailed description of the system considered in this research, as it has been defined in Section 3.3 and consists of the Loading Operations and Transportation, is given. In more detail, the trucks' flow, upon their arrival at plant's gates and until their departure from plant's premises, is described. When trucks arrive at the chemical plant, they head to the plant's gates in order to enter its premises. There it is checked if the truck has a booked appointment and if so, it is allowed to enter the plant premises (link 1). Then, trucks park in the designated parking area and drivers go to the documents check point (DCP) building to announce their arrival. There, apart from their arrival announcement also their documents are checked along with truck's compliance to the plant's safety standards. When the check is completed and the compliance with the safety standards is proven, trucks are informed about the loading bay that they are assigned to. It is important though to point out that this whole checking process is carried out manually. However, before the trucks head to their assigned loading bay to be served, they go on a scale in order to be weighted (link 2). This scale is on their way from the documents check point to the loading bays (links 2 and 3).



Number	From	To
1	Gates	DCP
2	DCP	Scale-in
3	Scale (in)	Loading Bays
4	Loading Bays	Scale-out
5	Scale (out)	DCP
6	DCP	Gates

Figure 3.3: Schematic Overview of Chemical Plant's loading facilities and trucks flow

In front of each loading bay, there is a queue where trucks can wait if the loading bay is occupied by another truck. In each one of these queues, one or two trucks maximum are allowed to wait due to safety reasons. Once the assigned to the truck loading bay becomes free, the truck can enter and start its service. The service time varies from 30 to 60 minutes depending on the loading bay. When the loading process is completed, the truck leaves the loading bay and goes again to the scale to be weighted (link 4). It is worth mentioning here that there is only one scale for all trucks to use, thus all trucks use the same scale both before entering and after exiting the loading bay. However, as the weighting time of each truck on the scale is very small, significantly less than a minute, queues are not formed here. Then, the truck heads again to the document check point (link 5). There, the driver receives the proper paperwork regarding the amount of carried product, receipts, custom papers etc. and when all this paperwork is completed, he/she can go to the truck and drive to the plant's gates in order to leave the chemical plant and head to the delivery location (link 6). A schematic overview of all the processes that a truck undergoes in order to get in, get served and get out of the chemical plant as well as the trucks' flow in the plant (presented with links) is depicted in Figure 3.3.

In this chemical plant there are six (6) loading bays available, but they are not all serving the same products. Each bay can serve a range of different liquid products that have different characteristics and different loading rates. In more detail, loading bays 1 and 2 have a loading time of 45 minutes while the rest have 30 minutes. This difference, in the service times of the loading bays consequently results in different appointment durations for the different loading bays on the current TAS. Also, different equipment is used per bay for the loading of each product type, thus the changing time from one product type to another in a loading bay is actually neglectable. Moreover, this chemical plant supplies clients apart from Belgium and in other countries like the Netherlands, France and Germany (Raj, 2019). Usually, the trucks which serve these countries originate their trip from that country, then they get loaded in the plant and return back in order to fulfill their delivery. Due to this fact, the uncertainty of trucks' arrival time at the plant increases significantly, as they have to travel considerably longer distances. For these reasons, truck drivers and trucking companies usually prefer to be earlier than their appointment slot time in plant's location and wait so that they do not lose their reserved timeslot (Wibowo & Fransoo, 2020).

3.5.2 Factors Affecting Trucks Arrival Time

Raj (2019) conducted a survey, among the truck drivers from different carriers, in this specific chemical plant in order to identify the main factors that affect the trucks arrival time at the plant's gates. Trucks drivers' responses were then statistically tested, with the use of Friedman's test, and then the weighted impact of each factor on the Arrival Time was calculated. These factors, both internal and external of the chemical plant, are presented in the Table 3.1 below.

Factor	**Weight [%]**
Congestion	25%
Force of Nature	9.3%
Technical Breakdown	11%
Road Diversion	20%
No Communication	13.3%
Previous Job	21.4%

Table 3.1: Survey Results Factors Affecting Trucks Arrival Time (Raj, 2019)

Thus, as it can be extracted from the findings of this survey that Congestion and Road Diversion, which are factors related directly to the road network, account for the 45% of the total impact on Trucks Arrival Time at the plant. Also, the communication lag between the truck drivers and the plant planner, as it has already been discussed, has an impact of 13.3%. In addition, unexpected events like weather conditions (force of nature) and equipment break downs have a combined impact on the arrival time of around 20%. Finally, the effect of the previously assigned job to the truck can affect its arrival time with a weighted impact of 21.4%. Consequently, the importance of creating a robust Truck Appointment System, where the stochasticity of the trucks arrival time is considered and there is some scheduling flexibility, it is proven again.

3.6 Stakeholders Analysis

In this section a brief description of the main stakeholders of this research, namely Chemical Plant, Trucking Companies (carriers) and Authorities, is given.

To start with, the main stakeholder of this project is the company that owns the chemical plant. They have the power and the means to try and make their operations more resilience, efficient and to recover faster from disruptions. In more detail, they are interested in having smooth operations, increasing their equipment's utilization rate and terminal's throughput while minimizing their overtime, thus increasing their productivity (Vanga et al., 2022; Raj, 2019). In addition, it is important for them to have a good relation with the trucking companies, who are the other main stakeholder of this project and with whom they are strongly connected. Trucking companies (carriers) aim at reducing the effect of disruptions in their operational plans and minimizing their trucks turnaround time in order to increase their utilization rate, which is significantly affected by the long waiting times. The final stakeholder is the authorities, governmental and regional, whose aim is the protection of the natural environment and thus the reduction of pollution, especially air pollution, which affects the wellbeing of the population living and working around the plant. In addition, they aim at retaining a good standard of road safety and keeping congestion under a certain level. Finally, it is important to point out that there is a conflict of interests between the stakeholders in the context of a chemical plant. This is explained as site managers tend to implement strict schedules in order to maximize site's productivity, while trucking companies aim to minimize their trucks turn-around time, which are not always congruent to each other (Wibowo & Fransoo, 2020).

In the context of this research, the interests of the two direct stakeholders, namely Chemical Plant and Trucking Companies (carriers), are considered and they are equally weighted (balanced) for the design of the new system. However, it is expected that the successful balance of the interests of these two stakeholders will also have a beneficial impact on authorities' interests, especially regarding the air pollution and reduction of long queues around the chemical plant.

3.7 Key Performance Indicators Definition

In this section, initially all the Key Performance Indicators (KPIs) related to this research are presented and are matched with the stakeholders for which they are important. These KPIs are formulated based on the objectives and interests of the different stakeholders, as they have been described in Section 3.6. Finally, a selection of the most important KPIs, for this research, is carried out and the chosen KPIs are presented. These selected KPIs form the base on which the evaluation of the proposed system is performed.

The main KPIs related to the proposed research are presented below:

- *Gate Waiting Time (GWT):* The waiting time before a truck enters the plant gates for service (gate entry time minus (–) truck actual arrival at the plant's premises)
- *Cycle Time:* The total time between truck's arrival at the plant and its exit from the plant (plant exit time minus (–) actual plant arrival time)
- *Number of Trucks Waiting Before the Gate (NTBG):* The number of trucks waiting before the chemical plant's entrance gate for service

- *<u>Number of Late Trucks (NLT):</u>* Number of trucks that are late more than "X" hours from their booked slot
- *<u>Slot Utilization (SU):</u>* The ratio of the productive time to the total available time of the loading bays (sum of the time that each loading bay is utilized divided by (/) the sum of the total available time of each loading bay)
- *<u>Finish Time (Makespan) (FT):</u>* The total time length (span) to complete the service of all trucks each day (The time that the final truck finishes its service minus (−) The open time of the loading bays in the morning)
- *<u>Number of Reschedules (NR):</u>* Represents the quantity of reschedules occurring per day

The Gate Waiting Time (GWT) is an important KPI for the carriers and the authorities, as during the waiting time trucks engines are usually idling, trucks productivity is reduced and if the duration of the waiting time is long, congestion and long queues can possibly occur around the plant's premises. Further, this KPI is a good measure of the chemical plant's environmental performance (footprint). The Cycle Time is an important KPI for the carriers as the lower this time is the higher the truck's utilization can be. The Number of Trucks Waiting Before the Gate (NTBG) is a significant KPI for all stakeholders, as the bigger the number of waiting trucks is the bigger the effects of the long queues and congestion around the chemical plant will be for all of them. The number of Late Trucks (NLT) is a significant KPI for the terminal operator (planner) as the equipment might be idling during the truck's booked appointment time and also efficient rescheduling might be difficult to be achieved for these trucks. The Slot Utilization (SU) KPI is important for the terminal operator as it shows the percentage of time that each loading bay is actually utilized and is not idling. The Finish Time (FT) KPI is important solely for the plant operator, as it is the time that the last truck is served and can identify if overtime is required or if there is a spare time during the plant's working hours. Finally, the Number of Reschedules (NR) is an indicative of the plant's planner workload.

KPIs are used in order to evaluate the performance of a system. Also, as it is suggested by their name, they have to capture the performance of the main processes and operations in a system. Consequently, from all the possible aforementioned KPIs, the most relevant to the goals of this research were chosen as the KPIs for this work. The KPIs that were chosen as the most important and will be the primary KPIs for the rest of this research are presented in the Table 3.2, along with the Stakeholder that they are important for and their units. These KPIs were chosen based on our understanding from the discussions with the Chemical Company and the paper of Vanga et al (2022). Further, the opted KPIs capture the key metrics for all the main stakeholders of this research.

KPI	Stakeholder	Units
Gate Waiting Time	Carriers & Authorities	Minutes
Slot Utilization	Chemical Plant	%
Finish Time (Makespan)	Chemical Plant	Minutes

Table 3.2: Selected KPIs for this Research

3.8 Chapter Summary

Initially, a brief description of the Petrochemical Supply Chain was given which can be categorized in three segments, namely upstream, midstream and downstream, according to the second classification of Sahebi (2013). The scope of this research is placed at the end of the midstream and the beginning of the downstream operations of the whole supply chain. In more detail, and as it is presented in the System Boundaries Section, this project is limited to the loading operations of the chemical plant and the road transportation, by the carriers, of the finished products to the customers. Yet, the transportation until the products delivery to the final customers is out of the scope of this study.

In literature, a wide variety of factors affecting the Trucks Arrival Times and consequently the efficiency of a typical Truck Appointment System have been identified. However, in this chapter the case specific factors for the Chemical Plant under study, located in the Antwerp region, were defined. These factors are the already congested road network of the region and the planned construction work for rehabilitating Antwerp's Ring Road. They are expected to have a significant impact on the operations of the chemical plant as the deviation between scheduled and actual trucks arrivals can result in overflow of finished products and consequently in production disturbances or need for extra inventory storage facilities. Further, the performance of the current Truck Appoint System (TAS) is expected to be considerably affected as more trucks will either arrive later or earlier than their appointment, as estimating congestion will be even more difficult in the future. Also, as the number of delayed trucks increases and the number of reschedules required will be increased along with truck queues outside the plant premises, so the benefits of implementing a TAS will be reduced. Thus, the need of developing of a new system, with higher flexibility and resilience against disruptions compared to the currently used TAS by the chemical plant, is made obvious.

Moreover, chemical plants have some distinct characteristics which differentiate their operations and procedures from other logistics sites. These characteristics are briefly the high safety standards and procedures that regulate their operations, the document checkup that each truck has to undergo in order to confirm the legitimacy of its operations and the compliance with the safety standards, the significantly higher loading time for each truck compared other logistics site – like a container terminal –, the relatively limited operating hours of the plants, the conflict of interest between the different stakeholders and their high complexity as a system.

The studied Chemical Plant is located in the Antwerp region of Belgium. Its inbound logistics (supply) are performed through marine transportation, while the outbound logistics (delivery to the customer) are performed through road and rail. For each arriving truck there is a strictly defined path, with different tasks completed at each step of it, since their arrival at the plant's gates until their departure from the plant. The main tasks of this path are the truck entrance through the Plant's Gates, the announcement of the truck's arrival at the plant and the check of their documents which is carried out at the Documents Check Point (DCP), the weight of the truck at the Scale, the loading process of the truck at the Loading Bays, the weight of the truck at the Scale after the loading has been completed, the completion of the paperwork at the DCP and finally the exit of the truck from the Plant's Gates. The chemical plant studied here has 6 loading bays which serve different products, and their loading time is either 30 or 45 minutes, depending on the loading bay. Also, the appointment duration at the currently in use Truck Appointment System (TAS) is not the same for all the loading bays, but it is related to the service time of the loading bay. Moreover, the current capacity utilization of the plant's loading infrastructure is around 60%-70% of its total daily available capacity (slots). Besides, the data from 2019, which is before the pandemic and the start of the works in the Antwerp's ring road, shows that the percentage of delayed truck arrivals is 20.5% (Raj, 2019). In addition, it is important to mention that this chemical plant supplies clients and in other countries apart from Belgium, like Netherlands and France. Usually, the trucks which serve these countries originate their trip from that country, which increases the uncertainty of the truck's travel time as distance increases. Furthermore, the factors affecting the Trucks Arrival Time at this plant, according to the truck drivers, have been identified as the Congestion (25%), the Road Diversion (20%), No Communication between drivers and plant's planner (13.3%), Force of Nature (9.3%), Technical Breakdown (11%) and Previous Job (21.4%) (Raj, 2019). The Stakeholders for this project are the Chemical Plant, Trucking Companies (carriers) and Authorities, which have different interests and objectives – often conflicting. Finally, the KPIs that will be used in this research were defined and they are, namely, the Gate Waiting Time, the Slot Utilization, and the Finish Time (Makespan).

In conclusion, in this chapter a description of the Chemical Plant under study and its loading operations was given. Also, the present situation of the Chemical Plant was illustrated and the challenges that are currently faced during the loading operations were identified. Moreover, quantitative data was used in order to obtain a better insight into the present situation and problems. Consequently, sub-Research Question 2 has been answered. Furthermore, the need for developing a new and more flexible system, in order to deal with trucks arrival deviations, is made clear.

Chapter 4: Truck Appointment Systems Description

In this chapter the Truck Appointment System designs are presented. In more detail, in Section 4.1 the currently in use Truck Appointment System by the Chemical Plant is described. Following, in Section 4.2 the proposed by this research Truck Appointment System is illustrated. Finally, in Section 4.3 the chapter summary along with the answer to sub-Research Questions 3 and 4 are given.

4.1 Truck Appointment System in Practice

In the chemical plant that is analyzed in this study, there is already a Truck Appointment System (TAS) in place. However, this TAS is the typical one with fixed timeslots which comes with several drawbacks as they have been explained in the Introduction and the Literature Review. In more detail, the plant's operator, through the designated online appointment system, announces the available timeslots (appointments). Also, through the same system, trucking companies see the slots availability and book one of the available slots. The timeslot choice is based on the better fitting to their schedule, in order to accomplish the on-time delivery of the products to the final customers. The duration of these timeslots is fixed and equal to the trucks' service time at each loading bay, thus loading bays 1 and 2 have lengthier appointments compared to the others. It is important to note that these appointments are booked in advance, before the actual arrival of the trucks to the plant. At the day of the appointment, trucks can arrive earlier than their slot time, but then they will have to wait as the loading operations at the terminal happen strictly based on the appointments schedule. If a truck arrives later than its booked slot, then it loses its slot and has to book a new one in order to be served. Alternatively, the rescheduling of the late truck can be performed by the slot manager upon truck's arrival at the plant. However, the next available appointment might be in a few hours or even the next day, as not all loading bays serve the same type of products which increases the complexity of finding a new slot. Besides, this rescheduling is performed manually, considering only the delayed truck and with minimal information available, thus it is sub-optimal from a system perspective (Vanga et al., 2022). Further, for the plant these reschedulings reduce the utilization of the loading facilities as well as the available buffer slots for future truck appointments (Vanga et al., 2022). Furthermore, it should be noted that in the current system truck drivers have only one side flexibility, to arrive earlier than their booked slot, in order not to miss their appointment time and consequently to wait a significant amount of time for a new slot. It is considered that this one-way flexibility puts a lot of pressure on truck drivers and trucking companies. In addition, in this system real-time information about the trucks' location and expected arrival time are not considered at all, as the loading sequence is strictly based on the static pre-defined schedule of the booked slots. For the rest of this research, the TAS system which is currently used in the chemical plant will be referred as *fixed slot design (d1)*. Finally, in Figure 4.1 below, the one-side flexibility of trucks' arrival time or similarly the time that a truck is expected arrive at the plant in order not to lose its booked slot of 11:30 is depicted.

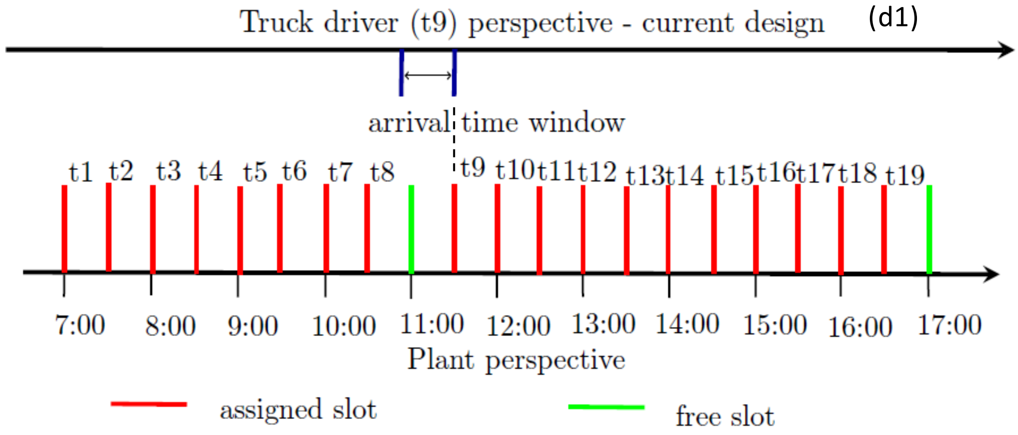


Figure 4.1: Current TAS (d1) for a booked slot at 11:30, truck driver's and plant's perspectives. Driver can only arrive earlier than 11:30 in order not to miss the appointment.

4.2 Proposed Truck Appointment System (TAS)

In this research an extension of the typical Truck Appointment System (TAS), with fixed slots, is proposed. The requirements for this new TAS, as they can de deduced from the previous sections, are the flexibility and responsiveness against truck arrival deviations and disruptions in general. In the proposed TAS, instead of a fixed time slot, a time-window is assigned to each truck. The duration of the provided time-window is longer than the actual service time. Consequently, the offered time-windows overlap with some other time-windows (appointments), before and after them. It should be noted that the length of each slot in the fixed design (d1) is equal to the trucks service time. This means that for the proposed system the booked time slots (session times (x)) are for reference/ indication only, as there is the time-window around them. Thus, the actual service sequence might be different from the reserved one. So, in order to deal with this problem a mathematical model which generates the actual loading sequence is developed aiming to increase terminal's utilization rate and reduce trucks waiting time. This model will determine and update the actual loading order, every "Y" minutes, based on the actual and Estimated Time of Arrival (ETA) of the trucks, information which is considered available for each truck, and by taking into account the objectives of the different stakeholders. The aforementioned mathematical (optimization) model is described in more detail in Section 5.1. The concept of this proposed system, to the best of our knowledge, is a topic that has not been researched again in this context.

The idea of implementing time-windows in a TAS is proposed as it adds flexibility in both sides of the booked timeslot for truck drivers, early and late arrival of truck, in contrast to the one side flexibility, only early arrivals – ideally only a few minutes earlier –, of the fixed slot design (d1). This extra flexibility is very important as it is expected to mitigate truck drivers' dilemma and reduce the stress levels that they feel about missing their slot due to unexpected delays, which are two main goals of this research. In addition, the update of the trucks' loading sequence based on real-time information is opted as it is a component which can increase the system's responsiveness against truck arrival deviations and disruptions of the real world. Furthermore, the truck's loading sequence update according to their ETAs, can also benefit the truck drivers to reduce significantly their waiting times, especially for those who arrive earlier than their assigned slot. At the same time, terminal's operator is also expected to be benefited from this constant update of the loading sequence due to the increased utilization rate of the loading bays compared to the current TAS system (d1), where if a truck misses its slot; that slot remains empty, and the equipment remains idling during that time. Moreover, for the rescheduling in the proposed design all the trucks that are expected to arrive at the plant in the next "V" minutes, based on the available ETA information, are considered. Thus, the outcome of this rescheduling is significantly improved, from a system perspective, compared to the current TAS design (d1), as a number of incoming trucks with their constraints are considered in the rescheduling in contrast to the myopic view of the current TAS (d1), in which only one truck is rescheduled at a time. The information about the truck ETAs derives from data obtained from the integration of logistics and traffic systems. Also, it is important to point out that due to the overlap of the time-windows it is impossible to assure for each arriving truck that it will be served immediately. As it cannot be guaranteed that there will be an available loading bay or a spot in the document check point as soon as the truck arrives at the plant. Instead, to all arriving trucks an *assured service start time (AST)* is given, which shows the maximum waiting time (AST) before their service will start with an *assured probability* (p_a) of this to happen. The AST and assured probability are not abstract numbers, but they represent something tangible. In order to explain their importance, two examples from the food delivery sector are used. These are the cases of Zomato and Domino's which both have in place a, partial or full, refund policy when the food delivery to the customer is performed later than the latest estimated delivery time. For the case of Domino's this time is 30 minutes (Dash, 2019; Domino's Pizza 30 Minutes Free Pizza Delivery Policy). Consequently, the connection between the latest delivery time in the food delivery sector and the AST in the proposed TAS is obvious and the importance of the assured probability is critical for determining the possible compensation. In addition, the importance of both the assured service start time (AST) and the assurance probability p_a along with the length of the time windows (l) for the successful implementation of the proposed design is made clear. The proposed design with the implementation of *time-windows and use of real-time information*, for the rest of this report, it will be referred as design *d2*. In Figure 4.2 below, an overview of the proposed design (d2) and the main design parameters is given.

Further, in this section the main design parameters for the proposed slot design d2 are presented and explained. These are the followings:

- *Session time (x):* This parameter shows the indicative start time that it is assigned to a particular customer (truck). It is important to point out that this time is not the earliest time that a truck can arrive at the plant, but it is actually the middle of the time window or similarly the time based on which the time-window is defined.
- *Session Length (l):* This parameter shows the duration of the available time window, during which a customer can be serviced with an assurance probability p_a in maximum AST minutes. So, the time window for a truck is defined as [x-l/2, x+l/2]. The units of this parameter are minutes or hours.
- *Assurance Probability (p_a):* shows the probability, for a truck which arrives during its booked time window, to be served before the end of assured service start time (AST). For instance, if the assurance probability is 95% and the service start time is 20 minutes, this means for a truck that arrives during its assigned time window that the maximum waiting time or similarly the later time that the service will start is 20 minutes with 95% probability.

- *Assured service start time (AST):* This parameter shows the latest time before or similarly the maximum waiting time before the truck's service will start with a probability of p_a. Of course, this parameter is valid only for trucks that arrive during their booked time window. Finally, it is important to point out that the assurance probability (p_a) and the assured service start time (AST) are highly correlated. The units of this parameter are minutes or hours.
- *Number of slots per day (n):* This parameter shows the total number of available slots in a day.

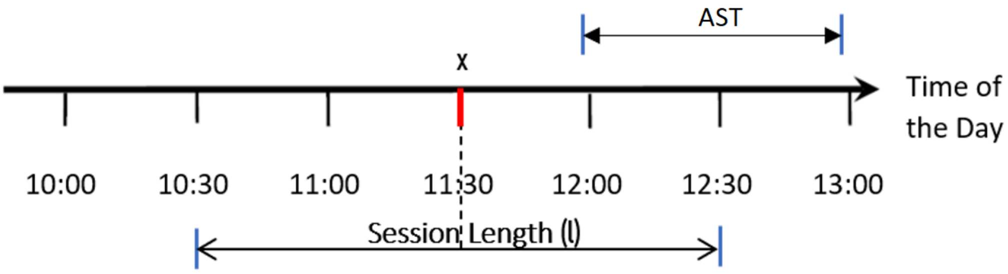


Figure 4.2: Proposed TAS (d2) for a booked slot at 11:30 and arrival time at 11:55, with illustration of the design parameters Session Length (l) of 2 hours and Assured Service time (AST) of 1 hour

Finally, an example of the proposed system (d2), followed by the comparison between the proposed (d2) and the currently used (d1) TAS, based on Figure 4.3, is given. Truck driver (t9) has booked a slot for 11:30. In the current design (d1), truck driver is expected to arrive, ideally, a few minutes before his/her booked slot. Arriving much earlier reduces truck's utilization rate as it has to wait outside the plant gates until the appointment time has come, but it does not affect their booked slot or plant's efficiency. However, if the driver arrives late, for instance 10 minutes, at 11:40, then the slot is canceled, and a new one has to be booked by themselves or they can be rescheduled by the slot manager later that day or the next day, according to the slot availability, in order to be served. Also, as this missed timeslot eventually remains empty it affects the chemical plant's performance, as its utilization level is decreased. In contrast, in the proposed design (d2), assuming a time window of 2 hours and an indicative time at 11:30, the truck driver can arrive at the terminal even at 10:30 and get through the gates and start the loading process at most after AST minutes. Similarly, the driver can arrive even at 12:25, enter in the terminal and get served at most after AST minutes from its arrival, without losing its slot. As it can be seen the session time (x) is only indicative and the driver has the flexibility to arrive from one hour before till one hour after the session time and still get served. This shows the high flexibility, in both ways - early and late arrival-, that the proposed system (d2) has in contrast to the current design (d1), where the service happens strictly based on the sequence of the booked appointments and late arrivals lead to no service for those trucks.

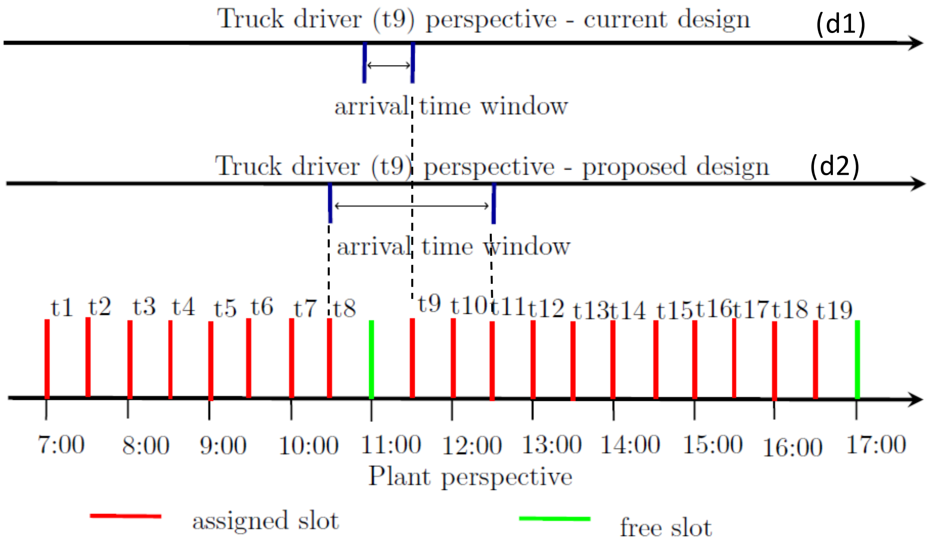


Figure 4.3: Current (d1) and Proposed (d2) TAS for a booked slot at 11:30 - Comparison regarding the flexibility of truck drivers' arrival so that they do not miss their slot

4.3 Chapter Summary

Initially, in this chapter a description of the Truck Appointment System that is currently used in the chemical plant under study is given. The implemented TAS, in this plant, is a typical TAS with fixed slots and consequently it has a few drawbacks, as they are described in the literature. In this TAS, the plant operator announces the available timeslots on an online appointment system, through which trucking companies book the slot that fits the best to their scheduling. These appointments are booked in advance, before the truck's arrival at the plant. The day of the appointment the truck is expected to arrive a few minutes before the booked slot time and to wait until the time of its appointment has arrived, as the loading is performed strictly based on the appointments schedule. If a truck arrives later than its booked timeslot, it misses its slot and has to book a new one or to get rescheduled by the slot manager, however the waiting time until the next available slot cannot be predicted and no minimum waiting time is guaranteed. Consequently, this leads to high pressure for truck drivers to arrive on time, even though disruptions can occur during their trip and significantly affect their arrival time at the plant. Further, the rescheduling performed by the slot manager is done manually and considers only one truck, thus it is sub-optimal from a system perspective. In addition, these reschedules reduce loading bays utilization and the availability of buffer slots for future truck appointments. Hence, sub-Research Question 3 has been answered as the characteristics and the drawbacks of the currently in use TAS were presented. Subsequently, a new TAS with the use of time-windows, real-time information and ETAs is proposed in order to face the aforementioned drawbacks of the typical TAS. The requirements for this new TAS are the flexibility and responsiveness against truck arrival deviations and disruptions in general. In more detail, in this system a time-window is assigned to each truck, with an indicative arrival time at the middle of the time-window (x). Additionally, the duration of the time-windows (l) is longer than the actual service time consequently there is an overlap between some time-windows. For this reason, an assured service start time (AST) and an assurance probability (p_a) is given to each truck, which show the maximum waiting time for a truck that arrived during its assigned time-window before its loading process starts and with what probability.

Consequently, the actual service sequence might be different from the reserved one. In order to determine the actual loading sequence an Optimization model is developed, which is run every “Y” minutes with updated information of the actual and Estimated Time of Arrival of the trucks, and creates the adjusted schedule for the loading operations. This proposed TAS is expected to significantly reduce the stress level of the truck drivers about missing their booked slot and the trucks waiting times. Moreover, it is expected to increase terminal’s utilization rate and generate improved, from a system perspective, loading schedules compared to the current TAS. Therefore, sub-Research Question 4 has been answered as the proposed TAS’s main components and structure along with its characteristics were described.

Chapter 5: Methodologies Used and Models Creations

In this chapter, the Optimization and Simulation models developed for this research are presented and hence sub-Research Questions 5 and 6 are answered. Initially, in Subsection 5.1.1 a brief literature review is performed followed by the description (Subsection 5.1.2), formulation (Subsection 5.1.3), and verification (Subsection 5.1.4) of the Optimization Model required for the (re)scheduling of trucks loading sequence in the proposed TAS. Further, the Simulation Model used in this research is described in Subsection 5.2.1, and then the integration of the developed Optimization Model in this model is explained in Subsection 5.2.2. Following, the input data for the Simulation model is depicted and the model's verification and validation are performed in Subsections 5.2.3 and 5.2.4 respectively. Finally, in Section 5.3 this chapter's summary is given.

However, before getting into further analysis, an overview of the developed Simulation model and its interaction with the Optimization model is given. It is noted that in the proposed TAS design (d2), the Optimization (rescheduling) model is an integral part of the design. Thus, it is required to be integrated and into the simulation model. To demonstrate this, an abstract representation of the simulation model, in which the optimization model has been integrated, is given in Figure 5.1. In this figure, the simulation environment is depicted with the light green rectangular, while the optimization model is depicted with the blue rectangular. In the simulation model, trucks are generated and travel to the chemical plant. When they reach the plant, they go to its gates to announce their arrival and either get into the plant or they are informed about their actual entering time. When a truck enters the plant, it gets serviced and then leaves the plant to perform the product delivery to the final customer. The actual loading sequence of the trucks is determined by the optimization model. The optimization model receives as inputs from the simulation model the trucks' real-time information and ETAs, the works-in-progress, information about the trucks that have entered the plant premises, the

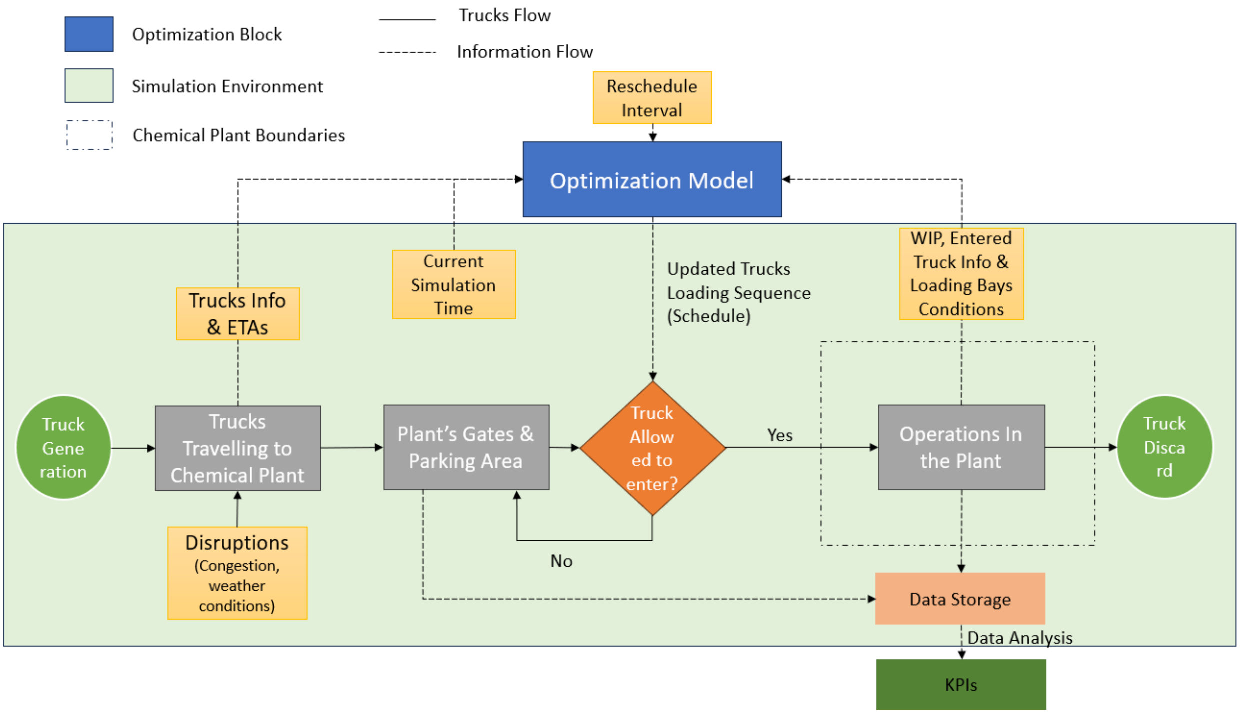


Figure 5.1: Interaction between Optimization and Simulation Model (Abstract Representation)

loading bays' condition, and the current simulation time. Based on this information, the optimization model is run every "Y" – specified by the Reschedule Interval –, and the updated loading sequence (schedule), for trucks to enter the plant, is determined. This new and optimized schedule is provided to the Plant's Gates, defining which trucks are allowed to enter the plant premises and at what time. In addition, throughout the simulation process, data from different operations is stored. Then, this data is statistically analyzed and the values of the system's KPIs are determined.

5.1 Optimization Model – Rescheduling

5.1.1 Brief Literature Review

For the development of the optimization model, which will perform the trucks (re)scheduling in the proposed TAS design (d2), literature review is performed. Aim of this literature review is to find related work in the field of TAS with the use of time-windows, and possibly a mathematical model that could be used as the base for formulating this research's model. However, in the field of optimization models and TASs with the use of time-windows only one paper was found, the paper of Chen and Jiang (2016) which aims at defining the optimal time-window length for each arriving vessel during which trucks could unload their containers in the container terminal. Thus, Chen's and Jiang's (2016) mathematical model cannot be used as a base for the development of this study's model as the aim of their optimization model and the model formulation approach are very different from that of this research. Consequently, research on other fields is conducted with focus on the job-shop scheduling problems, as their objective is to define the job sequence at the different stages and to perform jobs to machine assignment in order to optimize one or more chosen criteria (Naderi et al., 2008). Therefore, the relevance of these problem types with this study's is apparent. Moreover, in literature job-shop scheduling problems formulations are used, apart from production management, and in other fields like the electric vehicle charging coordination, the refueling of a fleet of vessels or trucks and the electrical household management in residential buildings (Berndorfer & Parragh, 2022; Nguyen et al., 2018).

In this paragraph, the presentation of some job-shop scheduling problems which can be used for the development of this study's mathematical model is given. To start with, Berndorfer and Parragh (2022) developed a Mixed-Integer Linear Programming model aiming to solve the problem of shop floor space assignment for the final product assembly with the objective of minimizing the total tardiness and utilized machine size. In this problem early start of the jobs is not allowed, however for each job there is a due-time window during which it has to be completed in order not to occur delay costs. This is a non-preemptive parallel machine scheduling problem, in which there are restrictions on the machines that each job can be performed on and where the production planning is done in a rolling horizon manner. Also, Nguyen et al. (2018) introduced a Mixed Integer Linear Programming (MILP) model formulation for handling the parallel machine scheduling problem with a single additional resource, the control of job processing time by a linear resource consumption function, with the objective of minimizing the total completion time of all jobs. This research was motivated by the electric vehicle charging coordination problem and thus each job has to be performed during the time-window of arrival and the assigned deadline. Hence, each job has two restrictions the time restriction and the resource consumption restriction. The planning horizon in this problem is divided into k time-steps and jobs are considered non-preemptive.

Moreover, Hung et al. (2017) proposed a Mixed-Integer programming model for the make-to-order (MTO) manufacturing environments with the objective of finding a feasible schedule – all jobs to be performed during their time-window – and if that is not possible then the aim is the minimization of the occurring earliness and tardiness costs of all jobs. In more detail, in this research the jobs scheduling problem on unrelated parallel machines with sequence dependent set up times and machine and job dependent processing rates is studied. For each job a time-window is defined by the ready date – earliest day to start, when all raw materials are available – and a due date – latest date the job has to be finished. A job is expected to be fully processed during its assigned time-window so that earliness and tardiness costs are avoided. Also, in this study the machine eligibility is considered, which means that not all jobs can be performed on all parallel machines. Finally, Missaoui and Ruíz (2022) created a Mixed Integer Linear Programming (MILP) model for the hybrid flowshop scheduling (HFS) problem with the objective of minimizing the total weighted earliness and tardiness from a due date window. HFS problems address the job scheduling through a set of stages in which multiple parallel machines are available. In this work two extensions of the typical problem were studied, firstly sequence dependent setup times were introduced and secondly a due date window was used instead of a due date.

5.1.2 Description, Requirements and Assumptions of the Optimization Model

The problem that this optimization model aims to address is the scheduling of the incoming trucks at the chemical plant for the proposed TAS design (d2) with the use of time-windows as it has been explained in Section 4.2. In more detail, the objective of this optimization model is to determine the trucks loading sequence and loading bay assignment based on their ETAs and promised service time while minimizing the total cost. The total cost consists of the sum over all trucks of the waiting time cost plus the sum of the penalty costs occurring from not serving on-time trucks during their assured service start time (AST). Also, it is important to point out that the trucks considered in the (re)scheduling are trucks that are near or at the plants, this information is obtained based on their ETA and real-time location, as the ETA's accuracy for trucks far from the plant decreases significantly.

The general description and the aim of the optimization model that will be developed have been discussed. However, the requirements that this model has to comply with still need to be addressed. To start with, all trucks that arrive at the chemical plant have to be served, yet with different priorities assigned to them based on their arrival time at the chemical plant, high priority is given to trucks that arrive during their booked time-window while low priority is given to the trucks that arrive outside of it. Also, a maximum waiting time limit, TL, before their service starts is determined for all trucks. Further, all trucks can be rescheduled based on their ETA and real-time information. In addition, each (re)scheduled truck must be assigned to a loading bay where the requested product type is available, as not all loading bays serve all product types. Moreover, trucks can enter a loading bay immediately when it is idle, as flexible service start times are used in the proposed model. Finally, at each loading bay only one truck can be served at a time.

From all the different models described in the previous section, that developed by Hung et al. (2017) is considered the most related to this work, and thus applicable to be used as the base for developing this research's mathematical model. The relation of these two problems is explained as:

- The existence of a time-window during which each job has to be completed is a basic component of both models.
- The unrelated parallel machines in the proposed system are the chemical plant's loading bays.
- The machine dependent processing rate is applicable in the proposed system as not all loading bays have the same service time.
- The machine eligibility constraint is applicable and in the proposed system as not all loading bays serve all types of products.
- Finally, the sequence dependent set up times and job dependent processing rates are not applicable in the proposed system thus some simplifications compared to the existing model are made.

Finally, the main assumptions for the development of the proposed optimization model are presented. These assumptions are that:

- Trucks without reservation (booked appointments) are not considered.
- The real-time location of trucks is considered to be known. With this information available and through the integration of logistics and traffic systems, the Estimated Time of Arrival (ETA) for each truck is obtained. For the purposes of this study, the ETA information for each truck is considered available and it is an input to the model. In the proposed model the ETA value is handled as deterministic, and its stochastic nature is ignored.
- Each truck can carry only 1 Product Type.
- Loading bays setup times between the service of different trucks are zero, as at each loading bay there are specific pumps and lines for each product type thus there is no need for cleaning or modifying anything between the service of trucks.
- Jobs are non-preemptive, meaning that when the loading process of a truck starts it cannot be interrupted until it has been finished.
- A theoretical cost DC, named penalty cost, for not serving a truck during the promised service time-window, is estimated, and used for the formulation of the objective function.
- Process times, like gate time, weighting time, loading time etc., are known and are handled as deterministic in the proposed model.
- Maintenance of the equipment is not considered in this model.
- Equipment failures are not considered in this model.
- The earliest loading start time on each loading bay is considered known at the time of rescheduling.
- Arrival time window and service time window are fixed and have the same duration for all trucks.

5.1.3 Mathematical Formulation of the Model

In this subsection, the Mathematical formulation of the proposed Optimization model, developed based on the model of Hung et al. (2017), is presented.

Indices

- i, j : Truck – Job
- *l* : Loading Bay

Sets

- L : Set of loading bays, L = $\{l_1, l_2, \ldots, l_{NL}\}$
- I : Set of Trucks (and Jobs), I = $\{i_1, i_2, \ldots, i_{NT}\}$ (That need to be Rescheduled)
- Î : Set of Trucks that arrived during their assigned time-window (on time) $\hat{I} \subseteq I$,
  $\hat{I} = \{\hat{\imath}_1, \hat{\imath}_2, \ldots, \hat{\imath}_{NOT}\}$
- Ï : Set of Trucks that arrive outside their assigned time-window $\ddot{I} \subseteq I$
- WIP : Set of Works In Progress (WIP) – trucks that are being serviced at the time of the rescheduling. This set includes also artificial jobs for the cases where a loading bay is empty. WIP = $\{w_1, w_2, \ldots, w_{NL}\}$

Parameters

- ETA_i : Expected Time of Arrival at the plant of truck i (updated in real time)
- R_{li} : Loading Bay (l) and Truck (j) mapping based on the product type
- CTW_i : Completion Time of Works in Progress i
- LW_i : Loading Bay that WIP i is assigned to
- NL : The Number of Loading bays
- NT : The number of Trucks to be rescheduled
- NOT : The number of On-time Trucks to be scheduled
- S_l : The service time at loading bay l, $l \in L$ [min]
- AST : The Length of the Assured Service Time-Window [min]
- TL : The Maximum waiting time for trucks arriving outside their assigned time window
- CurTime: The current time – the time that that the reschedule occurs/ is triggered
- M : Large Number (ex. 9999)
- DC : Penalty Cost for not serving On-Time Trucks during their AST (Delay Cost)
- a, b : parameters for the weighted average of the objective function

Decision Variables

- X_{il} : $\begin{cases} 1, \ if \ truck \ i \ is \ assigned \ to \ loading \ bay \ l \\ 0, otherwise \end{cases}$
- Y_{ij} : $\begin{cases} 1, \ if \ job \ i \ immediately \ precedes \ job \ j \ on \ the \ same \ machine \\ 0, otherwise \end{cases}$
- CT_i : The Completion Time of job i - Continuous Variable

Auxiliary Variables

- OTN_i : $\begin{cases} 1, \ if \ service \ of \ the \ on-time \ truck \ i \ starts \ later \ than \ AST \ window \\ 0, otherwise \end{cases}$

Objective Function:

$$Minimize \quad Z\colon\ a * \sum_{i \epsilon \mathrm{\hat{I}}} \left(CT_i - ETA_i - \sum_{l \in L} (S_l * X_{il}) \right) + \sum_{i \in \mathrm{\hat{I}}} OTN_i * DC + b * \sum_{i \epsilon \mathrm{\ddot{I}}} \left(CT_i - ETA_i - \sum_{l \in L} (S_l * X_{il}) \right) \quad (0)$$

subject to,

$$\sum_{l \in L} X_{il} = 1\,, \qquad \forall\, i \in I \qquad (1)$$

$$X_{il} \leq R_{li}\,, \qquad \forall\, i \in I, \forall\, l \in L \qquad (2)$$

$$\sum_{i \in (WIP \cup I)} Y_{ij} = 1\,, \qquad \forall\, j \in I \qquad (3)$$

$$\sum_{j \in I} Y_{ij} \leq 1\,, \qquad \forall\, i \in (WIP \cup I) \qquad (4)$$

$$Y_{ij} = 0\,, \qquad \forall\, i \in (WIP \cup I), \forall\, j \in WIP \qquad (5)$$

$$Y_{ij} \leq 1 - \left(X_{il} - X_{jl} \right), \qquad \forall\, i \in (WIP \cup I), \forall\, j \in I\,, \forall\, l \in L \qquad (6)$$

$$Y_{ii} = 0\,, \qquad \forall\, i \in I \qquad (7)$$

$$CT_j \geq CT_i + \sum_{l \in L} \left(S_l * X_{jl} \right) + M * \left(Y_{ij} - 1 \right), \qquad \forall\, i \in (WIP \cup I), \forall\, j \in I \quad (8)$$

$$CT_{w_i} = CTW_{w_i}, \qquad \forall\, w_i \in WIP \qquad (9)$$

$$CT_i \geq \sum_{l \in L} (S_l * X_{il}) + ETA_i\,, \forall\, i \in I \quad (10)$$

$$CT_i \geq CurTime\,, \qquad \forall\, i \in I \qquad (11)$$

$$CT_i - ETA_i - \sum_{l \in L} (S_l * X_{il}) \leq TL\,, \qquad \forall\ i \in I \qquad (12)$$

$$CT_i - AST - ETA_i - \sum_{l \in L} (S_l * X_{il}) \leq M * OTN_i\,, \qquad \forall\ i \in \hat{I} \qquad (13)$$

$$X_{w_i\, LW_i} = 1\,, \qquad \forall\, w_i \in WIP \qquad (14)$$

$$CT_i - \sum_{l \in L} (S_l * X_{il}) \geq CurTime\,, \qquad \forall\, i \in I \quad (15)$$

$$X_{il} \in \{0,1\}\,, \qquad \forall\, i \in (WIP \cup I), \qquad \forall\, l \in L \quad (16)$$

$$Y_{ij} \in \{0,1\}\,, \qquad \forall\, i \in (WIP \cup I), \forall\, j \in (WIP \cup I) \; (17)$$

$$OTN_i \in \{0,1\}\,, \qquad \forall\ i \in \hat{I} \qquad (18)$$

$$CT_i \in N, \qquad \forall\, i \in (WIP \cup I), \qquad (19)$$

The aim of the objective function (0) is to minimize the total weighted cost resulting from the waiting time of all on-time arriving trucks, the waiting time of all trucks that arrived outside their booked time-window and the penalty cost (time) for not serving on-time trucks during their AST. It should be noted that the units of the penalty cost (DC) are minutes. Constraint (1) ensures that each truck is assigned to exactly one of the loading bays. Constraint (2) enforces each truck to be assigned to a loading bay where the requested to transport product is available. Constraints (3), (4) and (5) are sequence constraint. In more detail, constraint (3) ensures that each truck that does not belong in the WIP set has to follow exactly one truck. Constraint (4) guarantees that each truck (job) is followed by 1 truck (job) at most. While constraint (5) enforces that no truck (job) can be scheduled before a starting (artificial) job or a WIP and that a starting truck (job) cannot follow any other truck. Constraint (6) ascertains that only when trucks (jobs) i and j are processed on the same loading bay can sequence variable Yij be equal to 1. This constraint is based on the work of Omar and Teo (2006). Constraint (7) imposes that each truck is served once in a loading bay or similarly that a truck cannot follow itself and be served again in the same loading bay. Constraint (8), ensures that the completion time of truck (job) i is less than or equal to the start time of truck (job) j when both trucks are assigned to the same loading bay and truck i immediately precedes truck j. Constraint (9) assures that the completion time of all WIP trucks (jobs) is equal to the time that their service is expected to have finished, estimated based on the available information of their start time. Constraint (10) determines that the Completion time of each truck (job) is greater than or equal to its service (processing) time on that loading bay plus its (truck's) arrival time at the plant. Constraint (11) bounds the service completion time of a truck to be greater than the current time of the (re)scheduling. Constraint (12) restricts the maximum waiting time until the service starts for all trucks at TL minutes, from their arrival time. Constraint (13) enforces auxiliary variable OTNi to get the value 1, when the waiting time for service of an on-time truck exceeds the AST minutes. Constraint (14) assigns all starting trucks $\in WIP$ to the loading bay that they are being serviced at the time of the (re)scheduling. Constraint (15) ensures that the service start time of truck i is greater or equal to the time that the (re)scheduling occurs. Finally, constraints (16), (17) and (18) are binary variable constraints while constraint (19) defines the natural decision variable Completion Time (CT_i).

5.1.4 Model Verification

Model verification is performed in order to confirm that the developed model has been implemented and works correctly with regard to the conceptual model. It is remarked that the mathematical model, presented in Subsection 5.1.3, has been implemented in Java and is solved (optimized) with the use of GUROBI, a commercial solver. Various scenarios have been developed and tested in order verify the model's performance. However, for briefness in this section only three different verification scenarios are presented. As the verification of these scenarios is performed manually, by comparing the optimization model's output with the logical scheduling of trucks, small scenarios are designed. In these scenarios, the developed optimization model is tested by modifying only some of the model's parameters, namely the number of loading bays and the number of trucks to be scheduled, for the scenarios' simplicity and in order to be able to assess them easily.

Initially the values of the parameters used in these scenarios must be defined. The service time of Loading Bay 1 is 60 minutes, while for Loading Bay 2 it is 45 minutes. The value of DC is 1 minute, the Assured Service Time window length is 120 minutes and the maximum waiting time for service to start 480 minutes. Further, the scaling parameters of the objective function α and b have the values of 1 and 0.01 respectively.

Verification Scenario 1

In this scenario, 1 loading bay [loading bay 1] and 2 trucks are considered. The first truck arrives at time 5 minutes but outside its assigned time window, thus it has Low service priority, while the second truck arrives at time 10 (minutes) but during its assigned time window, thus it has high service priority. WIP jobs are not considered and both jobs are eligible to be performed in loading bay 1. In Table 5.1 below, the main input parameters for the Optimization Model are presented, these are the Truck ID, the Truck Priority – high or low – and its ETA at the plant. Also, in this table the main outputs of the Optimization Model are depicted too, these are the value of the Objective Function, the Loading Bay to which a truck is assigned, the Service Start Time and the Service Completion Time. The outcome of the optimization model, it is presented in the Table 5.1 below, and it is the same with the expected, as truck 2 is served first on Loading Bay 1, prior to truck 1, as it has higher priority and despite the fact that it is expected to arrive 5 minutes later than truck 1.

Value of Objective Function 0.065 min

ID	Priority	Loading Bay	ETA [min]	Start Time [min]	Completion Time [min]
1	Low	1	5	70	130
2	High	1	10	10	70

Table 5.1: Optimization Model Inputs and Outputs for Verification Scenario 1

Verification Scenario 2

This scenario is the same as Verification Scenario 1 with the only difference that in this case there is a WIP job which is expected to be completed at time 30 minutes. The values of all the other parameters are exactly the same as in Verification scenario 1 and thus they are not presented here again. In Table 5.2 below, the main input parameters for the Optimization Model are presented, these are the Truck ID, the Truck Priority – high or low – and its ETA at the plant. Also, in this table the main outputs of the Optimization Model are depicted too, these are the value of the Objective Function, the Loading Bay to which a truck is assigned, the Service Start Time and the Service Completion Time. It should be noted that WIP has no priority, as it cannot be stopped until it has finished, and the key characteristic of the WIPs is that they occupy a loading bay until their service is completed. In this scenario it is expected that the objective value is going to have a higher value compared to the previous one, but the loading order must be kept the same but with different start times as the loading bay is initially occupied. The outcome of the optimization model is presented in the Table 5.2 below and it is as expected.

Value of Objective Function 20.85 min

ID	Priority	Loading Bay	ETA [min]	Start Time [min]	Completion Time [min]
WIP	-	1	-	-	30
1	Low	1	5	90	150
2	High	1	10	30	90

Table 5.2: Optimization Model Inputs and Outputs for Verification Scenario 2

Verification Scenario 3

In this scenario 2 loading bays and 2 trucks are considered, with the first one arriving outside its assigned time window at time 5 minutes and the second one at time 10 (minutes) but during its assigned time window. WIP jobs are not considered, and truck 1 can be serviced in both loading bays while truck 2 can only be serviced in loading bay 1. It is expected that the objective value in this scenario is going to be zero, as there are no WIPs and 2 loading bays available. Also, truck 2 must be assigned to loading bay 1 and consequently truck 1 should be assigned to loading bay 2. Truck 1 should be assigned even though it has arrived outside its time window as there is an idling loading bay and there is no other truck with high priority waiting to be served. In Table 5.3 below, the main input parameters for the Optimization Model are presented, these are the Truck ID, the Truck Priority – high or low – and its ETA at the plant. Furthermore, in this table the main outputs of the Optimization Model are depicted too, these are the value of the Objective Function, the Loading Bay to which a truck is assigned, the Service Start Time and the Service Completion Time. The outcome of the optimization model, it is illustrated in Table 5.3, and it is as expected.

Value of Objective Function -3.553E-15 = 0 min

ID	Priority	Loading Bay	ETA [min]	Start Time [min]	Completion Time [min]
1	Low	2	5	5	50
2	High	1	10	10	70

Table 5.3: Optimization Model Inputs and Outputs for Verification Scenario 3

5.2 Simulation Model and Integration of the Optimization Model

5.2.1 Simulation Model

The aim of this research, as it has already been discussed, is to examine the effect of a Time-Window based Truck appointment system, with the use of real-time truck information, truck ETA at the plant and real-time slot management, on the performance of the loading operations at a chemical plant. In order to investigate the added value of the proposed system it needs to be compared with the current loading operations of the chemical plant. However, the field of logistics is stochastic rather than deterministic, as all processes have an inherent uncertainty for instance the travel time, the probability of congestion, the loading duration and many more (Van Den Brink, 2023; Vanga et al., 2022). Also, the size of the system under study and the interaction between its components make its representation even more complex and hard. Consequently, simulation is the chosen modelling method for the representation, understanding and analysis of the system studied here. Moreover, simulation is an exceptional tool for analyzing the operational level of a system, which is the level that this research focuses on (Van Den Brink, 2023).

The simulation model developed in this study is based on an existing simulation model, created by Vanga et al. (2022), for the same Chemical Plant as studied here. The process flow diagram of this simulation model is depicted in Figure 5.2 and represents the case where the current TAS design (d1) is used. Further, it is noted that this simulation model is an already Verified and Validated model. The main components of the developed and the existing model are the same. However, a few modifications were needed in order to represent the operations of the proposed TAS with time-windows in the simulation model. The required changes are related to modifications on some simulation components, adjustments to some operational constraints (rules) and the integration of the proposed rescheduling model. The main characteristics of the system under study have been described in Section 3.5 and form the base for the development of the Simulation model for this research. The explanation of the main simulation components and the modeling process is performed in this subsection, based on the process flow diagram of the plant's loading system presented in Figure 5.3.

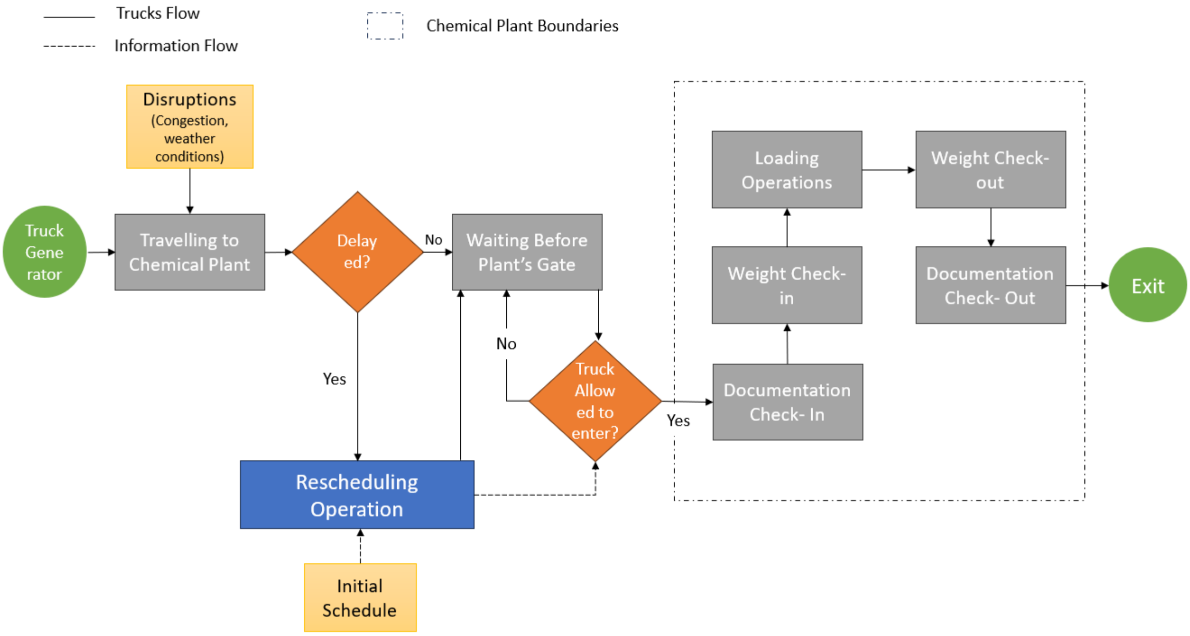


Figure 5.2: Process Flow Diagram of Plant's Loading System for the Current Desing (d1) (developed based on Vanga et al. (2022))

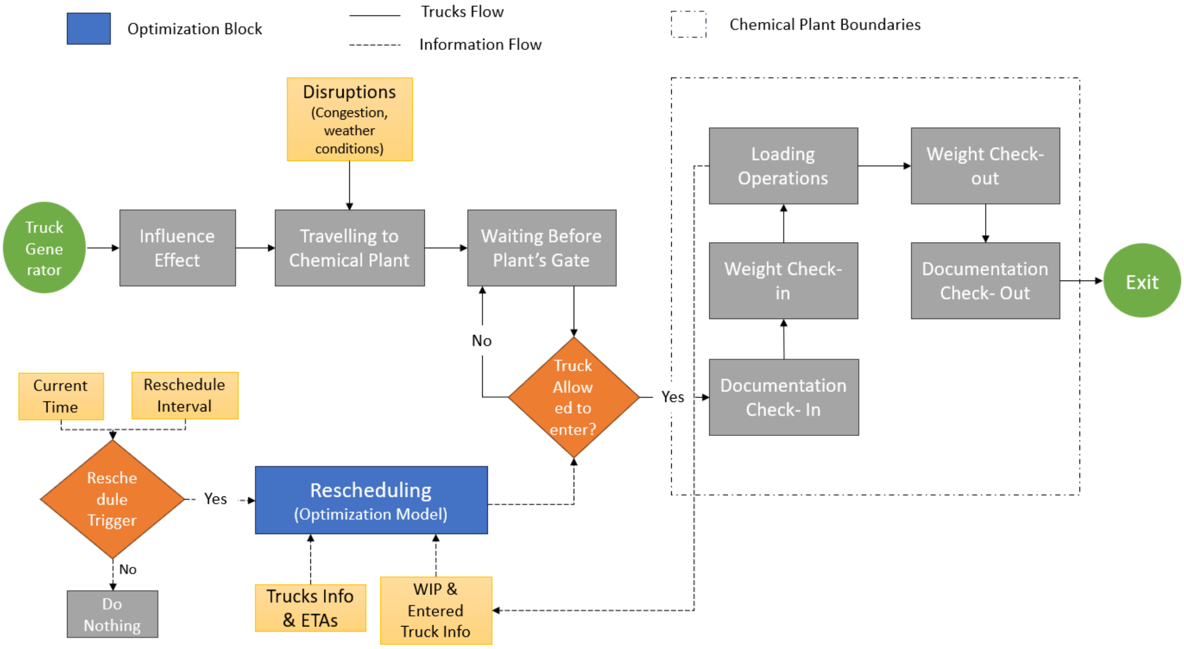


Figure 5.3: Process Flow Diagram of Plant's Loading System for the Proposed Design (d2)

Simulation's model description, based on the process flow diagram shown in Figure 5.3, begins with the system's source, namely Truck Generator, which generates the trucks (entities). In this module, the initial schedule for each day is specified, in more detail the quantity and the time that trucks are created is determined. Also, attributes like product type, originally assigned loading bay, trip origin and booked timeslot are assigned to the trucks. The generation of this initial schedule is performed based on historical data obtained from the Chemical plant under study. The next module is the Influence Effect, which changes the expected arrival time of trucks that comply with the proposed TAS, so that they can arrive during their assigned time window. This alteration is performed only on trucks that are expected to arrive earlier than their assigned timeslot and that comply to the proposed system, this is performed by delaying their initial's trip start time. This module is necessary for two reasons, firstly as the available trucks arrival data is based on the current situation and TAS, and thus it might not be representative for the proposed system, and secondly in order to study the effect of the proposed system in more realistic scenarios, as full compliance to the proposed system is considered unrealistic in the beginning of its implementation in practice. Furthermore, it is noted that this module is an addition to the existing simulation model developed by Vanga et al. (2022). Succeeding is the Traveling to the Chemical Plant module, which represents the trucks' trip to the Chemical Plant. In this module, the effect of disruptions, like congestion, weather conditions etc., is applied which affects the total travel time. Then, the Waiting Before Plant's Gate resembles the parking area outside the plant's gates. All the trucks that arrive at the plant wait there until they are allowed to enter the plant premises. The entrance order is determined by the schedule which is updated by the Rescheduling module, main component of which is the Optimization model. The Rescheduling module is explained more in depth in the next paragraphs.

The plant operations inside its premises are described by a series of simulation components with each one resembling a process described in Section 3.5. In more detail, the Documentation Check-In represents the operations performed at the Document Check Point. Following, the Weight Check-in depicts the truck weighting at the scale before getting serviced. While the Loading Operations resemble the actual loading process of the truck and the possible waiting time before the loading bay, if it is still occupied. Then, the Weight Check-out portrays the weight of the truck at the scale after the end of its service, used in order to calculate the total amount of product loaded on that truck. Succeeding, the Documentation Check-Out module represents the paperwork performed in the Documentation Check Point before a truck can leave the plant. It is important to point out the duration of these processes, in the simulation model, are not fixed (deterministic) but they are stochastic. The value of the process duration for each truck is sampled from the data provided by the chemical plant, except Documentation Check-in which has a fixed value. Finally, after the completion of the Documentation check-out process the trucks leave the plant premises and start their trip in order to deliver the products to the final customers. However, as it has been already explained this final part of the delivery to the customers is out of the scope of this research so when trucks leave the plant premises they go to the sink module, Exit, and exit the simulation model.

The last module of this process flow diagram that has not been discussed yet, presented in Figure 5.3, is the Rescheduling module. This module is triggered by the predetermined Rescheduling interval and not by the late truck arrivals as it was done in the previous research of Vanga et al. (2022) and is show in Figure 5.2. The activation of the Rescheduling module makes the optimization model, developed in the Subsection 5.1.3, to run and determine a new optimal schedule with inputs the truck ETAs, the WIP and the information of the trucks in the plant. Finally, it should be noted that in the aforementioned process flow diagram, of Figure 5.3, trucks flow is represented with a continuous black line while information flow is depicted with a black dotted line.

Finally, the main assumptions and remarks for the development of this Simulation model are presented. To start with, the assigned timeslot to a truck represents the time that the truck is expected to enter the plant and not the time that its service at the loading bay will start. Also, trucks that arrive earlier than the start-time of their assigned time-window, are considered Delayed, and not only those which arrive after the end of their assigned time-window. This means that a truck that has an appointment at 6.30 and arrives at 5.00 it is considered delayed – assuming 2 hours length time-window. Further, Documentation time In, as it has already been discussed, has a fixed value of 5 minutes and not a value sampled from the available data as the other processes. This is explained by the fact the available data from the chemical plant does not capture specifically the duration of this process, thus an estimation of this process duration had to be done by the company, and this is the value used here. Moreover, it should be noted that only the last 5 hours of trucks trip to the plant are considered in this Simulation model, which is considered sufficient as Vanga et al. (2022) have explained in their work because the quality of the ETA prediction is lower the further away a truck is and the rescheduling of a 5-hour away truck does not have any added value. Also, in this model trucks without prior booked appointments are not considered. This is a reasonable assumption according to Vanga et al. (2022) as in practice trucks do not arrive to the chemical plant without prior appointment reservation. In addition, it is noted that in the Simulation model, for every day that is simulated the following (next) day is left idle, meaning that no trucks are initially scheduled for that day. During this idle day, only the remaining trucks at the end of the actual simulation day can be assigned to. These remaining trucks are either trucks that arrived after the plant's close time or trucks that could not be served before the plant's close time as all loading bays were already occupied. This design choice is explained by the fact that the initial schedule, for each simulation day, is created at the beginning of each day, thus the schedule for next day is unknown beforehand. Consequently, the scheduling of trucks that cannot be served on their day of arrival, as the plant closes at night, cannot be rescheduled for the next day, as the schedule for that day is unknown, unless it is an idle day. Lastly, it is noted that this assumption will have a negative effect on the used KPIs. Furthermore, in the Simulation model there are two parameters, the Congestion and the Demand parameters, which both have 4 different levels, from 1 to 4, that represent distinct Congestion and Demand scenarios respectively. With the use of these parameters, it is easy to modify and thus test the performance of the simulated system under different congestion and demand conditions, but also to perform a worst-case and best-case scenario analysis. Lastly, this Simulation model is developed in the AnyLogic software with the use of Discrete Event Simulation. Discrete Event Simulation (DES) method was chosen as in the Simulation Model developed by Vanga et al. (2022), based on which this research's model was created, this method was used. However, this modeling approach is still considered a good choice and for the scope of this research in comparison to the Agent-Based Modeling (ABM), which is the other modeling alternative, as it has been explained in the literature review. This is explained by the fact that in ABM the focus is on the agent level and the interactions between them and their environment, consequently it captures better the behavior of a system in a micro scale. In the contrary, in DES the focus is more on a network level (Becker et al., 2006). Besides, Van Den Brink (2023) points out in his work that the major difference between these two methods is the extent to which the individual behavior is captured in each one, with the ABM capturing it significantly better. Though, the interactions between trucks in and out of the Chemical Plant are out of the scope of this research. Additionally, the queues and congestion creation as well as the loading bay assignment are defined (modeled) in a more aggregate – system level and they are not associated to the trucks' choices, in the development of this simulation's conceptual model. Also, ABM is a relatively new method which has not been yet widely applied in the truck logistics field mainly due to its high computational times in comparison to DES. Lastly, it is remarked that DES models the system with discrete states, and the system changes state only when an event occurs. In this model as events are defined the start and end time of each activity for each truck.

5.2.2 Integration of Optimization Model in the Simulation

In this subsection, the Integration of the Optimization Model in the Simulation is briefly described.

As it has been previously explained, the optimization model developed in Subsection 5.1.3, needs to be implemented in the Simulation model in order to test the effectiveness of the proposed system, since this optimization (rescheduling) model is a core component of the proposed TAS design (d2). As it has already been described, the developed optimization model has been implemented in java and is optimized with the use of Gurobi, a commercial Mixed Integer Linear Programming (MILP) solver. Moreover, the Simulation model created for this research in AnyLogic is coded in java too, thus there is compatibility between these two models as they are both developed in the same programming language. Further, the Gurobi solver is integrable into the AnyLogic software. Consequently, the integration of the Optimization Model in the Simulation is possible, but for its successful implementation a few steps need to be followed. The first step is the duplication and transfer of the optimization model in a function of the simulation model. Then, the creation and connection of the Optimization model's parameters and variables in the simulation model is required. This step is necessary not only for the proper execution of the Optimization model, but also for the automatic update of the rescheduling input data. Finally, the triggering condition of the rescheduling has to be defined, this is modeled with a state module in which inputs are the current time and the rescheduling interval. When the rescheduling time condition is fulfilled the Rescheduling Function, created in the first step, is called. When this function is called, the optimization model is solved with the use of Gurobi and a new (updated) loading schedule is created. Based on this new schedule trucks loading sequence is updated.

5.2.3 Input Data

Input data is a critical factor in the development of a Simulation model. Its importance derives from the high correlation between the quality and validity of model's outputs and the quality of the input data. The model's output quality is crucial as business decisions are made and processes are optimized according to the results of these models. Based on the input data the intervals of trucks dispatches, the process times of each operation and the demand for each product type are defined. The input data for this research is the same as Vanga et al. (2022) have used in their work and it has been obtained from the Chemical Plant studied here, representing the plant's operations for 70 workdays between November 2021 and March 2022. In more detail, in this data set there is information about the products demand, the trucks reservations in the current TAS, rescheduling information, truck origins, truck timestamps while performing different activities in the plant and more.

5.2.4 Verification and Validation

Verification and validation of the developed Simulation model are required to be performed in order to prove its credibility, similarly to the Optimization model. It is important to point out that the developed Simulation model is based on the model of Vanga et al. (2022) which is a verified and validated model. However, as some modifications were performed on that model further Verification and Validation is required.

To start with, for the Verification of the model mainly the tracing method was used, likewise Vanga et al. (2022). To implement this method various print statements were added in different modules and processes of the model while keeping track of the simulation time. Based on these print statements and the created visual representation of the system, the model's process flow logic and methods expected function were tested. A wide range of experiments were conducted, in which different trucks were "followed", visually and through the print statements, throughout the whole simulation process, from their generation until their disposal out of the system, in order to verify this model's formulation. Regarding the Simulation's model Validation, the fact that it is based in an already existing and validated model is very important. Nevertheless, the validity of the developed model was further examined using various validation techniques as they have been suggested in the literature by Sargent (2010). These techniques are Animation, Comparison to Other Model, Operational Graphics, and Traces. In more detail, Animation technique was used as in the simulation model there is a graphical representation of the trucks while they are in the simulated system, both as they travel to the plant and also as they are inside it and perform the various operations. Comparison to Other Models was implemented as the various results, mainly the outputs and the queues data, of the developed simulation model were compared to the already validated model developed by Vanga et al. (2022). Furthermore, Face Validity on this new Simulation model was performed by the Postdoctoral Research Ratnaji Vanga, who was the main developer of the Simulation model, found in the paper of Vanga et al. (2022), on which this research's Simulation model was based. Also, Operational Graphics technique was used by obtaining and assessing during the model's run the values of some performance measures, like the number of the loading bays occupied, the loading bays utilization level, the number of trucks in the plant, the number of trucks waiting outside the plant gates and the weighting platform utilization, in order to assure the model's proper behavior. In Appendix A, two examples of the data used for performing the Operational Graphics Validation are presented. Finally, Traces methodology was applied by following the behavior of different trucks (entities) through the model, from their generation until their discard at the sink, and aiming to prove if the model's logic is right and if the accuracy is satisfactory. Consequently, it is believed that, after the execution of all these aforementioned tests, the developed simulation model was built as intended (Verified) and that represents properly the real-world system (Validated).

5.3 Chapter Summary

Initially in this chapter a brief Literature review, aiming to identify related work in the field of TAS with the use of time-windows and possibly a mathematical model that could be used as the base for formulating this research's model, is performed. However, in the field of optimization models and TASs with the use of time-windows only one paper was found, the paper of Chen and Jiang (2016), and thus research is expanded and on other fields with job-shop scheduling problems gaining special focus, as their objective is similar to this research and in literature they are used and in other fields apart from production management. Finally, a presentation of some job-shop scheduling problems which could be used for the development of this study's mathematical model is given.

Following, the Optimization model is described, and its Requirements and formulation Assumptions are presented. In more detail, the objective of this optimization model is to schedule the trucks loading sequence and loading bay assignment based on their ETAs and promised service time while minimizing the total cost. The total cost consists of the sum over all trucks of the waiting time cost per truck and the penalty cost of not serving an on-time truck during its assured service start time (AST). Succeeding the model's requirements are introduced and are that all trucks that arrive at the chemical plant have to be served, yet with different priorities assigned to them, a maximum waiting time limit (TL) before the service starts is determined for all trucks, all trucks are rescheduled based on their ETA and real-time information, (re)scheduled truck must be assigned to a loading bay where the requested product type is available, flexible service start times are used in the proposed model and each loading bay can serve only one truck at a time. Consecutive, some extra characteristics of the proposed model, which are similar to the Hung's et al. (2017) work based on which the proposed optimization model was developed, are presented. These characteristics are the use of time-windows during which each job has to be completed, the unrelated parallel machines (loading bays), the machine dependent processing rate, the machine eligibility constraint – not all loading bays can serve all products – and the fact that jobs are considered non-preemptive. At last, some of the main assumptions are presented which are that trucks with no reservation (booked appointments) are not considered, loading bays setup times between different trucks are zero and equipment maintenance and failures are not considered. Finally, the Mathematical model formulation, of this Optimization model, along with its Verification are presented. In Figure 5.4 below, a Blackbox representation of the Optimization Model is given, in which the model's Inputs, Outputs, Decision Variables and Exogenous Parameters are displayed. This aforementioned information about the Optimization model together with its Mathematical Formulation answer the sub-Research Question 5, regarding the design and development of a real-time rescheduling system.

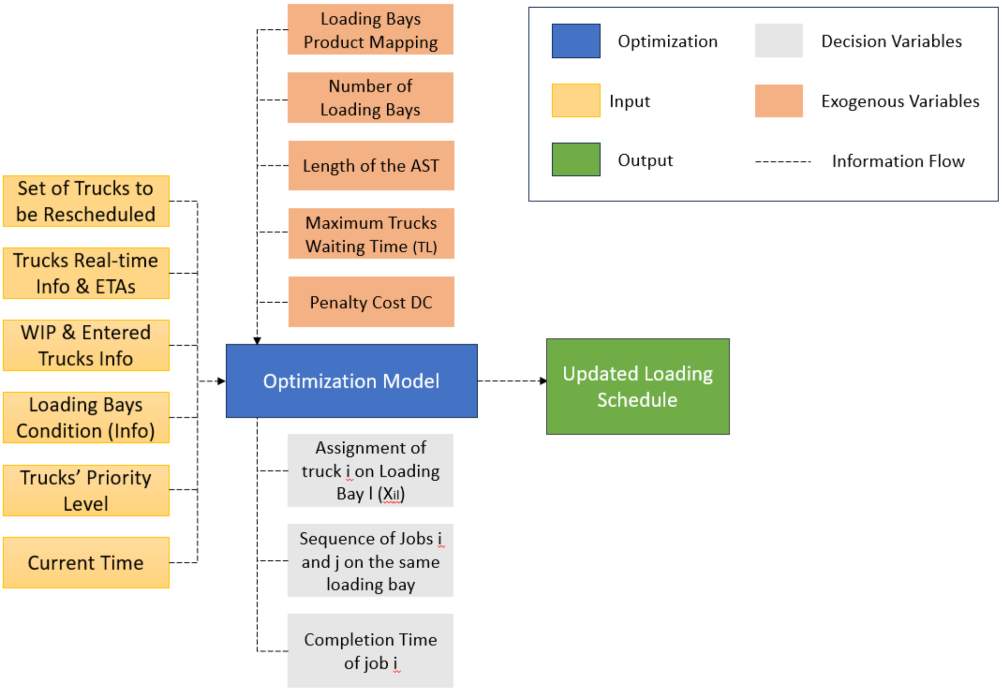


Figure 5.4: Optimization Model Blackbox Description

Subsequently, the focus of this chapter steers towards the Simulation model, created in this research, for the representation, understanding and analysis the system under study. The main characteristics of this system have been described in Section 3.5 and form the base for the development of the Simulation model for this research. These main characteristics – operations of the Chemical Plant are modeled with different simulations modules together with their interactions and form the Simulation model. In more detail, initially the Conceptual Model of the simulation model, based on the process flow diagram of the loading system presented in Figure 5.3, is depicted. In that the main processes, decisions, input data and the optimization process are illustrated followed by their explanation. The developed Conceptual model is implemented in the AnyLogic software and is modeled with the use of Discrete Event Simulation. Following, the integration of the Optimization model in the Simulation model is presented. This is possible as both models are coded in the same programming language and also the Gurobi solver, for the optimization model, can be integrated in the simulation model. Nevertheless, for the successful integration a few steps that need to be followed are described. Then, the importance of the Input data quality for the simulation model is explained and the data obtained and used in this research are briefly described. Finally, the performed processes for Verifying and Validating the model are illustrated. These answer the sub-Research Question 6 about modeling the loading operations of the Chemical Plant, as Simulation is the chosen modeling methodology and the integration of the Optimization model in it is required in order to represent the prosed system design (d2).

Chapter 6: Results

In this chapter, initially the parameters of the base case scenario, based on which the comparison of the two aforementioned TAS designs is performed, are specified in Section 6.1. In this section, the main characteristic and parameter values for the simulation model of the Base Case scenario are described. Following, in Section 6.2 the characteristics of the Current TAS configuration used for the comparison of the two TAS designs are determined. Then, in Section 6.3 the values of the Optimization model and the main Design parameters of the proposed system, design d2, are presented. Succeeding, in Section 6.4 the comparison between the current and the proposed TAS designs is executed. Subsequently, in Section 6.5 a sensitivity analysis on the effect of the Influence factor on the proposed system's performance is conducted. In Section 6.6 a discussion and reflection on the obtained results is performed and the research limitations are highlighted. Finally, in Section 6.7 the chapter's summary along with the answer to sub-Research Question 7 are given.

6.1 Base Case Scenario Definition

In this section the parameters of the simulation model for the Base case scenario are described. The Base Case scenario forms the base on which the two TAS designs are assessed. In order to have a fair comparison, between these two designs, the conditions under which both systems are tested must be the same. This means that demand, congestion and delay levels, but also trucks' service times and terminal's characteristics must be the same in both simulations.

Initially, the values of the parameter for the Base Case Simulation model are presented in Table 6.1. Congestion parameter has different levels, from 1 to 4, which represent distinct congestion scenarios. Similarly, Demand parameter has also different levels, from 1 to 4, which depict specific scenarios with increased demand. For both of these parameters Level 1 represents the current congestion and demand conditions of the system respectively. The term current conditions stands for the conditions during the period that the provided data by the company was captured.

Parameter	Value	Units	Description
Congestion Level	1	-	No change to current conditions
Demand Level	1	-	No change to current demand

Table 6.1: Base Case Simulation Model Parameters

Following, the values of the processes' duration in the chemical plant for a truck are depicted in Table 6.2. It should be noted that only the Documentation Time In process has a fixed value, as it has already been explained. While, for the other processes the values are sampled for each truck from the obtained historical data of the studied Chemical Plant. This data has been briefly described in Subsection 5.2.3. Thus, for the proper (fair) comparison of the two TAS designs, the process times at the chemical plant of each truck in both TAS configuration simulations must be the same. Consequently, in order to achieve this in the Simulation model the trucks and their assigned process times are duplicated in the model before they start their trip to the chemical plant. In this way, two trucks with the same process times, for all processes in the chemical plant, and delays head to the two different TAS configuration systems.

Parameters	Value	Units	Description
Documentation Time In	5	Minutes	Paperwork and Control Duration
Weight Check In	*	Minutes	Weighing Duration
Service Time	*	Minutes	Loading Duration
Weight Check Out	*	Minutes	Weighing Duration
Documentation Time Out	*	Minutes	Paperwork Duration

* These values are sampled for each truck from the Data Set obtained from the plant

Table 6.2: Input Data for the Loading Operation Processes

Finally, the parameters values of the plant characteristics, namely the number of loading bays, the plant's open and close hours and the number of available slots, are specified in Table 6.3. It should be remarked that from the 110 available timeslots during the plant's open hours, the 1st and 2nd loading bays have each 15 available slots while the rest loading bays have 20 each. Also, per loading bay there are 3 buffer slots available besides the aforementioned ones, which make the total number of available timeslots per day 128. Further, the service time of loading bays 1 and 2 is considered 60 minutes while for the rest loading bays is considered 45 minutes.

Parameters	Value	Units	Description
NL	6	Loading Bays	Number of Loading bays
Plant's Open time	6:30 (390)	Hour (Minutes)	-
Plant's Close time	21:30 (1290)	Hour (Minutes)	-
Total Number of Slots	110	Slots	Available Slots per day

Table 6.3: Parameters of Plant Characteristics

6.2 Current Truck Appointment System (TAS) Configuration

In this section, the configuration of the current TAS design (d1) for the simulation is determined. To start with, this TAS design (d1) is the one that is currently implemented in the chemical plant under study. This TAS design is a typical TAS, as it has already been described in Section 4.1, in which real-time information and ETAs estimations are not available. Also, it is noted that in this TAS design the daily available slots are not flexible and if a truck arrives late, it misses its slot. Furthermore, rescheduling is performed only for the delayed trucks, and it is executed manually either by the carriers or the plant's slot manager. In this rescheduling only the delayed truck is considered and usually the truck is assigned to the earliest available slot in which the product that the truck needs to transport can be served. Consequently, there are not any TAS specific parameters to be defined for this design's configuration as this design, especially the rescheduling, is relatively simple as it can also be seen in Figure 5.2.

6.3 Proposed Truck Appoint System (TAS) Configuration

In this section, the values of the parameters for the proposed TAS design (d2) configuration used for the simulation are illustrated. The proposed design is an extension of the typical TAS with the use of time-windows, real-time information and adaptive slot management for a chemical plan, as it has already been presented Section 4.2. Lastly, it is remarked that for the proposed system design the available appointment times are only for reference and initial booking as flexible service start times are used, as it has been already explained before.

Initially, the parameters of the Optimization model, described in Subsection 5.1.3, are defined in Table 6.4 below. It is noted that the values of the weight factors a and b, presented in the table below, were chosen to have two orders of magnitude difference so that higher importance on the on-time trucks, over the trucks arriving outside their time window, is given.

Parameter	Value	Units	Description
AST	30	Minutes	Assured Service Start Time
a	1	-	Weight factors of the Objective Function
b	0.01	-	
DC	1	Minutes	Penalty Cost for not serving on-time trucks during their AST
M	9999	-	Large Number
NL	6	Loading Bays	Number of Loading bays
S_l	60	Minutes	Service time Loading Bays 1,2
	45		Service time Loading Bays 3-6
TL	480	Minutes	Maximum Waiting Time

Table 6.4: Optimization Model Parameters

Following the value of the Probability of Influence is determined. This is the only Simulation model parameter whose value is defined irrespectively to the Base Case scenario, as it is related only to the simulation of the proposed design and it is not applicable to the current design, this has already been explained in Subsection 5.2.1. The Probability of Influence has a range from 0% to 100% and demonstrates the acceptance of the proposed system by the trucking companies. For this configuration the value of the Influence Factor is chosen to be 100%, meaning that all truck drivers are complying with this research's proposed TAS.

Subsequently, the values of the main design parameters for the Proposed TAS design (d2) are presented in Table 6.5. The time-window length has a range of values from 30 minutes to 4 hours. While for Rescheduling Frequency, a logical range of rescheduling time is considered between 15 and 45 minutes. Moreover, Trucks ETA for rescheduling parameter represents the trucks which are considered in the rescheduling, therefore only trucks that have arrived at the chemical plant or have an ETA of less than Z minutes are considered in the rescheduling. This is explained as rescheduling trucks being further away from the plant, which have high ETAs, does not add much value for the system. It should be pointed out though that the value of this parameter is related to the value of the Rescheduling frequency parameter, as it sets its higher limit. Thus, as it can be understood all these parameters, presented in this table, have a range of values for which they are applicable for and affect the performance of the proposed model. Consequently, for the performance of Sensitivity Analysis or the creation of the Experiment Scenarios, one or more of these parameters' values can be modified.

Parameter	Value	Units	Description
L	120 (2)	Minutes (Hours)	Time-window length
Rescheduling Frequency	30	Minutes	Time interval between consecutive Reschedules
Trucks ETA for rescheduling	30	Minutes	Trucks considered in the rescheduling

Table 6.5: Proposed TAS Main Design Parameters

6.4 Comparison between Current and Proposed TAS designs

In this section the comparison between the two TAS designs, Current (d1) and Proposed (d2), is conducted. These two systems' performance, under the same demand, congestion and delay conditions, is compared. The values of the Base Case and the designs' parameters have been specified in Sections 6.1 to 6.3. Aim of this evaluation is to investigate the potential benefits of the Proposed TAS in comparison to the Current TAS, used in the chemical plant, under the same conditions. Further, based on this comparison's outcomes, the effect of a less strict schedule and the use of trucks' real-time information and ETAs on Chemical Plant's (system's) performance is assessed. Moreover, it is important to point out that both cases are Simulated for a period of 6 months, during which the model's outputs are collected and the KPIs are calculated. It is worth noting that during this 6-month simulation period, approximately 6630 trucks were generated in each case, Current and Proposed. The evaluation of the performance of the different TAS designs is done based on the KPIs, described in Section 3.7, which namely are the Gate Waiting Time (KPI 1), Slot Utilization (KPI 2) and Finish Time (Makespan) (KPI 3). The values of the obtained KPIs values are presented in the tables and figures below.

<table>
<tr><th colspan="5">KPI 1 – Gate Waiting Time [min]</th></tr>
<tr><td>Model</td><td colspan="2">Current</td><td colspan="2">Proposed</td></tr>
<tr><td>Mean</td><td colspan="2">91.634</td><td colspan="2">5.018</td></tr>
<tr><td>Std</td><td colspan="2">110.921</td><td colspan="2">41.168</td></tr>
<tr><td>Max</td><td colspan="2">1299</td><td colspan="2">540</td></tr>
<tr><th colspan="5">KPI 2 – Slot Utilization [-]</th></tr>
<tr><td rowspan="2">Model</td><td colspan="2">Current</td><td colspan="2">Proposed</td></tr>
<tr><td>Theoretical</td><td>Actual</td><td>Theoretical</td><td>Actual</td></tr>
<tr><td>Mean</td><td>0.655</td><td>0.325</td><td>0.654</td><td>0.330</td></tr>
<tr><td>Std</td><td>0.093</td><td>0.050</td><td>0.102</td><td>0.054</td></tr>
<tr><td>Max</td><td>0.806</td><td>0.421</td><td>0.814</td><td>0.449</td></tr>
<tr><th colspan="5">KPI 3 – Makespan [min]</th></tr>
<tr><td>Model</td><td colspan="2">Current</td><td colspan="2">Proposed</td></tr>
<tr><td>Mean</td><td colspan="2">1689.63</td><td colspan="2">1530.97</td></tr>
<tr><td>Std</td><td colspan="2">280.55</td><td colspan="2">276.86</td></tr>
<tr><td>Max</td><td colspan="2">2020.13</td><td colspan="2">1988.93</td></tr>
</table>

Table 6.6: KPIs Analysis between Current and Proposed TAS configurations (N=6630 trucks)

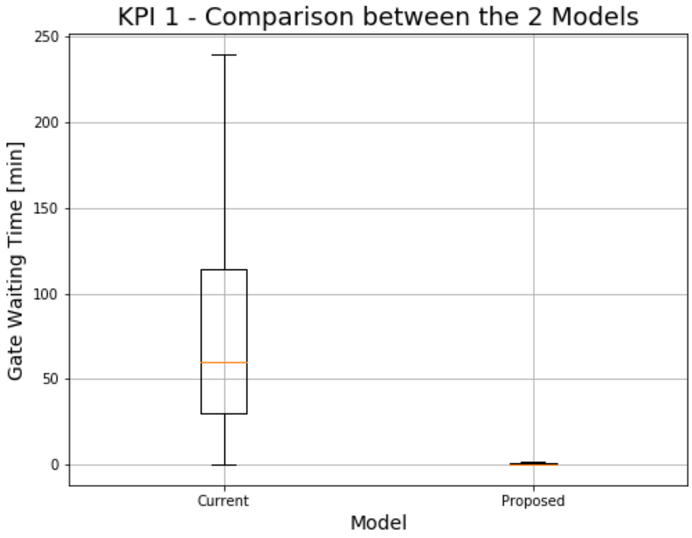


Figure 6.1: KPI 1 - Gate Waiting Time, Comparison between Current and Proposed TAS Design

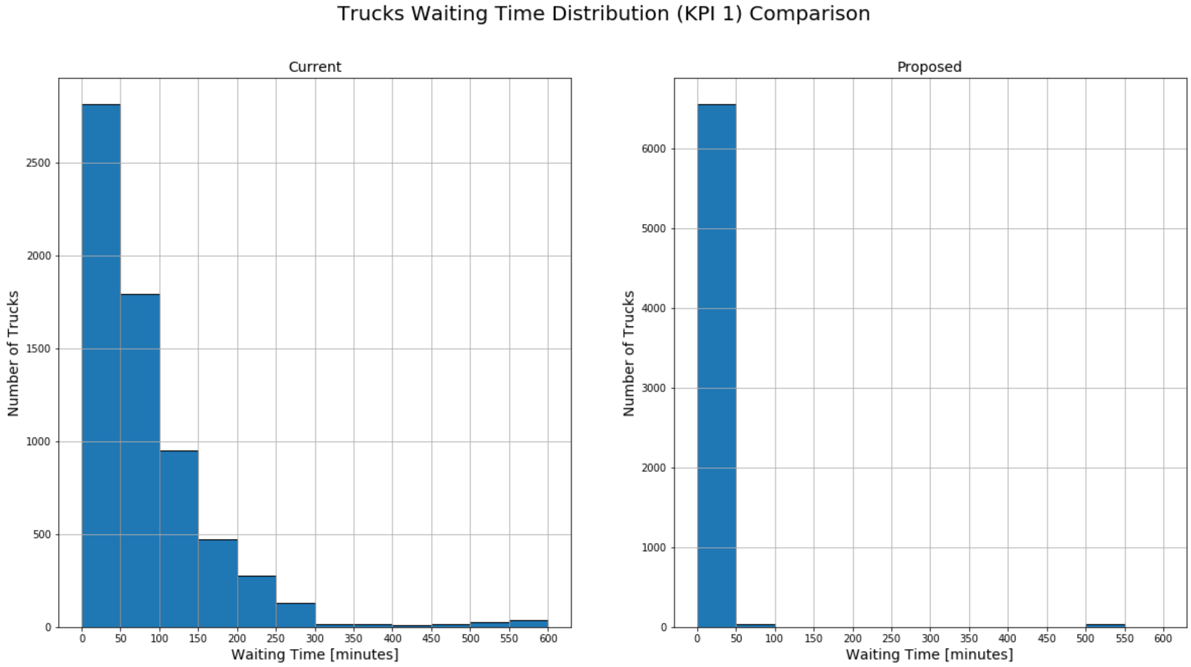


Figure 6.2: KPI 1 - Trucks Waiting Time Distribution for the Current and the Proposed TAS design

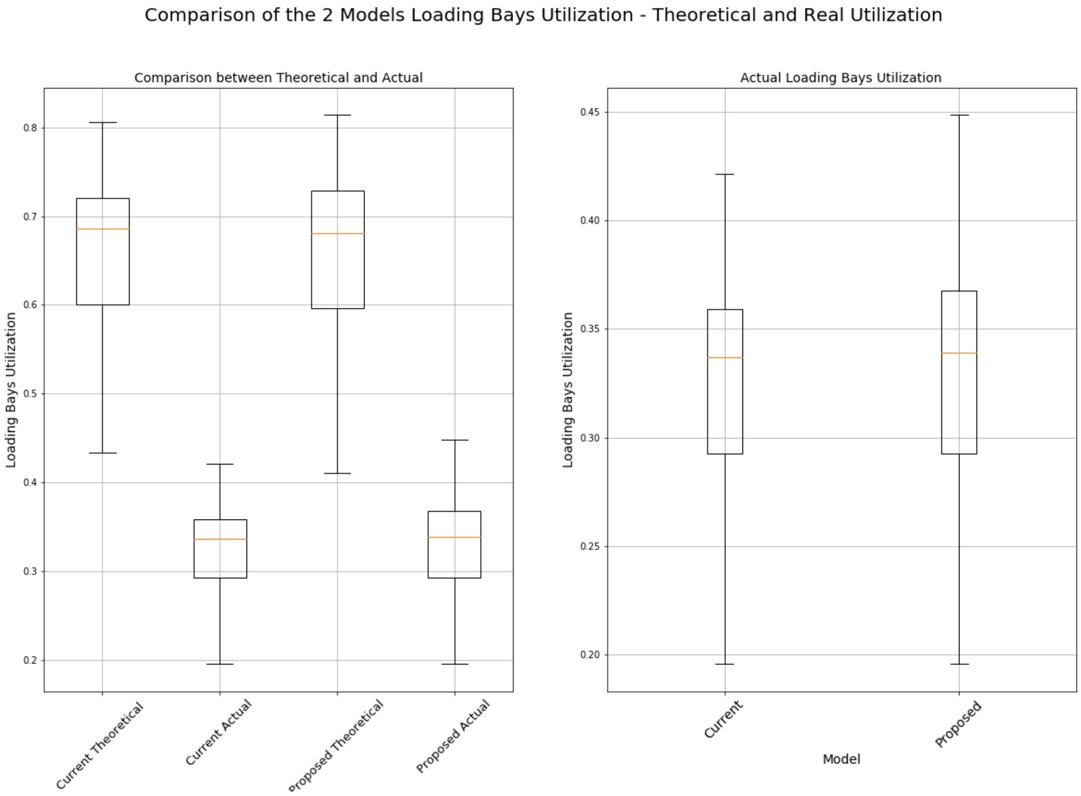


Figure 6.3: KPI 2 - Theoretical and Actual Loading Bays Utilization, Comparison Current and Proposed TAS design

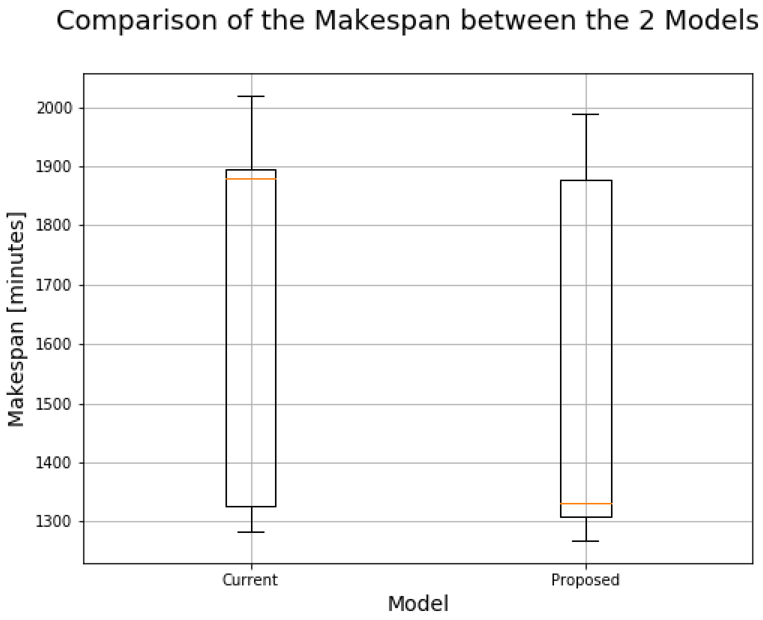


Figure 6.4: KPI 3 – Makespan, Comparison Current and Proposed Scenario TAS design

Based on the KPI values obtained from the simulation, presented in Table 6.6 and Figure 6.1 to Figure 6.4, it can be deduced that the Proposed system outperforms the Current system. In more detail, regarding the trucks waiting time at plant gates (KPI 1), it can be seen that a reduction of around 94.5% on the mean waiting time is achieved, from 91.63 to 5.02 minutes. This significant improvement can also be seen in Figure 6.2, in which the trucks waiting time distribution for each design is presented. Also, the standard deviation of the waiting time in the proposed system is 63% lower compared to the current one. Regarding, the Slot Utilization level (KPI 2), two different methods of calculating this KPI are used. The first one, Theoretical, is determined by sum of the number of trucks served at each loading bay multiplied with the respective service time at that loading bay, 45 or 60 minutes, and divided by the total available service time of the loading bays in a day. While the Actual Slot Utilization is calculated by the sum of all trucks actual service time at the loading bays divided by the total available service time of the loading bays in a day. However, despite the discrepancy between the values of Theoretical and Actual slot utilization, with the Actual Utilizations being nearly half of the Theoretical, the values for the two systems are very similar. Moreover, about the Makespan (KPI 3), the Proposed system seems to be performing better compared to the current one as it has approximately 10% lower mean value, similar standard deviation and lower maximum value. Finally, it should be noted that the value of the Assurance Probability (Pa) has a mean value of 98.4% and standard deviation of 0.015, meaning the 98.4% of all trucks that arrived during their time-window, during the 6-month simulation period, were served during their Assured Service Start Time (AST).

6.5 Sensitivity Analysis

After the comparison of the two TAS designs, a sensitivity analysis on the effect of the Influence Factor, acceptance of the proposed system by the carriers, on the prosed system's performance is conducted. As it has already been explained in Subsection 5.2.1, the Influence Factor represents the percentage of trucks (carriers) that comply with the proposed TAS. For the trucks that comply with the proposed system, if their arrival time at the plant is expected to be earlier than the start of their time-window, their initial's trip start time is delayed so that they can arrive at the plant during their assigned time-window. However, this arrival time alteration is not considered possible for complying trucks that are expected to arrive after the end of their time-window, as it is assumed that the factors which delayed their arrival are out of their control, in contrast to the early arrivals. The values of the models' parameters for the sensitivity analysis are the same with those described for the proposed model in Section 6.3 and the Base Case definition in Section 6.1, except the Influence Factor. For this parameter 6 different levels have been chosen to be tested, from 0% to 100% with a step of 20%, which are presented in Table 6.7 below. Aim of this sensitivity analysis is to examine the effect of Influence Factor on the Proposed System's performance. This knowledge is important for the practical implementation of this system and the determination of the critical (minimum) acceptance percentage for the successful implementation of the proposed system.

Influence Factor's Testing Levels					
1	2	3	4	5	6
0%	20%	40%	60%	80%	100%

Table 6.7: Testing Levels of Influence Factor

The Simulation model is run for a period of 6 months for each Influence Factor level, similarly to the comparison of the two TAS designs in Section 6.4, and approximately 6630 trucks are generated for each level. During this simulation period the model's outputs are collected and the KPIs are calculated. The effect of the Influence Factor on the proposed system's performance is analyzed based on the main KPIs, defined in Section 3.7. The values of these KPIs are presented in the tables and figures below.

KPI 1 – Gate Waiting Time [min]						
Influence Level	0%	20%	40%	60%	80%	100%
Mean	13.707	12.742	11.498	8.432	6.503	5.018
Std	52.106	56.378	55.303	46.475	46.727	41.168
KPI 2 – Slot Utilization (Actual) [-]						
Influence Level	0%	20%	40%	60%	80%	100%
Mean	0.330	0.328	0.329	0.331	0.328	0.330
Std	0.053	0.051	0.053	0.052	0.054	0.054
Max	0.432	0.426	0.447	0.409	0.448	0.449
KPI 3 – Makespan [min]						
Influence Level	0%	20%	40%	60%	80%	100%
Mean	1468.149	1579.616	1601.557	1533.748	1513.128	1530.970
Std	265.208	298.414	293.025	278.390	274.360	276.856
Max	1941.533	2044.767	2092.617	1961.600	1949.767	1988.933
Pa – Assurance Probability [-]						
Influence Level	0%	20%	40%	60%	80%	100%
Mean	0.967	0.977	0.977	0.981	0.986	0.984
Std	0.026	0.021	0.019	0.015	0.014	0.015
Min	0.889	0.905	0.917	0.927	0.947	0.938
Max	1.00	1.00	1.00	1.00	1.00	1.00

Table 6.8: KPIs and Pa Analysis per Influence Factor Level (Sensitivity Analysis) (N=6630 trucks)

Percentage of On-time & Arrived Outside their Assigned Time Window Trucks per Influence Level

	0%	20%	40%	60%	80%	100%
On-Time [%]	54.06	61.24	68.09	77.06	84.47	92.40
Outside Time Window [%]	45.94	38.76	31.91	22.94	15.53	7.60

Table 6.9: Distribution of Trucks Arrival per Influence Factor Level (N=6630 trucks)

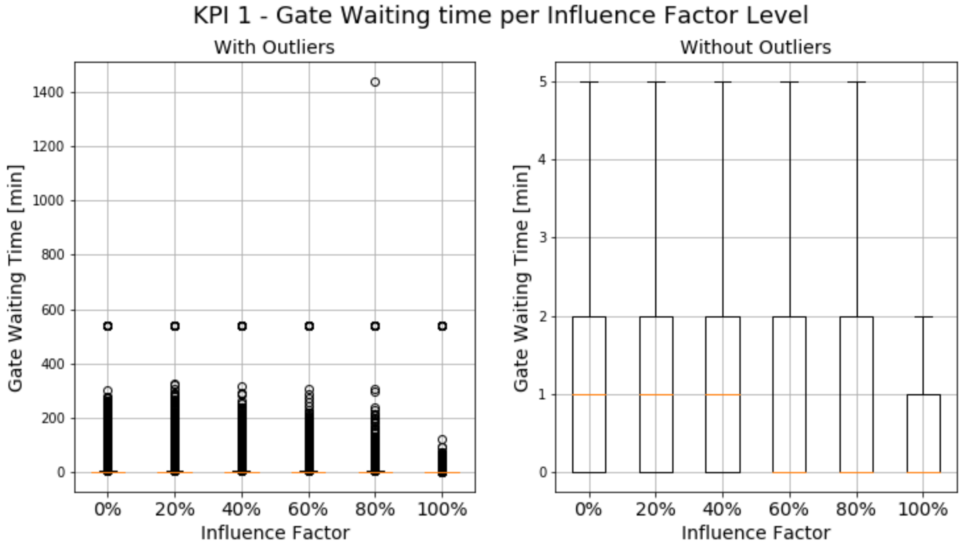


Figure 6.5: KPI 1 - Gate Waiting time per Influence Factor Level (With and Without Outliers)

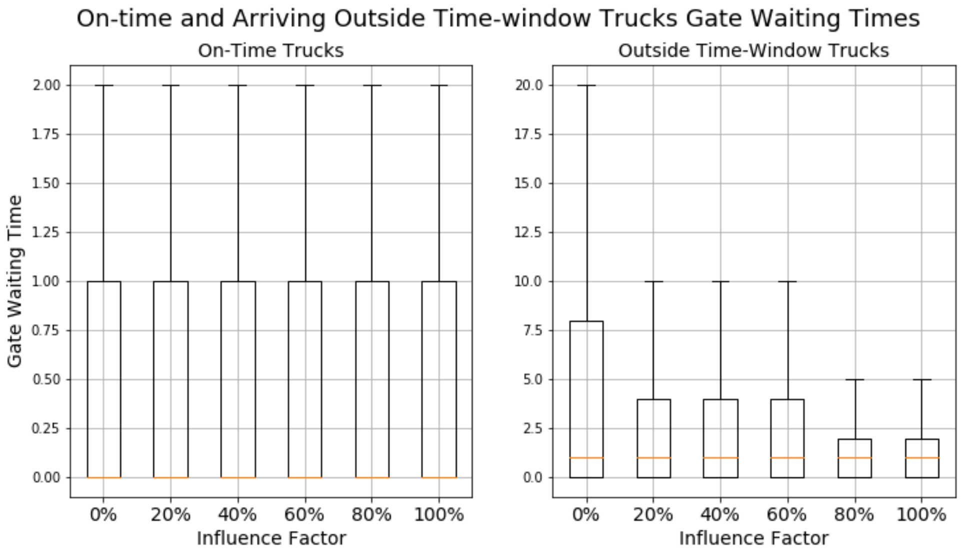


Figure 6.6: Analysis of Gate Waiting Time per On-time Trucks and Arriving Outside their Time-windows Trucks

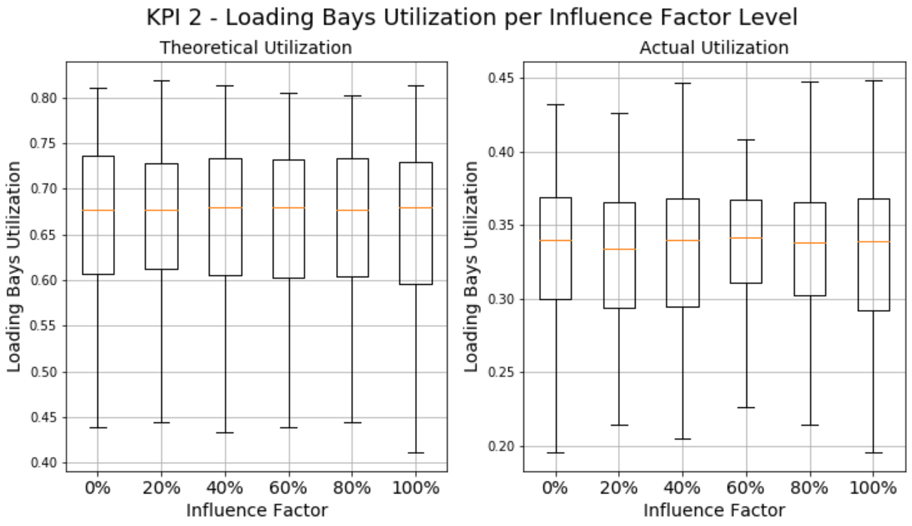


Figure 6.7: KPI 2 - Theoretical and Actual Loading Bays Utilization per Influence Factor Level

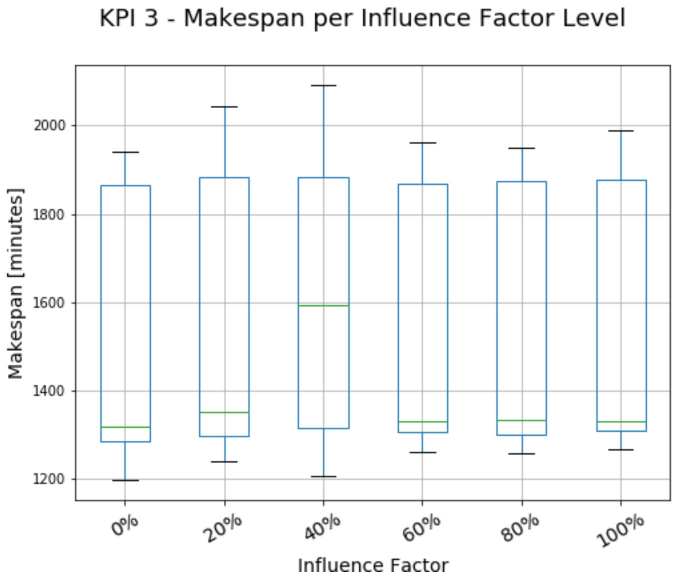


Figure 6.8: KPI 3 - Makespan per Influence Factor Level

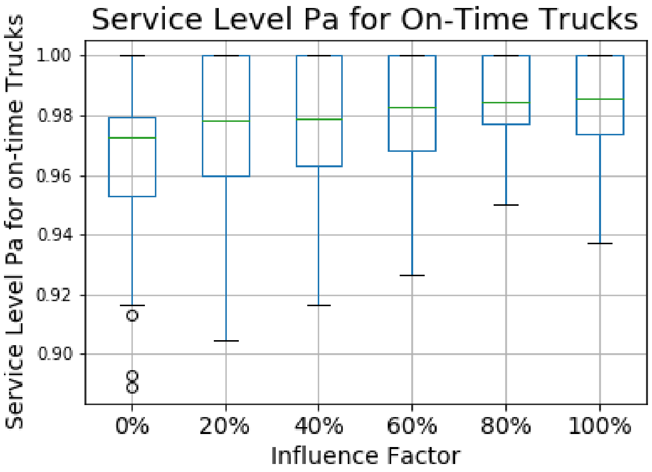


Figure 6.9: Assurance Probability – Service Level (Pa) per Influence Factor Level

The effect of the Influence Factor, truck's compliance, on the Proposed System is analyzed based on the KPI values obtained from performed simulations, and they are presented in Table 6.8 andTable 6.9 and in Figure 6.5 toFigure 6.8. From these it can be deducted that the main effect of the Influence Factor is on the trucks Gate Waiting Time (KPI 1), while for the rest KPIs its effect is marginal or none. In more detail, regarding the trucks waiting time at plant gates (KPI 1), it can be seen both from Table 6.8 and Figure 6.5 that the higher the level of the Influence Factor the lower the trucks average waiting time is, with the waiting time of the 100% Influence Level being almost 3 times less than the 0%, 5.02 and 13.71 minutes respectively. Also, as the Influence Factor level increases the standard deviation of the waiting times is slightly decreasing. At last, from Figure 6.6 it can be observed that as the Influence Factor level increases the waiting time for trucks that arrive outside their assigned time-window decreases significantly. Furthermore, regarding the Slot Utilization level (KPI 2), it can be noticed from Table 6.8 and Figure 6.7 that the Influence Factor has no effect on it, both for the Theoretical and Actual utilization level. Besides, regarding the Makespan (KPI 3), based on Table 6.8 and Figure 6.8 it can be remarked that the Influence Factor seems to have some effect on it, with the 0% level having the lowest mean, standard deviation, and maximum value from all the other levels and the 80% level having the second-best performance. However, the effect of the Influence Factor on KPI 3 is not linear. Finally, it is noted, based on Table 6.8 and Figure 6.9, that the value of the Assurance Probability (Pa) is improved as the Influence Factor Level increases, as the mean value of Pa is increased, and the standard deviation is reduced. Nonetheless, this improvement is not huge as in the 0% Influence Factor is 96.7% and in the 100% is 98.4%. Thus, all trucks that arrive during their time-window have a very high probability to be served through their Assured Service Start Time (AST) window, irrespective the Influence Factor level.

6.6 Discussion and Reflection

The aim of this research is to develop a TAS with the use of time-windows and real-time information in order to improve the performance of the loading operations at a Chemical Plant, both for the plant owner and the trucking companies. Also, the reduction of truck drivers stress level regarding missing their booked slot and the improvement of system's environmental footprint are considered in this analysis. The proposed design was implemented in a simulation model and was compared with the currently used TAS design at the chemical plant under study. Further, a sensitivity analysis on the effect that the proposed system's acceptance, by the carriers, has on the loading operations performance was conducted.

Based on these preliminary results, a significant improvement on system's performance between the proposed and the current system can be noticed, with only exception the loading bays utilization which seems to be the same for both systems. However, more experiments and a small-scale testing of the proposed system in practice would be useful for further justification of the obtained results. In addition, the sensitivity analysis of the Influence Factor Levels demonstrate that the system's performance is quite robust as it is not severely affected by the level of truck drivers' compliance to it. The only exception on this are the waiting times of the trucks that arrive outside their assigned time-windows, whose waiting time is decreased as the compliance level increases. Nevertheless, the trucks arrival data on which the Influence Factor was applied, is real data obtained from the current operations of the Chemical Plant consequently it cannot be guaranteed that this modified arrival pattern, based on the Influence Factor, will resemble the actual truck arrival pattern when the new (proposed) system is implemented in practice. Moreover, it should be noted that in both system's, current and proposed, and for all Influence Factors the loading bays have a relatively low average and maximum utilization level, 33% and 45% respectively. According to this fact, and despite the deceptive values of the Theoretical utilization which have a mean value of around 65% and a maximum value of 80%, it is made clear that the plant has a significant portion of loading bays time unutilized and thus it has the ability, and in the current scenario, to increase the throughput of loaded trucks. Furthermore, in this research's performed experiments congestion has not been explicitly considered, as its effect on trucks arrival times is already captured by the available data. Nonetheless, this congestion level captured by this data is representative of the period between November 2021 and March 2022, during which some measures for the pandemic were still in place and the construction work on Antwerp's ring road had not started yet. Consequently, the effect of the congestion, especially due to the construction work on Antwerp's ring road and the increasing volumes of products transported through the port of Antwerp, requires more attention in order to make the simulation model's outputs more representative of the current and future road conditions. Also, the trucks origin location is not considered as a factor which affects their arrival time at the plant, as in the Simulation model the origin country is assigned randomly to a truck and irrespective to the travel time. Yet, this might not be the case and data analysis is required in order to test the possible correlation between truck origin and arrival time. Besides, it is worth noting that the Assured Service Start Time (AST), even at 30 minutes as it is considered throughout this research, results in a very high Assurance Probability (Pa) of approximately 97% to 98%, depending on the Influence Factor level, for all on-time trucks to start their service during this service time-window. This outcome shows that despite the given time-window of 120 minutes to each truck – aiming to add a two-way flexibility in order to reduce the pressure that drivers feel– it is still possible, and with almost 98% assurance probability, to have the trucks service start in a reasonable time, less than 30 minutes, from their arrival time at the plant. Finally, it should be mentioned that in all cases, even in the 100% compliance case, there is still a percentage of trucks that arrive at the plant outside their time-window, as it can be seen in Table 6.9. This can be explained by the fact that carriers might be willing to arrive during their assigned time-window, but disruptions out of their control, like congestion, car accidents, truck breakdowns, etc. occur and affect their arrival time at the plant.

Furthermore, as it has already been discussed and to the best of the authors knowledge, at the moment of writing this Master Thesis there is no other published research using of truck specific time-windows in a Truck Appointment System. Thus, this research proposes a new type of TAS which aims in achieving high system performance while overcoming the strict, not flexible and adaptable to disruptions, nature of the TAS. The only other research found in the literature using time-windows for trucks is the paper of Chen and Jiang (2016), which however focuses on vessel dependent time-windows, which define the time during which trucks have to arrive, but these time-windows are not truck dependent. Also, the design approach and focus of that work is not relevant to this work. Consequently, even though that these two research seem to cover theoretically a similar topic they are not comparable. However, as this research also focuses on the loading operations of a Chemical Plant, a field which as it has already been mentioned is understudied, some works in this field related to this research can be found. In more detail, four different works proposing new and improved types of TAM systems for the loading operations of a Chemical Plant or a Liquid Bulk (Chemical) Terminal are available, and consequently it is interesting to compare the performance of these different TAS under the same conditions. These TAM systems are the joint-Optimization Model for a TAS, in which the interests of the various stakeholders are accommodated, designed by Wibowo & Fransoo (2020), the Integrated Predictive and Optimization Model with the use of real-time truck ETA information introduced by Prakoso (2021), the use of an Optimization Model and real-time truck ETA data for rescheduling all trucks proposed by Vanga et al. (2022) and the combination of the TAS and the Drop and Swap developed by Van Den Brink (2023). It is worth noting that all these works have been published very recently, between 2020 and 2023. From these systems, those of Prakoso (2021) and Vanga et al. (2022) use as case-study the same Chemical Plant with this research and therefore the comparison of the systems performance is more straightforward. Nonetheless, the comparison with Prakoso's (2021) TAS is not possible as in his study synthetic data was used, while in this research real data from the plant is used. Further, for the comparison between the system proposed by Vanga et al. (2022) and the developed in this research it is remarked that exact comparison, with the use of Statistical Analysis tools, is not possible, as the experiments output data is not available. However, the assessment of these two systems' performance is conducted by comparing the mean values and standard deviations of the KPIs for both systems. From this comparison it is noticed that the proposed system, by this study, has a significantly lower trucks Average Waiting Time, 5.02 minutes compared to the 70 minutes of the other system. In addition, the standard deviation of the trucks waiting time is considerably lower in the proposed system. Moreover, the mean value of the Makespan shows a reduction of around 15% in the proposed system compared to that of Vanga et al. (2022), yet Makespan's standard deviation is notably higher in the proposed system. The difference in the performance, between these two models, is most likely due to the utilization of flexible appointment start times in the proposed system in contrast to the fixed appointment start times used in the system developed by Vanga et al. (2022).

Limitations

For the development of the Optimization and Simulation Models a few assumptions and simplifications were made. These form the limitations of this research and are highlighted in this section.

To start with, the limited contact with the Chemical Plant's side during the performance of this research is a critical limitation. However, during those meetings a good insight was obtained regarding the operations of the loading facilities and some of the problems that they came up against. Also, it was agreed to collect and provide for this research actual data of the plant's loading operations. However, for the rest of this research no further feedback was provided, thus their perspective and reflection on the developed models as well as on the assumptions and simplifications that were made is lacking. Due to this reason, the values for some critical parameters, like the penalty cost DC and the weight parameters, a and b, in the objective function of the Optimization Model, were based on the author's understanding of the system and discussion with this thesis supervisors.

Furthermore, in this research the contact with the carriers, companies and drivers, was not possible. Consequently, their perspectives and concerns were indirectly incorporated in the design of the proposed system. In more detail, for determining carriers' objectives this research was based solely in literature review and the opinions on this topic of some people from the chemical plant. In addition, due to this inability of reaching the carriers, there was no data available regarding the actual trucks' trips, their chosen routes, the trip durations, truck breakdowns frequency, etc., data regarding this was obtained solely from the Chemical Plant's data where the origin of a truck and its arrival time at the plant were captured.

Finally, some assumptions and simplifications of the developed models which might be limiting the outcomes of this research are remarked. Initially, the fact that in this research the maintenance and the failures of the equipment are not considered, despite the significant effect that they can have on the system's performance, is a critical limitation. However, due to the fact that the Chemical Plant has a significant amount of spare time, even in the current situation, the effect of these two factors on its performance is expected to be small. But if plant's throughput increases or if disruptions become more severe then these two factors, equipment's maintenance and failures, can cause a significant diversion in the performance of the simulated system and the real-world case. Additionally, the data provided by the Chemical Plant represents 70 workdays between November 2021 and March 2022, which can be considered limited as possible periodic trends in demand and truck arrival patterns cannot be captured. Further, the period that this data was captured some measures against Covid were still in place, thus both demand and congestion levels might not be representative of the typical plant's operation. Also, each truck is considered to be able to carry only 1 Product Type, which might not be the case in the real system, as each truck has several compartments. The scheduling of such a system is possible, and with the current optimization model after some small modifications, but the scheduling complexity will be increased significantly. Furthermore, the simplification of the Simulation model, that for each simulated day the following (next) day is left idle, is another limitation of this study as it has a negative effect on the KPIs values and the representation of the actual system. In addition, in this research the real-time location of trucks is considered to be known, and based on it the estimation of ETAs is performed. This assumes that all carriers have accepted to use and have already installed the required GPS equipment on their trucks. But also, it assumes that the integrated logistics and traffic systems for estimating the trucks ETAs has been developed and works properly. Despite the significance of the ETA information for this research, the development of a system for obtaining them is out of the scope of this work and this is why in the proposed system the ETA information for each truck is considered available for use. Efforts in developing such a system for real-word systems are part of the FTMAAS project, with which this research is associated too. At last, in this research only a single case was examined, which despite the fact that it shows significant improvement in system's performance, it might not be sufficient for generalizing its outcomes.

6.7 Chapter Summary

Initially in this chapter the values of the parameters for the Base Case scenario, based on which the comparison of the two TAS designs is performed, are specified. Then, the characteristics of the Current TAS configuration are described. Following, the values of the Optimization model and the main Design parameters for the Proposed TAS configuration are defined. Subsequently, the comparison between the Current and the Proposed TAS designs, under the same conditions, is performed. The two designs are simulated for a 6-month period during which 6630 trucks are generated. During this period the values of the main KPIs are obtained, and their values are presented and in Table 6.10, in which the Mean value for each KPI is presented along with its standard deviation in the parenthesis. Based on this comparison's results it can be deduced that the Proposed TAS performs significantly better compared to the currently in use TAS. The biggest improvement compared to the current system is noticed on the trucks' Gate Waiting Time (KPI 1), which is significantly lower. This KPI is primary important for the Carriers and the Authorities. In addition, the Makespan (KPI 3) shows an improvement of around 10%, in comparison to the system used in practice. This KPI is important for the Chemical Plant. However, the Slot Utilization (KPI 2) appears to be the same for both systems. This KPI is important for the Chemical Plant. Succeeding, sensitivity analysis is carried out on the effect that the Influence Factor, compliance to the proposed system, has on the system's performance. The value of each KPI and Influence Level can be seen and in Table 6.11, in which the Mean value for each KPI is presented along with its standard deviation in the parenthesis. From the results of the Sensitivity's Analysis, it is concluded that the Influence Factor has the higher effect on the Gate Waiting Time (KPI 1), for which as it increases the waiting time decreases significantly. Regarding, the other two KPIs, the Influence Factor has no effect on the Slot Utilization while on the Makespan it seems to have some marginal effect. These remarks also answer the sub-Research Question 7, with respect to the effect of the proposed TAS on the objectives of the various stakeholders in compassion to the current model. Finally, the experiments outcomes are discussed and reflected to the literature, and the research limitations are presented.

	Current		**Proposed**	
KPI 1 – Gate Waiting Time [min]	91.63 (110.92)		5.02 (41.17)	
KPI 2 – Slot Utilization	Theoretical	Actual	Theoretical	Actual
	0.655 (0.093)	0.325 (0.050)	0.654 (0.102)	0.330 (0.054)
KPI 3 – Makespan [min]	1689.63 (280.55)		1530.97 (276.86)	

Table 6.10: KPIs Analysis between Current and Proposed Design. Mean value and standard deviation in the parenthesis (N=6630 trucks)

	Influence Factor Level					
	0%	20%	40%	60%	80%	100%
KPI 1 – Gate Waiting Time [min]	13.707 (52.106)	12.742 (56.378)	11.498 (55.303)	8.432 (46.475)	6.503 (46.727)	5.018 (41.168)
KPI 2 – Slot Utilization (Actual)	0.330 (0.053)	0.328 (0.051)	0.329 (0.053)	0.331 (0.052)	0.328 (0.054)	0.330 (0.054)
KPI 3 – Makespan [min]	1468.15 (265.21)	1579.62 (298.41)	1601.56 (293.03)	1533.748 (278.390)	1513.13 (274.36)	1530.97 (276.86)

Table 6.11: Sensitivity Analysis - KPIs Analysis per Influence Factor Level. Mean value and standard deviation in the parenthesis (N=6630 trucks)

Chapter 7: Conclusion and Recommendations

In this chapter, initially in Section 7.1 the answer to the main Research Question is given, by answering the sub-Research Questions, and the Conclusions of this research are drawn. Also, in Section 7.2 Recommendations for Future Research are proposed.

7.1 Conclusion

The objective of this research is to design and assess the performance of a time-window based Truck Appointment System (TAS), with adaptive slot management and the use of real-time ETA information, for the loading operations in a Chemical Plant. The main components of the proposed system are the time-windows, assigned to each truck, the use of real-time information and the adaptive determination of trucks' loading sequence. The aim of this system is to improve loading bays' utilization level, improve trucks' service level and reduce their waiting times and thus the queues. The proposed system is further is expected to reduce the pressure on truck drivers fearing to lose their booked slot, and is designed to improve system's resilience against disruptions, and especially on truck arrival uncertainties owing to traffic congestion. Also, the adaptive slot management is performed with the use of a Mathematical (Optimization) Model and all trucks can be rescheduled in the proposed system. Moreover, a Simulation model was developed to emulate the real system of the Chemical Plant and assess the performance of the proposed TAS, under different scenarios. To the best of our knowledge there is no other research on a TAS with the use of truck specific time-windows.

<u>Research Questions</u>

The main Research Question of this study is:

> *"What is the effect of a Time-Window based Truck Appointment System (TAS) on the performance of the loading facility at a chemical plant for the different stakeholders?"*

In order to answer the main Research Question, sub-research questions were developed and answered first. From these deduced answers, the answer to the main research question was synthesized.

<u>Sub-RQ1:</u> What is the state-of-the-art towards traffic management around logistics sites?"

In order to answer this sub-research question, a literature review was performed on the topic of traffic management around logistics sites. However, it is noted that in this work, the term traffic management reflects the measures for handling the problem of long queues of parked or waiting trucks around or at the gates of logistics sites and the congestion caused by them. Initially, the description of this problem in the literature and its causes were identified. Then, the solutions proposed in the literature to handle the problem were summarized. The Truck Appointment System (TAS) turned out to be the most extensively researched and applied system in practice. However, as the typical TAS has some significant drawbacks, the new research on the filed focuses on designing improved TASs. The main attributes of these new TASs are the higher flexibility, robustness and efficiency, especially against disturbances. Also, the new TASs aim at increasing the acceptance and compliance of the trucking companies towards them. In order to achieve these, new approaches, technologies and methodologies are studied. Such approaches are the combination of different TAM systems, the collaborative or joint optimization of the schedule, in which the interests of all the stakeholders are considered during the system's optimization, and the utilization of new technologies and real-time information for trucks rescheduling. The benefits of using real-time information to reschedule, as compared to the solutions where no-information is available, for a TAS have been proven in the literature. The methodologies used in the state-of-the-art research are the Optimization, Simulation and a combination of these two. For solving the optimization models either linear/ integer solvers are used or heuristic methods. While, for the Simulation models, discrete event and agent-based simulation are the two most applied methodologies with agent-based being able to capture better the system's behavior in a more micro scale compared to the discrete event.

<u>Sub-RQ2:</u> *"What is the current situation of the loading operations in the chemical plant under study?"*

The chemical plant under study is located in the Antwerp region of Belgium. Its inbound logistics (supply) is performed through marine transportation, while the outbound logistics (delivery to the customer) is performed through road and rail. The loading operations of trucks and rail wagons are performed in the same loading bays, but at different times – after the plant has closed for trucks – due to safety reasons. For each truck that arrives at the plant there is a strictly defined set of processes that need to be followed in order to get into the plant, get loaded and exit the plant. This set of processes is visualized in Figure 3.3 and includes the announcement of the truck's arrival at the plant and the check of their documents at the Documents Check Point (DCP), the weight of the truck at the Scale, the actual loading process of the truck at the Loading Bays, the weight of the truck at the Scale after the loading has been completed, the completion of the paperwork at the DCP and the truck's exit from the Plant's Gates. In the chemical plant under study, there are 6 loading bays which serve different products, and their loading time is either 30 or 45 minutes, depending on the loading bay. Further, in each loading bay there is dedicated equipment for serving each product type, consequently there is no cleaning time or change time between the service of two consecutive trucks in the same loading bay. Also, the appointments' duration of the currently in use TAS are not the same for all the loading bays, but are dependent to the service time of the loading bay. Moreover, the current capacity utilization of the plant's loading infrastructure is around 60%-70% of its total daily available capacity (slots). In addition, the data from 2019, which is before the pandemic and the start of the works in the Antwerp's ring road, shows that the percentage of delayed truck arrivals is 20.5% (Raj, 2019). Besides, this chemical plant supplies clients supplies clients outside Belgium including countries like the Netherlands and France. Furthermore, disruptions related to the road network is the most common reason affecting the trucks arrival time at the plant, according to the truck drivers.

The Stakeholders of this project are the Chemical Plant, Trucking Companies (carriers) and the Authorities, which have different interests and objectives – often conflicting.

<u>Sub-RQ3:</u> *"Which are the characteristics of the current TAS?"*

The Truck Appointment System (TAS) currently used in the chemical plant is a typical TAS with fixed slots, which has a few drawbacks as they are described in the literature. In this TAS, the plant operator announces the available timeslots on an online appointment system, through which trucking companies book the slot that fits the best to their scheduling. These appointments are booked in advance, before the truck's arrival at the plant. At the day of the appointment the truck is expected to arrive a few minutes before the beginning of the booked timeslot and to wait until the time of its appointment has arrived, as the loading is performed strictly based on the appointments schedule. If a truck arrives later than its booked timeslot, it misses its slot and has to book a new one or to get rescheduled by the slot manager, however the waiting time until the next available slot cannot be predicted and no minimum waiting time is guaranteed. Consequently, this causes high pressure to truck drivers as disruptions can occur during their trip and can significantly affect their arrival time at the plant. Furthermore, the rescheduling performed by the slot manager is done manually and considers only one truck thus, it is sub-optimal from a system's perspective. Finally, these reschedules reduce loading bays utilization and the availability of buffer slots for future truck appointments.

Sub-RQ4: *"Which are the components and the structure of a new and improved TAS with the use of time-windows and real-time information?"*

A new Truck Appointment System, with the use of time-windows and real-time information, is proposed in order to solve some of typical TAS's drawbacks and to improve its performance. The main features for this new TAS are the flexibility and responsiveness against truck arrival deviations and disruptions in general. While the main components of this system are the use of truck dependent arrival and service time-windows, the utilization of real-time information (and trucks' ETAs) and the adaptive trucks rescheduling model. Specifically, in the proposed system a time-window is assigned to each truck, with an indicative arrival time (x) at the middle of the time-window. The assigned time-windows are longer than the actual service times, allowing overlap between time-windows. For this reason, an assured service start time and an assurance probability is given to each truck, giving the maximum waiting time for a truck that arrived during its assigned time-window before its loading process starts and with what probability. Consequently, the actual service sequence might be different from the reserved one. In order to determine the actual loading sequence an Optimization model is developed, which is run every "Y" minutes with updated information of the actual and Estimated Time of Arrival of the trucks, and creates the adjusted schedule for the loading operations. The proposed TAS is expected to significantly reduce the stress level of the truck drivers, about missing their booked slot, and the trucks waiting times. Moreover, it is expected to increase terminal's utilization and to improve the loading schedules compared to the current TAS.

Sub-RQ5: *"How is the real-time rescheduling model designed and which parameters are taken into account in the optimization?"*

For the formulation of the real-time rescheduling algorithm, initially the determination of the model's decision variables, parameters and constraints is required. These are defined based on the characteristics of the loading operations and the requirements of the proposed TAS, which have been described in the previous sub-research questions. The objective of this rescheduling model is to define the trucks loading sequence and loading bay assignment, based on their ETAs and promised service time, while minimizing the total cost and complying with the system's constraints. The total cost consists of two parts, the total weighted cost, resulting from the weighted average of all trucks waiting time, and the penalty cost of not servicing on-time trucks during their assured service start time (AST). The decision variables are the truck assignment on loading bay l (X_{il}), the truck sequence on a loading bay (Y_{ij}) and the service completion time of a truck (CT_i). The model's requirements (constraints) include that all trucks that arrive at the chemical plant have to be served, albeit with different priorities; a maximum waiting time limit (TL) before the service starts is determined for all trucks; trucks are rescheduled based on their ETA and real-time information; assignment of a (re)scheduled truck to a loading bay where the requested product type is available; flexible service start times; each loading bay can serve only one truck at a time. Further, some characteristics of the proposed model, which are similar those of Hung's et al. (2017) based on which this study's optimization model was developed, are critically discussed. These characteristics are the use of time-windows during which each job has to be completed, the unrelated parallel machines (loading bays), the machine dependent processing rate, the machine eligibility constraint – not all loading bays can serve all products – and the fact that jobs are considered non-preemptive. Moreover, the main assumptions of this model are presented which are that trucks with no reservation (booked appointments) are not considered, loading bays setup times between different trucks are zero and equipment maintenance and failures are not considered. Finally, it is noted that this model's Mathematical formulation can be found in Subsection 5.1.3.

Sub-RQ6: *"How can the loading operations of the Chemical Plant be modelled?"*

For modeling the loading operations of the Chemical Plant, Simulation is the chosen methodology in this research. A replica of the actual system is created, with some simplifications for its easier understanding and analysis. For the creation of a Simulation model that represents the actual operations of the chemical plant under study, the main characteristics of the system had to be identified first. These characteristics have been described in Section 3.5 and form the base for the development of the Simulation model. Following, these main characteristics and operations of the system are modeled, with different simulations modules, together with their interactions and combined form the Simulation model. In Figure 5.3, the Conceptual Model of the simulation model is presented. In this model the main processes, decisions, input data and the optimization process are illustrated. Finally, it is noted that the developed Conceptual model is implemented in the AnyLogic software and is modeled with the use of Discrete Event Simulation.

Furthermore, for the assessment of the proposed TAS design (d2) the integration of the developed Optimization model, presented in Subsection 5.1.3, in the Simulation model was required, as this rescheduling model is a critical component of the proposed TAS design. The integration is possible as both models are coded in the same programming language (Java). Also, the Gurobi solver used for the model's optimization, can be integrated in the simulation model as well. Nevertheless, for the successful integration, a few steps are required. These steps are the duplication and transfer of the optimization model in a function of the simulation model, the creation and connection of the Optimization model's parameters and variables in the simulation model, which allows the automatic update of the input data in the rescheduling model, and the determination of the triggering condition for the rescheduling process in the Simulation model, as in the proposed TAS design rescheduling is performed periodically – every "Y" minutes.

Sub-RQ7: *"What is the effect of the proposed Truck Appointment System on the objectives of the different Stakeholders compared to the one used in current practice?"*

For the assessment of the proposed Truck Appointment System, a Base Case Scenario was defined. This scenario forms the base for a fair comparison of the two TAS designs. For this purpose, the configurations for both TAS, Current TAS (d1) and Proposed TAS (d2), were described and their parameter values were determined. These two TAS configurations (designs) were compared based on the Base Case scenario, under the same conditions. According to their outputs and the KPIs values obtained, the effect of the proposed TAS on the objectives of the different stakeholders was evaluated. These results are presented in Table 7.1. For the Chemical Plant, the most applicable KPIs are the Slot Utilization and the Makespan.

Slot Utilization (KPI 2) does not appear to be improved by the proposed system and actually has the same values in both systems. However, the Makespan (KPI 3) shows an improvement of around 10%, compared to the current system. Regarding the other stakeholders, namely Carriers and Authorities, the Gate Waiting Time (KPI 1) is the most relevant KPI. This KPI has the highest improvement compared to the current TAS, as a reduction of around 94.5% on the mean waiting time is achieved, from 91.63 to 5.02 minutes, and its standard deviation decreased by 63%. Furthermore, Sensitivity Analysis on the effect that the Influence Factor – truck's compliance to the proposed system– has on the system's performance is conducted. Based on the model's outcomes and KPIs values for each tested level of the Influence Factor, its effect on the proposed TAS performance and the objectives of the different stakeholder was assessed. These results are presented in Table 7.2. From this analysis, it is concluded that the Influence Factor has the higher effect on the Gate Waiting Time (KPI 1) – relevant to Carriers and Authorities – as it increases the waiting time decreases significantly. Regarding, the other two KPIs related to the Chemical Plant, the Influence Factor has no effect on the Slot Utilization while on the Makespan the effect appears to be marginal.

	Current		**Proposed**	
KPI 1 – Gate Waiting Time [min]	91.63 (110.92)		5.02 (41.17)	
KPI 2 – Slot Utilization	Theoretical	Actual	Theoretical	Actual
	0.655 (0.093)	0.325 (0.050)	0.654 (0.102)	0.330 (0.054)
KPI 3 – Makespan [min]	1689.63 (280.55)		1530.97 (276.86)	

Table 7.1: KPIs Analysis between Current and Proposed Design. Mean value and standard deviation in the parenthesis (N=6630 trucks)

	Influence Factor Level					
	0%	20%	40%	60%	80%	100%
KPI 1 – Gate Waiting Time [min]	13.707 (52.106)	12.742 (56.378)	11.498 (55.303)	8.432 (46.475)	6.503 (46.727)	5.018 (41.168)
KPI 2 – Slot Utilization (Actual)	0.330 (0.053)	0.328 (0.051)	0.329 (0.053)	0.331 (0.052)	0.328 (0.054)	0.330 (0.054)
KPI 3 – Makespan [min]	1468.15 (265.21)	1579.62 (298.42)	1601.56 (293.03)	1533.75 (278.39)	1513.13 (274.36)	1530.97 (276.86)

Table 7.2: Sensitivity Analysis - KPIs Analysis per Influence Factor Level. Mean value and standard deviation in the parenthesis (N=6630 trucks)

The Main Research Question can now be answered based on the aforementioned answers to the sub-Research Questions.

The outputs of the developed Simulation Model answer the main research question, as they determine the values of the KPIs. Based on these KPIs values, the performance evaluation of the proposed Truck Appointment System (TAS) with time-windows is conducted for the different stakeholders. Furthermore, the Sensitivity Analysis on the effect of the Influence Factor – truck's compliance to the proposed system– on the proposed design's performance gives a better insight and understanding of this system. Based on the comparison of the simulation outcomes of the two TAS configurations (designs), it can be deduced that the Proposed TAS performs significantly better compared to the currently in use TAS, with the biggest improvement noted on the trucks' Gate Waiting Time (KPI 1). Regarding the effect of the proposed TAS with time-windows on the stakeholders, for the Chemical Plant the relevant

KPIs are the Slot Utilization (KPI 2) and the Makespan (KPI 3), which show no and a 10% improvement, respectively, compared to the currently use TAS. Also, the effect of the Influence Factor on them is zero and marginal respectively. Regarding, the Carriers and the Authorities the related KPI is the Gate Waiting Time (KPI 1), which appears to have the highest improvement compared to the current TAS, as a reduction of around 94.5% on the mean waiting time is achieved, from 91.63 to 5.02 minutes, and its standard deviation decreased by 63%. Further, this KPI is affected positively by the Influence Factor, as the Gate Waiting Time is reduced as the compliance to the proposed system increases. Finally, it is worth noting that in the proposed TAS design, there is not a trade-off on the performance of the different KPIs, meaning that the improvement of one does not result in a deterioration of the others.

Furthermore, based on this research's outcomes it can be concluded that a less strict TAS, compared to the typical one, can improve significantly the system's performance. In addition, these results dictate that some of the severe problems that logistics terminals, like chemical plants, face due to congestion and trucks arrival uncertainty, can be notably improved with the proposed design. Specifically, the remarkable reduction of trucks' average waiting time has a positive effect on the reduction of truck queues length at the plants gates, as well as the number of trucks waiting with their engines idling in the parking area. Also, congestion around logistics sites can be reduced as the number of trucks waiting on the roadside and in queues, affecting the roads flow, will be diminished. Additionally, the reduction of trucks' waiting times increases their Utilization, as their turn-around time is decreased, and reduces their fuel consumption, as they wait for shorter time with their engines idling. Moreover, the environmental footprint of the loading facility – estimated indirectly from the trucks Gate Waiting Time (KPI 3) – is expected to be significantly improved compared to the current situation. This is explained as the trucks waiting outside the plant's gate or in queues in order to get into the plant are considered in the literature to have a significant contribution on the terminal's environment footprint. Consequently, reducing their waiting times is expected to shorten the time that the trucks are waiting with their engines idling emitting pollutants and thus improve the chemical plant's environmental footprint. Thus, as air pollution and congestion are expected to be reduced the livability of the terminal's surrounding area will be improved. Lastly, the flexible start-times, of the proposed TAS design, improve significantly the system's resilience against the trucks' arrival time uncertainty.

7.2 Recommendations for Further Research

The preliminary results of the proposed time-window based Truck Appointment System with the use of real-time information are very promising. Consequently, further research is warranted in order to confirm its benefits. In this section, topics for further research are proposed.

To start with, as this system has been designed to improve system's resilience against disruptions, and especially against trucks' arrival uncertainty, it is critical to be tested under different congestion scenarios and assess its performance. This is highly relevant as the construction work on Antwerp's Ring Road is expected to begin soon and is highly likely to increase congestion. Also, sensitivity analysis on the effect of increased demand on the system's performance is another intriguing topic to study. Indeed, currently the utilization of the loading bays is quite low, around 60% of the booked slots and 32% of the loading bays available time, and usually problems start to arise when utilization reaches around 80-90%.

Moreover, the research on possible correlations between the different parameters of the proposed TAS, namely Assured Service Start Time, Assurance Probability and Session Length, is an interesting topic to study. This will provide a better understanding of the system parameters and the effect they have on the system's performance. Furthermore, the level of acceptance and the actual effect that this system is expected to have on the truck drivers, is also a fascinating topic for research. The findings of this study are very important as actual feedback from drivers can be obtained about the reduction or not of the stress level that they experience, especially about missing their booked slot, and can also give indications of their actual compliance level to the proposed system. Such research can be performed with questionnaires handed to the truck drivers at the gates of the studied chemical plant in order to obtain their feedback prior to the possible implementation of this system in practice. Finally, an extension of the created mathematical model can be developed in which some assumptions of this model are removed. For example, trucks can carry more than one product types in different compartments of their tanks, and the equipment failures and maintenance can be considered.

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Appendix A – Research Paper

Time-window based Truck Appointment System with Adaptive Slot management and Real-Time Truck Information: A case study for the loading operations in a Chemical Plant

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Abstract

Long truck queues and congestion around terminals is a common sight, however they come with many negative externalities for all the stakeholders involved. Truck Appointment System (TAS) is the most commonly used system to face these problems, but it still has some drawbacks and limitations. Consequently, in this research an extension of the typical TAS is proposed to improve its performance. The main components of this system are the use of truck dependent time-windows, the utilization of real-time information and the adaptive trucks rescheduling model. The duration of the arrival time-windows is longer than the actual service times, allowing overlap between time-windows. Thus, the actual service sequence might be different from the reserved one. To determine the actual loading sequence an Optimization model is developed, which is run periodically while utilizing real-time truck information. A chemical plant is used as a case study in this research. The performance of the proposed TAS is assessed with the use of a Simulation model. The outcomes of this research suggest that the a less strict TAS can significantly improve the system's performance, especially trucks' waiting time. Also, the system's resilience against disruptions and the plant's environmental footprint are improved, while queues are reduced.

Keywords: Truck Appointment System, Time-windows, ETA, Real-time Information, Rescheduling, Slot Management, Chemical Plant, Optimization, Simulation

1 Introduction

Long truck queues, parked trucks on the roadside, and congestion around logistic sites, like container terminals and chemical plants, is a common sight (Wibowo & Fransoo, 2020). However, these queues outside the gates of the logistics sites come with many negative externalities for both terminal operators and trucking companies as well as for the environment and the population living in the surrounding areas (Wibowo & Fransoo, 2020; Chen et al., 2013; Neagoe et al., 2021; Heilig et al., 2017).

To face these aforementioned problems a few solutions have been proposed in the literature. These can be classified into three large categories which are the terminal's expansion, the improvement of the terminal's efficiency and the management of truck arrivals (Chen et al., 2013; Motono et al., 2016). From them, Truck Arrival Management (TAM) category has gained the most attention and more specifically the Truck Appointment System (TAS) is the most researched and implemented system of this category (Chen et al., 2013). This is justified as it is a relatively low-cost and simple to implement solution which has already been implemented in many container terminals since the early 2000s (Neagoe et al., 2021). TAS aims to control trucks arrival rate with the objective to smooth out truck arrivals and maintain gate congestion under a certain level or unlikely to happen and thus reduce congestion and emissions around terminals (Chen et al., 2013; Sharif et al., 2011; Wibowo & Fransoo, 2020).

However, practical experience shows that TAS performance is not uniform and in its typical form has a few drawbacks, like its inflexibility (strict schedule), the reduced reliability of the appointment times, and the low resilience against typical disruptions (Chen et al., 2013; Li et al., 2016; Wibowo & Fransoo, 2020). Thus, new research on the field focuses on improving TAS's robustness and efficiency especially against disturbances while at the same time increasing the compliance of the trucking companies to the TAS with the use of new approaches and technologies. Furthermore, the vast majority of research on the TASs is focused on container terminals, despite the fact that other types of terminals, like chemical plants and bulk terminals, face the aforementioned issues as well. Hence, further research is required in these types of terminals, especially in order to capture the special characteristics of these terminals (Neagoe et al., 2021; Wibowo & Fransoo, 2020).

Consequently, the goal of this research is to design a time-window based Truck Appointment System (TAS) with the use of real-time information and adaptive slot management. The idea of the proposed model is based on the typical TAS, but with the relaxation of some of its typical and strict constraints and with the use of new technologies – like GPS and utilization of real-time information. In this proposed design, truck specific time-windows are used. The aim of the proposed TAS design is to improve system's performance against disruptions and to overcome some of the main shortcoming of a typical TAS. A chemical plant is used as a case study for the implementation and testing of the proposed TAS design. The performance of the proposed design, for the various stakeholders, is measured and assessed with the use of several KPIs.

The remainder of this paper is structed as followed. In Section 2, the main findings of the literature review and the research gaps are presented. In Section 3, the System Description is given. Following, in Section 4 the proposed Truck Appoint System is described. In Sections 5 and 6 the Optimization and Simulations models are described. Then, in Section 7 the Experimental procedure is analyzed. While in Section 8 the Simulation results are presented and discussed. Finally, in Section 9 the Conclusions are drawn followed by recommendations for future research.

2 Literature Review

Literature review is conducted in order to identify the previous research on the logistics field regarding facing congestion, long truck queues and disruptions in general around logistics sites. As it has been already explained in the Introduction, congestion and long queues have many negative externalities for all the stakeholders. Consequently, extensive research has been conducted on this field. TAS is the most researched and implemented system, but still has some shortcoming and limitations which the current research aims to improve. Thus, the focus of this literature review is to identify the state-of-the-art research approaches and methods applied on the field to face the aforementioned problems.

2.1 New Research on the Field

The new research on the field focuses in improving TAS's flexibility, robustness and efficiency especially against disturbances, while at the same time increasing the compliance of the trucking companies to the TAS with the use of new approaches and technologies. Some state-of-the-art approaches dealing with these problems include the collaborative optimization of the TAS schedule and the utilization of real-time information with the use of new technologies. Collaborative or joint optimization of the TAS schedule approach, aims at increasing trucks' compliance to the TAS. Wibowo and Fransoo (2020) present a model in order to define the optimum slots length for a TAS in a chemical plant, while considering the perspectives of all the different stakeholders. The findings of this research suggest firstly that the implementation of TAS in chemical plants can significantly improve their performance and secondly that the main advantage of the joint optimization is the redistribution of the benefits from the TAS usage to all stakeholders. Finally, the utilization of real-time information for the trucks rescheduling is another approach which has gained recently quite some attention in the research of logistics field, especially after the start of the Freight Traffic Management As A Service (FTMAAS) project (Freight Traffic Management as a Service, 2020). Aim of the FTMAAS project is to create information value chains from data, by connecting and integrating real-life logistics and traffic management systems, while one of its use cases focuses on the accurate estimation of truck arrival times based on real-time information and the use of this estimation for dynamic rescheduling (Freight Traffic Management as a Service, 2020). The research from Larbi et al. (2011) examines the value of incoming trucks arrival information in the cross-docking operations under three different levels of available information. The findings of this research suggest that there is significant benefit when having and utilizing full information on the truck arrivals compared to the case when this information is not available and that distant future information does not further improve the obtained solution. Regarding the use of real-time information in TAS, two studies were found, both of which are part of the FTMAAS project. Prakoso (2021) presented a predictive model which incorporates the use of real-time ETA information for optimizing the TAS's schedule, but it is also very beneficial when rescheduling is required. A Machine Learning technique was used for the estimation of the trucks' arrival time. In this study only delayed trucks are rescheduled. This research's outcomes suggest that the utilization of the information, obtained from the integration of the logistics operations and the traffic systems, for the (re)scheduling of a TAS can enhance the operational efficiency of terminal's loading operations. Vanga et al. (2022), proposed an extension of Prakoso's (2021) work where the obtained real-time information is still utilized for the (re)scheduling of a TAS but in which there is the flexibility of all trucks to be rescheduled with the aim of minimizing the trucks average waiting time. The results of this research demonstrate again the benefits of using the real-time information in a TAS as system's overall performance is improved compared to the case where no information is available.

The methods used in the state-of-the-art research are the Optimization, Simulation and a combination of these two. For solving the optimization models either linear/ integer solvers are used or heuristic methods. While, for the Simulation models, discrete event and agent-based simulation are the two most applied methodologies with agent-based being able to capture better the system's behavior in a more micro scale compared to the discrete event. Vanga et al. (2022) proposed a rescheduling optimization model for a TAS in the chemical industry with the use of real-time information. Nevertheless, in order to assess the performance of the proposed optimization model they developed a discrete event simulation model, which represents the loading operations of the studied chemical plant. With the integration of the optimization model in this simulation model the evaluation of the proposed rescheduling system was made possible.

2.2 Optimization Models

In the proposed TAS design, by this research, an optimization model is required, which will perform the trucks (re)scheduling. Thus, for the development of this model literature review is performed. Aim of this literature review is to find related works and model formulations in the field of TAS with the use of time-windows. However, in the field of optimization models and TASs with the use of time-windows only one paper was found, the paper of Chen and Jiang (2016) which aims at defining the optimal time-window length for each arriving vessel during which trucks could unload their containers in the container terminal. The aim of this optimization model and the model formulation approach are very different from that of this research and thus they cannot be used. Consequently, research on other fields is conducted with focus on the job-shop scheduling problems as their objective is to define the job sequence at the different stages and to perform jobs to machine assignment in order to optimize one or more selected criteria (Naderi et al., 2008). Therefore, the relevance of these problem types with the studied is apparent.

Some job-shop scheduling problems which are related to this study and could be used for the development of this study's mathematical model are presented. To start with, Berndorfer and Parragh (2022) developed a Mixed-Integer Linear Programming model aiming to solve the problem of shop floor space assignment for the final product assembly, with the objective of Minimizing the total tardiness and utilized machine size. In this problem early start of the jobs is not allowed, however for each job there is a due-time window during which it has to be completed in order not to occur delay costs. This is a non-preemptive parallel machine scheduling problem, with machine eligibility and a rolling horizon production planning. Moreover, Hung et al. (2017) proposed a Mixed-Integer programming model for the make-to-order (MTO) manufacturing environments with the objective of finding a feasible schedule – all jobs to be performed during their time-window – and if that is not possible then the aim is the minimization of the occurring earliness and tardiness costs of all jobs. In more detail, in this research the jobs scheduling problem on unrelated parallel machines with sequence dependent set up times and machine and job dependent processing rates is studied. For each job a time-window is defined by the ready date – earliest day to start– and a due date – latest date the job has to be finished. A job is expected to be fully processed during its assigned time-window so that earliness and tardiness costs are avoided. Also, in this study the machine eligibility is considered. Finally, Missaoui and Ruíz (2022) created a Mixed Integer Linear Programming (MILP) model for the hybrid flowshop scheduling (HFS) problem with the objective of minimizing the total weighted earliness and tardiness from a due date window. HFS problems address the job scheduling through a set of stages in which multiple parallel machines are available. In this work two extensions of the typical problem were studied, firstly sequence dependent setup times were introduced and secondly a due date window was used.

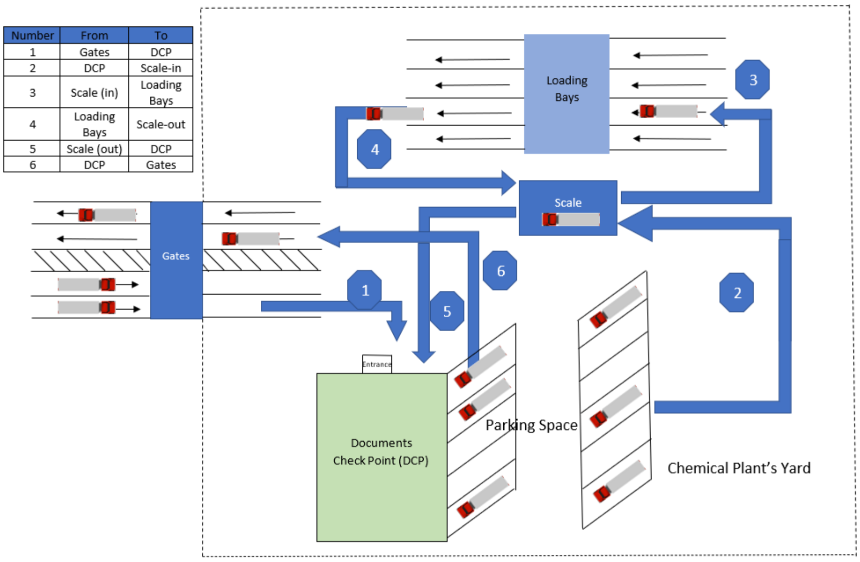
The literature gaps that the present research aims to fill are the proposal of a new TAS, extension of the typical TAS with relaxation of some of its typical and strict constraints, along with the use of new technologies in order to improve system's performance against disruptions and overcome some of the main shortcoming of a typical TAS. Also, the implementation of a TAS in a chemical plant is another gap that this research aims to address. The use of TAS in chemical plants is significantly understudied in the literature, as the vast majority of research has been on containers terminals. The importance of researching further the TAS in different logistics sites and especially in the chemical industry derives from the fact that for the implementation of such a system there is no universal formula and each terminal's specific characteristics and conditions must be considered, as Chen et al. (2013) and Wibowo & Fransoo (2020) indicated. Additionally, advanced methods, like optimization and discrete event simulation, are implemented complementary to the aforementioned approaches.

3 System Description

3.1 System Description

In this research a chemical plant located in the Antwerp region of Belgium is used as a case study. Its inbound logistics (supply) are performed through marine transportation, while the outbound logistics (delivery to the customer) are performed through road and rail. However, in the present research, only the road outbound logistics are considered. Further, it is noted that the focus of this research is limited to the loading operations of the chemical plant and the road transportation of the finished products to the customers, yet the final delivery of the products to the customers is out of the scope of this research.

Following, a detailed description of the system considered in this research, consisting of the Loading Operations and Transportation, is given based on Figure A- 1. For each truck arriving at the plant there is a strictly defined path, with different tasks completed at each step of it, from its arrival at the plant's gates until its departure from the plant. The main tasks of this path are the truck entrance through the Plant's Gates, the announcement of the truck's arrival at the plant, the check of their documents and the compliance with the plant's safety standards which is carried out at the Documents Check Point (DCP), the weight of the truck at the Scale, the loading process of the truck at the Loading Bays, the weight of the truck at the Scale after the loading has been completed, the completion of the paperwork at the DCP and finally the exit of the truck from the Plant's Gates. In the chemical plant under study, there are 6 loading bays which serve different products, and their loading time is either 30 or 45 minutes, depending on the loading bay. Further, different equipment is used per bay for the loading of each product type, thus the changing time from one product type to another in a loading bay is actually neglectable. Also, the appointments' duration of the currently in use TAS are not the same for all the loading bays, but are dependent to the service time of the loading bay. Moreover, the current capacity utilization of the plant's loading infrastructure is around 60%-70% of its total daily available capacity (slots). In addition, the data from 2019, which is before the pandemic and the start of the works in the Antwerp's ring road, shows that the percentage of delayed truck arrivals is 20.5% (Raj, 2019). In addition, this chemical plant supplies clients outside Belgium including countries like the Netherlands and France. Usually, the trucks which serve these countries originate their trip from that country, which increases the uncertainty of the truck's travel time as distance increases. Consequently, truck drivers prefer to arrive earlier than their slot time at the plant's location and wait, so that they do not lose their reserved timeslot (Wibowo & Fransoo, 2020). Furthermore, according to the truck drivers, disruptions related to the road network is the most common reason affecting their arrival time at the plant (Raj, 2019).



Number	From	To
1	Gates	DCP
2	DCP	Scale-in
3	Scale (in)	Loading Bays
4	Loading Bays	Scale-out
5	Scale (out)	DCP
6	DCP	Gates

Figure A- 1: Schematic Overview of Chemical Plant's loading facilities and trucks flow

The Stakeholders for this project are the Chemical Plant, the Trucking Companies (carriers), and the Authorities, which have different interests and objectives – often contradictory. The KPIs that are used in this research are the Gate Waiting Time, showing the waiting time of a truck before entering the plant gates to get serviced, the Slot Utilization, representing the ratio of the productive time to the total available time of the loading bays, and the Finish Time (Makespan), capturing the total time length (span) to complete the service of all scheduled trucks. The first KPI is important for the Carriers and the Authorities, while the last two are important for the Chemical Plant.

3.2 Problem Specification

Apart from the factors, identified in the literature, that affect the Trucks Arrival Times and consequently the efficiency of a typical Truck Appointment System, also a few case specific factors for the Chemical Plant under study are identified. These factors are the already congested road network of the region, the increasing amount of freight handled through the port of Antwerp, and the planned construction work for rehabilitating Antwerp's Ring Road (Prakoso, 2021; Raj, 2019; Vanga et al., 2022). All these aforementioned factors create an environment where road congestion and subsequently travel times and delays are expected to be increased even more compared to the current situation. Consequently, they are expected to have a significant impact on the operations of the chemical plant as the deviation between scheduled and actual trucks arrivals can result in overflow of finished products and consequently in production disturbances or need for extra inventory storage facilities. Further, the performance of the current Truck Appoint System (TAS) is expected to be considerably affected as more trucks will either arrive later or earlier than their appointment. Also, as the number of delayed trucks increases and the number of reschedules required will be increased along with truck queues outside the plant premises, so the benefits of implementing a TAS will be reduced. Thus, the need of developing of a new system, with higher flexibility and resilience against disruptions compared to the currently used TAS by the chemical plant, is made obvious. Moreover, chemical plants have some distinct characteristics which differentiate their operations and procedures from other logistics sites (Wibowo & Fransoo, 2020). These characteristics are briefly the high safety standards and procedures that regulate their operations, the document checkup that each truck has to undergo in order to confirm the legitimacy of its operations and the compliance with the safety standards, the significantly higher loading time for each truck compared other logistics site, the relatively limited operating hours of the plants and their high complexity as a system (CEFIC & ECTA, 2009; CEFIC & ECTA, 2013; Wibowo & Fransoo, 2020).

3.3 Truck Appointment System in Practice

In the chemical plant that is analyzed in this study, there is already a Truck Appointment System (TAS) in place. However, this TAS is the typical one with fixed timeslots which comes with several drawbacks. In this TAS, the plant operator announces the available timeslots on an online appointment system. Through this system, trucking companies see the slots availability and book one of the available slots, which fits the best to their scheduling. The duration of these timeslots is fixed and equal to the trucks' service time at each loading bay. These appointments are booked in advance, before the truck's arrival at the plant. t the day of the appointment the truck is expected to arrive a few minutes before the beginning of the booked timeslot and to wait until the time of its appointment has arrived, as the loading is performed strictly based on the appointments schedule. If a truck arrives later than its booked timeslot, it misses its slot and has to book a new one or to get rescheduled by the slot manager, however the waiting time until the next available slot might be in a few hours or even the next day.

Moreover, the rescheduling performed by the slot manager is done manually and considers only one truck thus, it is sub-optimal from a system's perspective. Also, these reschedules reduce loading bays utilization and the availability of buffer slots for future truck appointments (Vanga et al., 2022). Furthermore, it is noted that in the current system truck drivers have only one side flexibility, to arrive earlier than their booked slot, so that they do not miss their booked appointment. This one-way flexibility is considered to put a lot of pressure on truck drivers and trucking companies. For the rest of this research, the TAS system which is currently used in the chemical plant will be referred as *fixed slot design (d1)*. Finally, in Figure A-3, the one-side flexibility of trucks' arrival time at the plant, for booked slot at 11:30, is depicted.

4 Proposed Truck Appointment System

A new Truck Appointment System, with the use of time-windows and real-time information, is proposed in this research in order to solve some of typical TAS's drawbacks and to improve its performance. The main requirements for this new TAS are the flexibility and responsiveness against truck arrival deviations and disruptions in general. While the main components of this system are the use of truck dependent arrival and service time-windows, the utilization of real-time information (and trucks' ETAs) and the adaptive trucks rescheduling model. Specifically, in the proposed system a time-window is assigned to each truck, with an indicative arrival time (x) at the middle of the time-window. The assigned time-windows are longer than the actual service times, allowing overlap between time-windows. For this reason, an *assured service start time (AST)* and an *assurance probability* (p_a) is given to each truck, giving the maximum waiting time (AST) for a truck that arrived during its assigned time-window before its loading process starts and the probability of this to happen. Consequently, the actual service sequence might be different from the reserved one. In order to determine the actual loading sequence an Optimization model is developed, which is run every "Y" minutes with updated information of the actual and Estimated Time of Arrival of the trucks, and creates the adjusted schedule for the loading operations. The mathematical formulation of this model is presented in Section 5.4. The concept of this proposed system, to the best of our knowledge, is a topic that has not been researched again in this context. This proposed design with the implementation of time-windows and use of real-time information, for the rest of this report, it will be referred as design *d2*.

The idea of implementing time-windows in a TAS is proposed as it adds flexibility in both sides of the booked timeslot for truck drivers, early and late arrival of truck, in contrast to the one side flexibility, only early arrivals, of the fixed slot design (d1). This extra flexibility is expected to mitigate truck drivers' dilemma and reduce the stress levels that they feel about missing their slot due to unexpected delays, which are two main goals of this research. Also, it is expected to increase carriers compliance to the proposed system. In addition, the update of the trucks' loading sequence based on real-time information is selected as it is a component which can increase the system's responsiveness against truck arrival deviations and disruptions of the real world. Furthermore, the truck's loading sequence update according to their ETAs, can also benefit the truck drivers to reduce significantly their waiting times. Further, terminal's utilization is also expected to be improved from this constant update of the loading schedule compared to the current TAS system (d1). In the rescheduling in the proposed design, all the trucks that are expected to arrive at the plant in the next "V" minutes are considered. Thus, the outcome of this rescheduling is significantly improved, from a system perspective, compared to the current TAS design (d1), as a number of incoming trucks are considered in the rescheduling. The information about the truck ETAs derives from data obtained from the integration of logistics and traffic systems.

The main design parameters of the proposed design (d2) are described. Firstly, it is the *session time (x)*, which shows the indicative start time that it is assigned to a particular customer (truck) and represents the middle of the time window. Then is the *session Length (l)*, which shows the duration of the available time window, during which a customer can be serviced with an assurance probability p_a in maximum AST minutes. So, the time window for a truck is defined as [x-l/2, x+l/2]. Following the *assurance Probability (p_a)* shows the probability, for a truck which arrives during its booked time window, to be served before the end of assured service start time (AST). Finally, *assured service start time (AST)* shows the maximum waiting time before the truck's service will start with a probability of p_a. Of course, this parameter is valid only for trucks that arrive during their booked time window. In Figure A-2 an overview of these design parameters is given.

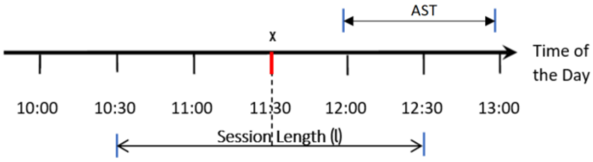


Figure A-2: Proposed TAS (d2) for a booked slot at 11:30 and arrival time at 11:55, with illustration of the design parameters Session Length (l) of 2 hours and Assured Service time (AST) of 1 hour

Finally, an example of the truck drivers' perspective on the proposed system (d2) and the currently used (d1) TAS, based on Figure A-3 is given. Truck driver (t9) has booked a slot for 11:30. In the current design (d1), truck driver is expected to arrive, a few minutes before the booked slot. In contrast, in the proposed design (d2), assuming a time window of 2 hours and an indicative time at 11:30, the truck driver can arrive at the terminal from 10:30 till 12:30 and get through the gates and start the loading process at most after AST minutes. This shows the high flexibility, in both ways that the proposed system (d2) has in contrast to the current design (d1), where the service happens strictly based on the order of the booked appointments and late arrivals lead to no service for those trucks.

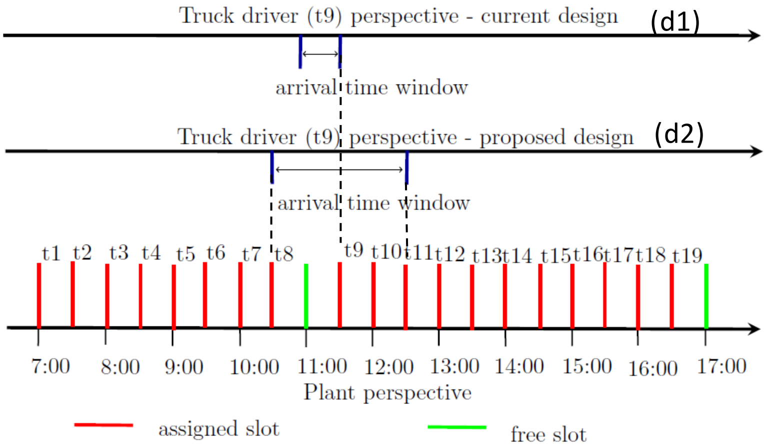


Figure A-3:Current (d1) and Proposed (d2) TAS for a booked slot at 11:30 - Comparison regarding the flexibility of truck drivers' arrival so that they do not miss their slot

5 Optimization Model

5.1 Problem Description

The problem that this optimization model aims to address is the (re)scheduling of the incoming trucks at the chemical plant for the proposed TAS design (d2) with the use of time-windows.

In more detail, the objective of this optimization model is to determine the trucks loading sequence and loading bay assignment based on their ETAs and promised service time while minimizing the total cost. The total cost consists of two parts, the total weighted cost, resulting from the weighted average of all trucks waiting time, and the penalty cost of not servicing on-time trucks during their assured service start time (AST). Also, it is important to point out that the trucks considered in the (re)scheduling are trucks that are near or at the plants, this information is obtained based on their ETA and real-time location, as the ETA's accuracy for trucks far from the plant decreases significantly.

5.2 Problem Requirements

The requirements for this study's model are specified in this paragraph. To start with, all trucks that arrive at the chemical plant have to be served, yet with different priorities assigned to them based on their arrival time at the chemical plant, high priority is given to trucks that arrive during their booked time-window while low priority is given to the trucks that arrive outside of it. Also, a maximum waiting time limit, TL, before their service starts is determined for all trucks. Further, all trucks can be rescheduled based on their ETA and real-time information. In addition, each (re)scheduled truck must be assigned to a loading bay where the requested product type is available, as not all loading bays serve all product types. Moreover, trucks can enter a loading bay immediately when it is idle, as flexible service start times are used in the proposed model. Finally, at each loading bay only one truck can be served at a time.

5.3 Model Assumptions

The main assumptions for the development of the proposed optimization model are presented. These assumptions are that trucks without reservation (booked appointments) are not considered. Also, the real-time location of trucks is considered to be known, and through the integration of logistics and traffic systems the Estimated Time of Arrival (ETA) for each truck is obtained. For the purposes of this study, the ETA information for each truck is considered available and it is an input to the model. In the proposed model the ETA value is handled as deterministic, and its stochastic nature is ignored. Further, each truck can carry only 1 Product Type. In addition, loading bays setup times between the service of different trucks are zero, as at each loading bay there are specific pumps and lines for each product type thus there is no need for cleaning or modifying anything between the service of trucks. Furthermore, jobs are considered non-preemptive, meaning that when the loading process of a truck starts it cannot be interrupted until it has been finished. Besides, a theoretical cost DC, named penalty cost, for not serving a truck during the promised service time-window, is estimated, and used for the formulation of the objective function. Additionally, process times, like gate time, weighting time, loading time etc., are known and are handled as deterministic in the proposed model. Moreover, maintenance and equipment failures are not considered in this model. The earliest loading start time on each loading bay is considered known at the time of rescheduling. Finally, arrival time window and service time window are fixed and have the same duration for all trucks.

5.4 Mathematical Formulation of the Model

From the different models described in the Literature Review, that developed by Hung et al. (2017) is considered the most related to this work, and thus applicable to be used as the base for developing of this research's mathematical model. Consequently, the Mathematical formulation of the proposed Optimization model, was developed based on their model, and is presented here.

Indices

- i, j : Truck – Job
- *l* : Loading Bay

Sets

- L : Set of loading bays, L = *{l_1, l_2, …, l_{NL}}*
- I : Set of Trucks (and Jobs), I = *{i_1, i_2, …, i_{NT}}* (That need to be Rescheduled)
- Î : Set of Trucks that arrived during their assigned time-window (on time) Î⊆I, $\hat{I} = \{\hat{\imath}_1,\ \hat{\imath}_2, \dots,\ \hat{\imath}_{NOT}\}$
- Ï : Set of Trucks that arrive outside their assigned time-window Ï⊆I
- WIP : Set of Works In Progress (WIP) – trucks that are being serviced at the time of the rescheduling. This set includes also artificial jobs for the cases where a loading bay is empty. WIP = *{w_1, w_2, …, w_{NL}}*

Parameters

- ETA_i : Expected Time of Arrival at the plant of truck i (updated in real time)
- R_{li} : Loading Bay (l) and Truck (j) mapping based on the product type
- CTW_i : Completion Time of Works in Progress i
- LW_i : Loading Bay that WIP i is assigned to
- NL : The Number of Loading bays
- NT : The number of Trucks to be rescheduled
- NOT : The number of On-time Trucks to be scheduled
- S_l : The service time at loading bay l, $l \in L$ [min]
- AST : The Length of the Assured Service Time-Window [min]
- TL : The Maximum waiting time for trucks arriving outside their assigned time window
- CurTime: The current time – the time that that the reschedule occurs/ is triggered
- M : Large Number (ex. 9999)
- DC : Penalty Cost for not serving On-Time Trucks during their AST (Delay Cost)
- a, b : parameters for the weighted average of the objective function

Decision Variables

- X_{il} : $\begin{cases} 1, \ if\ truck\ i\ is\ assigned\ to\ loading\ bay\ l \\ 0, otherwise \end{cases}$
- Y_{ij} : $\begin{cases} 1, \ if\ job\ i\ immediately\ precedes\ job\ j\ on\ the\ same\ machine \\ 0, otherwise \end{cases}$
- CT_i : The Completion Time of job i - Continuous Variable

Auxiliary Variables

- OTN_i : $\begin{cases} 1, \ if\ service\ of\ the\ on-time\ truck\ i\ starts\ later\ than\ \ AST\ window \\ 0, otherwise \end{cases}$

Objective Function:

$$Minimize \quad Z\!:\ a * \sum_{i \in \hat{I}} \left(CT_i - \ ETA_i - \sum_{l \in L} (S_l * X_{il}) \right) + \sum_{i \in \hat{I}} OTN_i * DC + \ b * \sum_{i \in \ddot{I}} \left(CT_i - \ ETA_i - \sum_{l \in L} (S_l * X_{il}) \right) \ (0)$$

subject to,

$$\sum_{l \in L} X_{il} = 1\,, \qquad \forall\, i \in I \qquad (1)$$

$$X_{il} \leq R_{li}\,, \qquad \forall\, i \in I, \forall\, l \in L \qquad (2)$$

$$\sum_{i \in (WIP \cup I)} Y_{ij} = 1\,, \qquad \forall\, j \in I \qquad (3)$$

$$\sum_{j \in I} Y_{ij} \leq 1\,, \qquad \forall\, i \in (WIP \cup I) \qquad (4)$$

$$Y_{ij} = 0\,, \qquad \forall\, i \in (WIP \cup I), \forall\, j \in WIP \qquad (5)$$

$$Y_{ij} \leq 1 - \left(X_{il} - X_{jl} \right), \qquad \forall\, i \in (WIP \cup I), \forall\, j \in I\,, \forall\, l \in L \qquad (6)$$

$$Y_{ii} = 0\,, \qquad \forall\, i \in I \qquad (7)$$

$$CT_j \geq CT_i + \sum_{l \in L} \left(S_l * X_{jl} \right) + M * \left(Y_{ij} - 1 \right), \qquad \forall\, i \in (WIP \cup I), \forall\, j \in I \quad (8)$$

$$CT_{w_i} = CTW_{w_i}, \qquad \forall\, w_i \in WIP \qquad (9)$$

$$CT_i \geq \sum_{l \in L} (S_l * X_{il}) + ETA_i\,, \forall\, i \in I \quad (10)$$

$$CT_i \geq CurTime\,, \qquad \forall\, i \in I \qquad (11)$$

$$CT_i - ETA_i - \sum_{l \in L} (S_l * X_{il}) \leq TL\,, \qquad \forall\; i \in I \qquad (12)$$

$$CT_i - AST - ETA_i - \sum_{l \in L} (S_l * X_{il}) \leq M * OTN_i\,, \qquad \forall\; i \in \hat{I} \qquad (13)$$

$$X_{w_i\, LW_i} = 1\,, \qquad \forall\, w_i \in WIP \qquad (14)$$

$$CT_i - \sum_{l \in L} (S_l * X_{il}) \geq CurTime\,, \qquad \forall\, i \in I \quad (15)$$

$$X_{il} \in \{0, 1\}\,, \qquad \forall\, i \in (WIP \cup I), \qquad \forall\, l \in L \quad (16)$$

$$Y_{ij} \in \{0,1\}\,, \qquad \forall\, i \in (WIP \cup I), \forall\, j \in (WIP \cup I) \; (17)$$

$$OTN_i \in \{0,1\}\,, \qquad \forall\; i \in \hat{I} \qquad (18)$$

$$CT_i \in N, \qquad \forall\, i \in (WIP \cup I), \qquad (19)$$

The aim of the objective function (0) is to minimize the total weighted cost resulting from the waiting time of all on-time arriving trucks, the waiting time of all trucks that arrived outside their booked time-window and the penalty cost (time) for not serving an on-time truck during their AST. It should be noted that the units of the penalty cost (DC) are minutes. Constraint (1) ensures that each truck is assigned to exactly one of the loading bays. Constraint (2) enforces each truck to be assigned to a loading bay where the requested to transport product is available. Constraints (3), (4) and (5) are sequence constraint. In more detail, constraint (3) ensures that each truck that does not belong in the WIP set has to follow exactly one truck.

Constraint (4) guarantees that each truck (job) is followed by 1 truck (job) at most. While constraint (5) enforces that no truck (job) can be scheduled before a starting (artificial) job or a WIP and that a starting truck (job) cannot follow any other truck. Constraint (6) ascertains that only when trucks (jobs) i and j are processed on the same loading bay can sequence variable Yij be equal to 1. This constraint is based on the work of Omar and Teo (2006). Constraint (7) imposes that each truck is served once in a loading bay or similarly that a truck cannot follow itself and be served again in the same loading bay. Constraint (8), ensures that the completion time of truck (job) i is less than or equal to the start time of truck (job) j when both trucks are assigned to the same loading bay and truck i immediately precedes truck j. Constraint (9) assures that the completion time of all WIP trucks (jobs) is equal to the time that their service is expected to have finished, estimated based on the available information of their start time. Constraint (10) determines that the Completion time of each truck (job) is greater than or equal to its service (processing) time on that loading bay plus its (truck's) arrival time at the plant. Constraint (11) bounds the service completion time of a truck to be greater than the current time of the (re)scheduling. Constraint (12) restricts the maximum waiting time until the service starts for all trucks at TL minutes, from their arrival time. Constraint (13) enforces auxiliary variable OTNi to get the value 1, when the waiting time for service of an on-time truck exceeds the AST minutes. Constraint (14) assigns all starting trucks $\in WIP$ to the loading bay that they are being serviced at the time of the (re)scheduling. Constraint (15) ensures that the service start time of truck i is greater or equal to the time that the (re)scheduling occurs. Finally, constraints (16), (17) and (18) are binary variable constraints while constraint (19) defines the natural decision variable Completion Time (CT_i).

5.5 Model Verification

Model verification is performed in order to confirm that the developed model has been implemented and works correctly with regard to the conceptual model. It is remarked that the mathematical model, presented previously, has been implemented in Java and is solved (optimized) with the use of GUROBI, a commercial solver. Various scenarios have been developed and tested in order verify the model's performance. However, for briefness in this section only two simple verification scenarios are presented, as the verification of these scenarios is performed manually, by comparing the optimization model's output with the logical scheduling of trucks.

Verification Scenario 1: Truck with lower priority arrives first at the plant
In this scenario, 1 loading bay and 2 trucks are considered. Truck 1 arrives 5 minutes earlier than truck 2, but outside its assigned time window, thus it has Low service priority. While the truck 2 arrives during its assigned time window, so it has high service priority. WIP jobs are not considered, and both jobs are eligible to be performed in loading bay 1. Consequently, it is expected that truck 2, as it has higher priority, will be serviced first and when its service finish, truck 1 will be serviced. The outcome of the optimization model is the same as expected.

Verification Scenario 2: 2 loading bays and 2 trucks
In this scenario 2 loading bays and 2 trucks are considered, with truck 1 arriving outside its assigned time window 5 minutes earlier than truck 2 which arrives during its assigned time window. WIP jobs are not considered, and truck 1 can be serviced in both loading bays while truck 2 can only be serviced in loading bay 1. It is expected that the objective value in this scenario is going to be zero, as there are no WIPs and 2 loading bays available, and the truck 2 must be assigned to loading bay 1, and consequently truck 1 should be assigned to loading bay 2. Truck 1 should be assigned even though it has arrived outside its time window as there is an idling loading bay and there is no other truck with high priority waiting to be served. The

outcome of the optimization model is as it was expected, with truck 1 assigned to loading bay 2, truck 2 assigned to loading bay 1 and objective function having a value of 0.

6 Simulation Model

6.1 Simulation Model

The aim of this research is to examine the effect of the proposed TAS design (d2) on the performance of the loading operations at a chemical plant. In order to investigate the added value of the proposed system it needs to be compared with the current loading operations of the chemical plant. However, the field of logistics is stochastic rather than deterministic, as all processes have an inherent uncertainty for instance the travel time, the occurrence of congestion, the loading duration etc (Van Den Brink, 2023; Vanga et al., 2022). Also, the size of the system under study and the interaction between its components make its representation even more complex and hard. Consequently, simulation is the chosen modelling method for the representation, understanding and analysis of the system studied here. Moreover, simulation is an exceptional tool for analyzing the operational level of a system, which is the level that this research focuses on (Van Den Brink, 2023).

The simulation model developed in this study is based on an existing simulation model, created by Vanga et al. (2022), for the same Chemical Plant as studied here. A few modifications were needed in order to represent the operations of the proposed TAS in the simulation model. These required changes are related to modifications of some simulation components, adjustments to some operational constraints (rules) and the integration of the proposed rescheduling model. The main characteristics of the system under study have been described in System Description section and form the base for the development of this research's Simulation model.

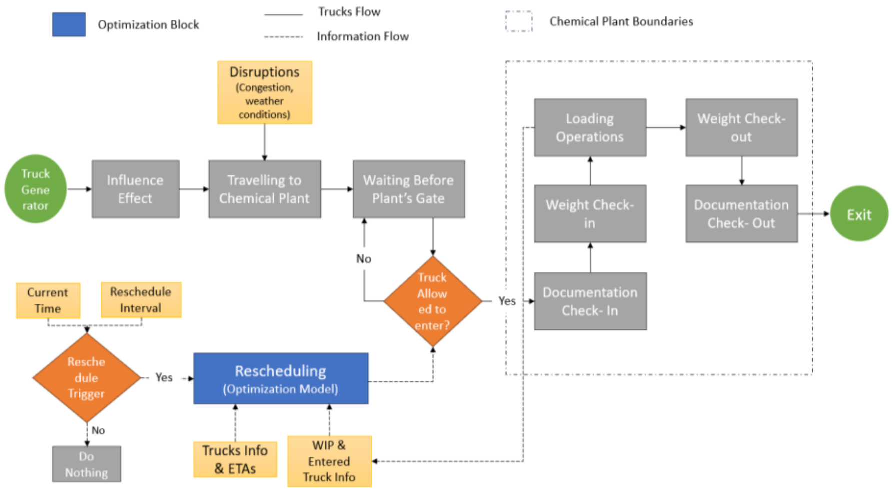


Figure A-4: Process Flow Diagram of Plant's Loading System for the Proposed Design (d2)

The Simulation's model description, based on the process flow diagram shown in Figure A-4, begins with the system's source, namely Truck Generator, which generates the trucks (entities). This module specifies the initial schedule for each day, in more detail the quantity and the time that trucks are created is determined. Also, attributes like product type, originally assigned loading bay, trip origin and booked timeslot are assigned to the trucks. The next module is the Influence Effect, which changes the expected arrival time of trucks that comply with the proposed TAS, so that they can arrive during their assigned time window. This alteration is performed only on trucks that are expected to arrive earlier than their assigned timeslot and that comply to the proposed system, this is performed by delaying their initial's trip start time. This module is necessary as the available trucks arrival data is based on the current situation and TAS, and thus it might not be representative for the proposed system. Furthermore, it is noted that this module is an addition to the existing simulation model developed by Vanga et al. (2022). Succeeding is the Traveling to the Chemical Plant module, which represents the trucks' trip to the Chemical Plant. In this module, the effect of disruptions, like congestion, weather conditions etc., is applied which affects the total travel time. Then, the Waiting Before Plant's Gate resembles the parking area outside the plant's gates. All the trucks that arrive at the plant wait there until they are allowed to enter the plant premises. The entrance order is determined by the schedule which is updated by the Rescheduling module.

The plant operations inside its premises are described by a series of simulation components with each one resembling a process described in System Description section. In more detail, the Documentation Check-In represents the operations performed at the Document Check Point. Following, the Weight Check-in depicts the truck weighting at the scale before getting serviced. While the Loading Operations resemble the actual loading process of the truck and the possible waiting time before the loading bay, if it is still occupied. Then, the Weight Check-out portrays the weight of the truck at the scale after the end of its service, used in order to calculate the total amount of product loaded on that truck. Succeeding, the Documentation Check-Out module represents the paperwork performed in the Documentation Check Point before a truck can leave the plant. It is noted that the duration of these processes, in the simulation model, are stochastic. The value of the process duration for each truck is sampled from the data provided by the chemical plant, except Documentation Check-in which has a fixed value. Finally, after the completion of the Documentation check-out process the trucks leave the plant premises and go to the sink module, Exit, and exit the simulation model. The last module of this process flow diagram that has not been discussed yet, presented in Figure A-4, is the Rescheduling module. This module is triggered by the predetermined Rescheduling interval. The activation of the Rescheduling module makes the developed optimization model, to run and determine a new optimal schedule with inputs the truck ETAs, the WIP and the information of the trucks in the plant. Further, in the aforementioned process flow diagram, trucks flow is represented with a continuous black line while information flow is depicted with a black dotted line. Finally, this Simulation model is developed in the AnyLogic software with the use of Discrete Event Simulation.

6.2 Model Assumptions and Simplifications

The main assumptions and simplifications for the development of this Simulation model are presented. To start with, the assigned timeslot to a truck represents the time that the truck is expected to enter the plant and not the time that its service at the loading bay will start. Also, trucks that arrive earlier than the start-time of their assigned time-window, are considered Delayed, and not only those which arrive after the end of their assigned time-window. Further, Documentation time In, has a fixed value of 5 minutes and not a value sampled from the available data as the other processes. Moreover, it should be noted that only the last 5 hours of trucks trip to the plant are considered in this Simulation model, which is considered sufficient as the quality of the ETA prediction is lower the further away a truck is and the rescheduling of faraway truck does not have any added value. Also, in this model trucks without prior booked appointments are not considered, as in practice trucks do not arrive to the chemical plant without prior appointment reservation. In addition, in the Simulation model, for every day that is simulated the following (next) day is left idle, meaning that no trucks are initially scheduled for that day. During this idle day, only the remaining trucks at the end of the actual simulation day can be assigned to. This design choice is explained by the fact that the initial schedule, for each simulation day, is created at the beginning of each day, thus the schedule for next day is unknown beforehand. Consequently, the scheduling of trucks that cannot be served on their day of arrival, as the plant closes at night, cannot be rescheduled for the next day, as the schedule for that day is unknown, unless it is an idle day. Lastly, it is noted that this assumption will have a negative effect on the used KPIs.

6.3 Integration of Optimization Model in the Simulation

The developed optimization model needs to be implemented in the Simulation model to test the effectiveness of the proposed system, since this optimization (rescheduling) model is a core component of the proposed TAS design (d2). The developed optimization model has been implemented in java and is optimized with the use of Gurobi, a commercial Mixed Integer Linear Programming (MILP) solver. Moreover, the Simulation model created for this research in AnyLogic is coded in java too, thus there is compatibility between these two models as they are both developed in the same programming language. Further, the Gurobi solver is integrable into the AnyLogic software. Consequently, the integration of the Optimization Model in the Simulation is possible. Finally, the triggering condition of the rescheduling has to be defined, this is modeled with a state module in which inputs are the current time and the rescheduling interval. When the rescheduling time condition is fulfilled the optimization model is solved with the use of Gurobi and a new (updated) loading schedule is created. Based on this new schedule trucks loading sequence is updated.

6.4 Input Data

The input data for this research is the same as Vanga et al. (2022) have used in their work and it has been obtained from the Chemical Plant studied here, representing the plant's operations for 70 workdays between November 2021 and March 2022. In this data set there is information about the products demand, the trucks reservations in the current TAS, rescheduling information, truck origins, truck timestamps while performing different activities in the plant and more.

6.5 Verification and Validation

Verification and validation of the developed Simulation model are performed in order to prove its credibility, similarly to the Optimization model. The Simulation model is based on the model of Vanga et al. (2022) which is a verified and validated model. However, as some modifications were performed on that model further Verification and Validation is required. For the model verification the tracing method was used. To implement this method various print statements were added in different modules and processes of the model while keeping track of the simulation time. Based on these print statements and the created visual representation of the system, the model's process flow logic and methods expected function were tested. A wide range of experiments were conducted in which different trucks were tracked to verify the model's formulation. The validity of the developed model was examined using four out of the validation techniques suggested in the literature by Sargent (2010). The Animation technique was used as in the simulation model there is a graphical representation of the trucks while they are in the simulated system. Comparison to Other Models was implemented as the results of the developed simulation model were compared to the already validated model developed by Vanga et al. (2022). Furthermore, Face Validity on this new Simulation model was performed by the Postdoctoral Research Ratnaji Vanga, who was the main developer of the Simulation model on which this research's Simulation model was based. Also, Operational Graphics technique was used by obtaining and assessing during the model's run the values of some performance measures to assure the model's proper behavior. Finally, Traces methodology was applied by following the behavior of different trucks (entities) through the model and aiming to prove if the model's logic is right and if the accuracy is satisfactory. The aforementioned tests provided credible evidence that the developed simulation model was built as intended (Verified) and that it represents properly the real-world system (Validated).

7 Experiments

7.1 Base Case Scenario Definition

For the assessment of the proposed TAS design and the comparison with the current TAS design, a Base Case Scenario is defined. The Base Case scenario forms the base on which the two TAS designs are assessed and ascertains that the conditions under which both systems are tested are the same, so that their comparison is fair. This means that demand, congestion and delay levels, but also trucks' service times and terminal's characteristics have the same values in both simulations.

The values of the parameter for the Base Case Simulation model are presented in this section. Initially, the values of the processes' duration in the chemical plant for a truck are determined. It should be noted that only the Documentation Time In process has a fixed value, as it has already been explained. While, for the other processes, namely Weight Check In, Service Time, Weight Check Out and Documentation Time out, the values are sampled for each truck from the obtained historical data of the studied Chemical Plant. This data has been briefly described part 6.4. Thus, for the proper (fair) comparison of the two TAS designs, the process times at the chemical plant of each truck in both TAS configuration simulations must be the same. Consequently, in order to achieve this in the Simulation model the trucks and their assigned process times are duplicated in the model before they start their trip to the chemical plant. In this way, two trucks with the same process times, for all processes in the chemical plant, and delays head to the two different TAS configuration systems.

Finally, the parameters values of the plant characteristics are specified. The studied chemical plant has 6 loading bays, and it operates from 6:30 till 21:30 every day. It is remarked that from the 110 available timeslots during the plant's open hours, the 1st and 2nd loading bays have each 15 available slots while the rest loading bays have 20 each. Also, per loading bay there are 3 buffer slots available besides the aforementioned ones, which make the total number of available timeslots per day 128. Further, the service time of loading bays 1 and 2 is considered 60 minutes while for the rest loading bays is considered 45 minutes.

7.2 Current Truck Appointment System (TAS) Configuration

In this section, the configuration of the current TAS design (d1) for the simulation is determined. The TAS design (d1), which is currently implemented in the chemical plant under study, is a typical TAS in which real-time information and ETAs estimations are not available. Also, in this TAS design the daily available slots are not flexible and if a truck arrives late, it misses its slot. Furthermore, rescheduling is performed only for the delayed trucks, and it is executed manually either by the carriers or the plant's slot manager. In this rescheduling only the delayed truck is considered and usually the truck is assigned to the earliest available slot in which the product that the truck needs to transport can be served. Consequently, there are not any TAS specific parameters to be defined for this design's configuration as this design, especially the rescheduling, is relatively simple.

7.3 Proposed Truck Appoint System (TAS) Configuration

In this section, the values of the parameters for the proposed TAS design (d2) configuration used for the simulation are illustrated. Initially, the parameters of the developed Optimization model are defined. The assured Service Start Time has a value of 30 minutes, while the weight factors, a and b, of the objective function have a value of 1 and 0.01 respectively. The penalty cost (DC) has a value of 1 minute and the service time for loading bays 1 and 2 is 60 minutes while for the rest is 45 minutes. Finally, the Maximum Waiting Time (TL) is set at 480 minutes. Following the value of the Probability of Influence is determined. This is the only Simulation model parameter whose value is defined irrespectively to the Base Case scenario, as it is related only to the simulation of the proposed design. The Probability of Influence has a range from 0% to 100% and demonstrates the acceptance of the proposed system by the trucking companies. For this configuration the value of the Influence Factor is chosen to be 100%, meaning that all truck drivers are complying with this research's proposed TAS.

Subsequently, the values of the main design parameters for the Proposed TAS design (d2) are determined. The time-window length has a range of values from 30 minutes to 4 hours, and in this configuration is set at 120 minutes (2 hours). While for Rescheduling Frequency, a logical range of rescheduling time is considered between 15 and 45 minutes, and it is set here at 30 minutes. Moreover, Trucks ETA for rescheduling parameter represents the trucks which are considered in the rescheduling, therefore only trucks that have arrived at the chemical plant or have an ETA of less than Z minutes are considered in the rescheduling, and in this configuration is set at 30 minutes.

8 Results and Discussion

8.1 Comparison between Current and Proposed TAS designs

In this section the comparison between the two TAS designs, Current (d1) and Proposed (d2), is conducted. These two systems' performance on the Base Case scenario is compared. Both designs are Simulated for a period of 6 months, during which the model's outputs are collected and the KPIs are calculated. It is worth noting that during this 6-month simulation period, approximately 6630 trucks were generated in each case, Current and Proposed. The evaluation of the performance of the different TAS designs is done based on the KPIs, which namely are the Gate Waiting Time (KPI 1), Slot Utilization (KPI 2) and Finish Time (Makespan) (KPI 3). The values of the obtained KPIs values are presented in the tables and figures below.

	Current		**Proposed**	
KPI 1 – Gate Waiting Time [min]	91.63 (110.92)		5.02 (41.17)	
KPI 2 – Slot Utilization	Theoretical	Actual	Theoretical	Actual
	0.655 (0.093)	0.325 (0.050)	0.654 (0.102)	0.330 (0.054)
KPI 3 – Makespan [min]	1689.63 (280.55)		1530.97 (276.86)	

Table A-1: KPIs Analysis between Current and Proposed Design. Mean value and standard deviation in the parenthesis (N=6630 trucks)

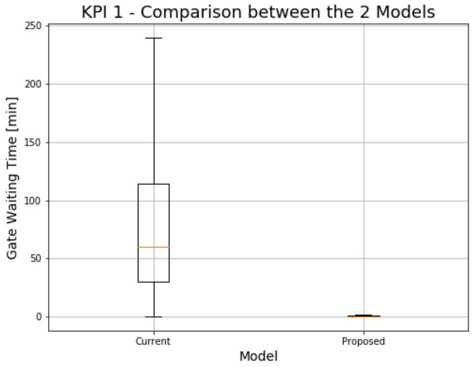


Figure A-5: KPI 1 - Gate Waiting Time, Comparison between Current and Proposed TAS Design

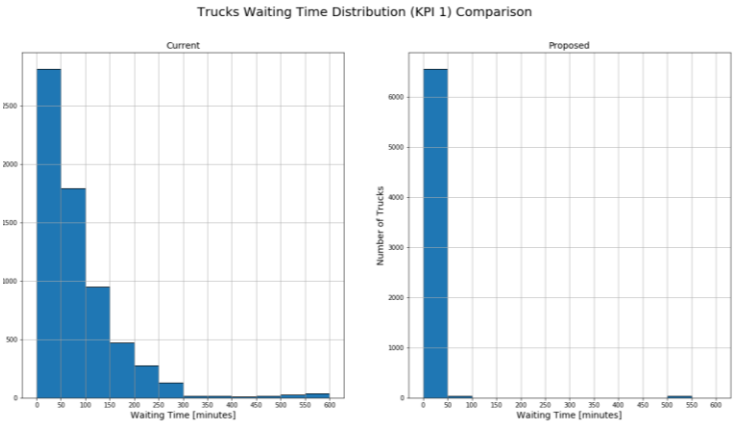


Figure A-6: KPI 1 - Trucks Waiting Time Distribution for the Current and the Proposed TAS design

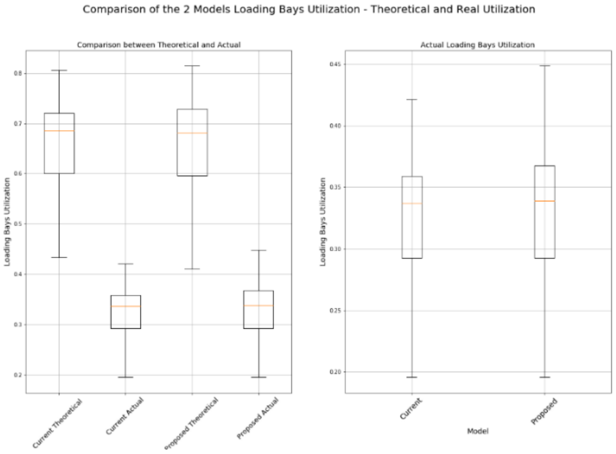


Figure A-7: KPI 2 - Theoretical and Actual Loading Bays Utilization, Comparison Current and Proposed TAS design

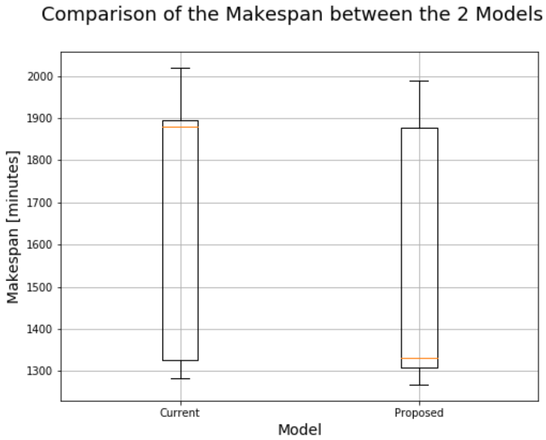


Figure A-8: KPI 3 – Makespan, Comparison Current and Proposed Scenario TAS design

Based on the KPI values obtained from the simulation, presented in Table A-1 and Figure A-5 to Figure A-8, it can be deduced that the Proposed system outperforms the Current system. Regarding the trucks waiting time at plant gates (KPI 1), it can be seen that a reduction of around 94.5% on the mean waiting time is achieved, from 91.63 to 5.02 minutes. This significant improvement can also be seen in Figure A-6, in which the trucks waiting time distribution for is presented. Also, the standard deviation of the waiting time in the proposed system is 63% lower compared to the current one. Regarding, the Slot Utilization level (KPI 2), two different methods of calculating this KPI are used. The first one, Theoretical, is determined by sum of the number of trucks served at each loading bay multiplied with the respective service time at that loading bay and divided by the total available service time of the loading bays in a day. While the Actual Slot Utilization is calculated by the sum of all trucks actual service time at the loading bays divided by the total available service time of the loading bays in a day. However, despite the discrepancy between the values of Theoretical and Actual slot utilization, with the Actual Utilizations being nearly half of the Theoretical, the values for the two systems are very similar. Moreover, about the Makespan (KPI 3), the Proposed system seems to be performing better compared to the current one as it has approximately 10% lower mean value, similar standard deviation and lower maximum value. Finally, it should be noted that the value of the Assurance Probability (Pa) has a mean value of 98.4% and standard deviation of 0.015, meaning the 98.4% of all trucks that arrived during their time-window, during the 6-month simulation period, were served during their Assured Service Start Time (AST).

8.2 Sensitivity Analysis

After the comparison of the two TAS designs, a sensitivity analysis on the effect of the Influence Factor, acceptance of the proposed system by the carriers, on the prosed system's performance is conducted. Influence Factor represents the percentage of trucks (carriers) that comply with the proposed TAS. For the trucks that comply with the proposed system, if their arrival time at the plant is expected to be earlier than the start of their time-window, their initial's trip start time is delayed so that they can arrive at the plant during their assigned time-window. However, this arrival time alteration is not considered possible for complying trucks that are expected to arrive after the end of their time-window, as it is assumed that the factors which delayed their arrival are out of their control. The values of the models' parameters for the sensitivity analysis are the same with those described previously for the proposed model and the Base Case definition, except the Influence Factor. For this parameter 6 different levels have been chosen to be tested, from 0% to 100% with a step of 20%. Aim of this sensitivity analysis is to examine the effect of Influence Factor on the Proposed System's performance. This knowledge is important for the practical implementation of this system and the determination of the critical (minimum) acceptance percentage for the successful implementation of the proposed system. The Simulation model is run for a period of 6 months for each Influence Factor level, similarly to the comparison of the two TAS designs, and approximately 6630 trucks are generated for each level. During this simulation period the model's outputs are collected and the KPIs are calculated. The effect of the Influence Factor on the proposed system's performance is analyzed based on the main KPIs. The values of these KPIs are presented in the tables and figures below.

	Influence Factor Level					
	0%	20%	40%	60%	80%	100%
KPI 1 – Gate Waiting Time [min]	13.707 (52.106)	12.742 (56.378)	11.498 (55.303)	8.432 (46.475)	6.503 (46.727)	5.018 (41.168)
KPI 2 – Slot Utilization (Actual)	0.330 (0.053)	0.328 (0.051)	0.329 (0.053)	0.331 (0.052)	0.328 (0.054)	0.330 (0.054)
KPI 3 – Makespan [min]	1468.15 (265.21)	1579.62 (298.42)	1601.56 (293.03)	1533.75 (278.39)	1513.13 (274.36)	1530.97 (276.86)
Pa – Assurance Probability [-]	0.967 (0.026)	0.977 (0.021)	0.977 (0.019)	0.981 (0.015)	0.986 (0.014)	0.984 (0.015)

Table A-2: KPIs and Pa Analysis per Influence Factor Level (Sensitivity Analysis) Mean value and standard deviation in the parenthesis (N=6630 trucks)

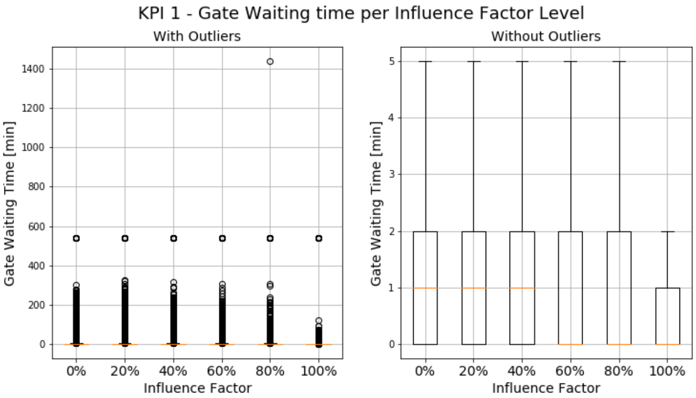


Figure A-10: KPI 1 - Gate Waiting time per Influence Factor Level (With and Without Outliers)

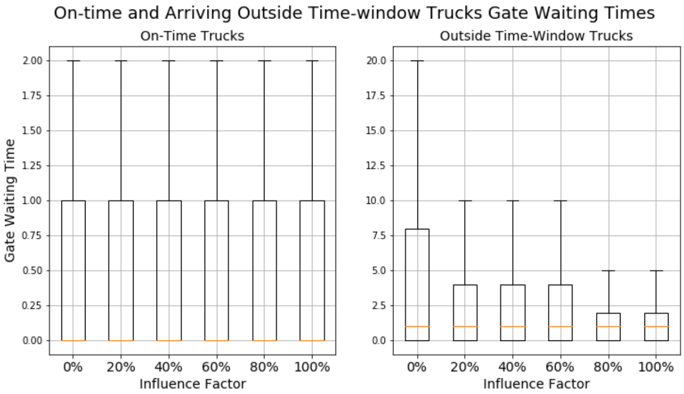


Figure A-9: Analysis of Gate Waiting Time per On-time Trucks and Arriving Outside their Time-windows Trucks

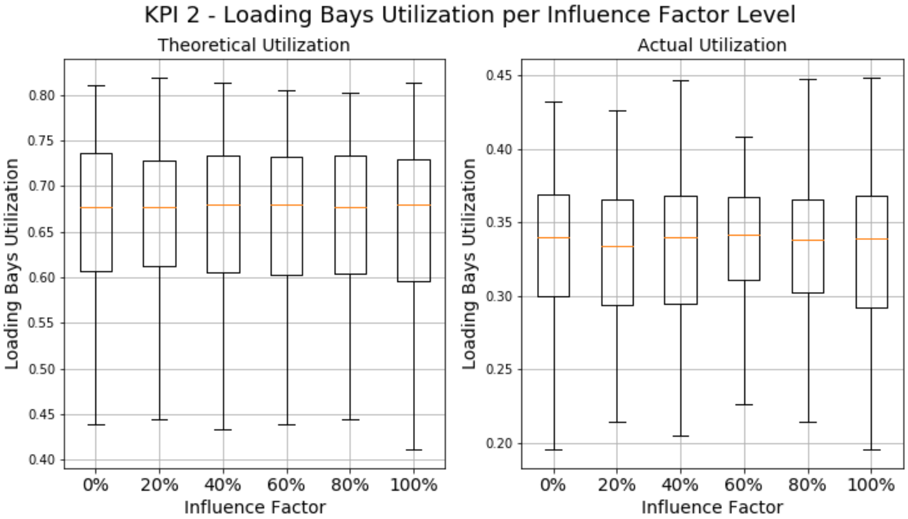


Figure A-11: KPI 2 - Theoretical and Actual Loading Bays Utilization per Influence Factor Level

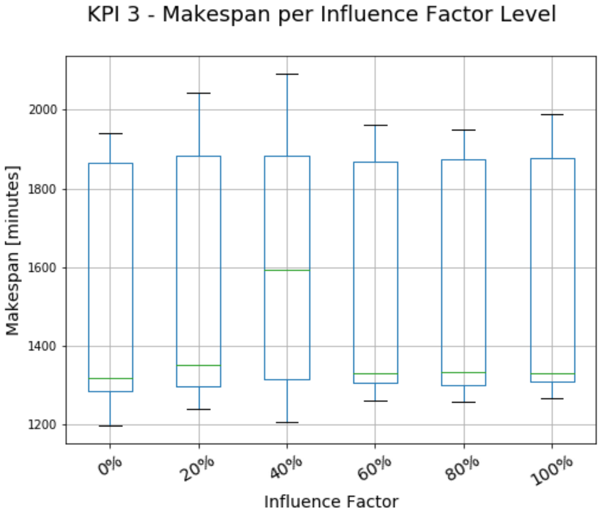


Figure A-12: KPI 3 - Makespan per Influence Factor Level

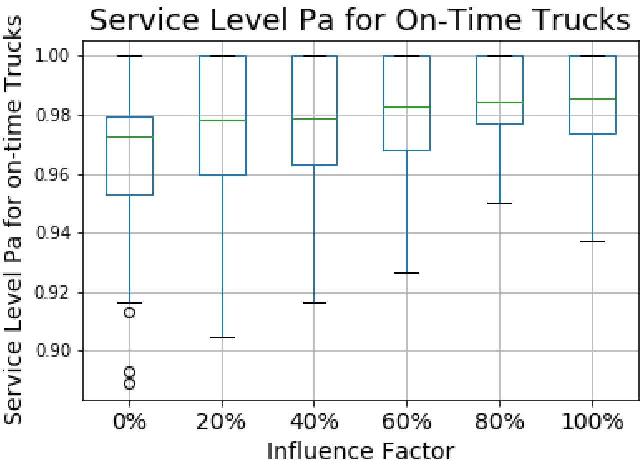


Figure A-13: Assurance Probability – Service Level (Pa) per Influence Factor Level

The effect of the Influence Factor, truck's compliance, on the Proposed System is analyzed based on the KPI values obtained from performed simulations, and they are presented in Table A-2 and in Figure A-10 Figure A-12. From these it can be deducted that the main effect of the Influence Factor is on the trucks Gate Waiting Time (KPI 1), while for the rest KPIs its effect is marginal or none. In more detail, regarding the trucks waiting time at plant gates (KPI 1), it can be seen both from Table A-2and Figure A-10 that the higher the level of the Influence Factor the lower the trucks average waiting time is, with the waiting time of the 100% Influence Level being almost 3 times less than the 0%, 5.02 and 13.71 minutes respectively. Also, as the Influence Factor level increases the standard deviation of the waiting times is slightly decreasing. At last, from Figure A-11 it can be observed that as the Influence Factor level increases the waiting time for trucks that arrive outside their assigned time-window decreases significantly. Furthermore, regarding the Slot Utilization level (KPI 2), it can be noticed from Table A-2 and Figure A-11 that the Influence Factor has no effect on it, both for the Theoretical and Actual utilization level. Besides, regarding the Makespan (KPI 3), based on Table A-2 and Figure A-12 it can be remarked that the Influence Factor seems to have some effect on it, with the 0% level having the lowest mean, standard deviation, and maximum value from all the other levels and the 80% level having the second-best performance. However, the effect of the Influence Factor on KPI 3 is not linear. Finally, it is noted, based on Table A-2 and Figure A-13, that the value of the Assurance Probability (Pa) is improved as the Influence Factor Level increases, as the mean value of Pa is increased, and the standard deviation is reduced. Nonetheless, this improvement is not huge as in the 0% Influence Factor is 96.7% and in the 100% is 98.4%. Thus, all trucks that arrive during their time-window have a very high probability to be served through their Assured Service Start Time (AST) window, irrespective the Influence Factor level.

8.3 Discussion and Reflection

The aim of this research is to develop a TAS with the use of time-windows and real-time information in order to improve the performance of the loading operations at a Chemical Plant, both for the plant owner and the trucking companies. The proposed design was implemented in a simulation model and was compared with the currently used TAS design at the chemical plant under study. Further, a sensitivity analysis on the effect that the proposed system's acceptance, by the carriers, has on the loading operations performance was conducted.

Based on these preliminary results, a significant improvement on system's performance between the proposed and the current system can be noticed, with only exception the loading bays utilization which seems to be the same for both systems. However, more experiments and a small-scale testing of the proposed system in practice would be useful for further justification of the obtained results. In addition, the sensitivity analysis of the Influence Factor Levels demonstrate that the system's performance is quite robust as it is not severely affected by the level of truck drivers' compliance to it. The only exception on this are the waiting times of the trucks that arrive outside their assigned time-windows, whose waiting time is decreased as the compliance level increases. Furthermore, in this research's performed experiments congestion has not been explicitly considered, as its effect on trucks arrival times is already captured by the available data. Moreover, the Assured Service Start Time (AST), even at 30 minutes as it is considered throughout this research, results in a very high Assurance Probability (Pa) of approximately 97% to 98%, depending on the Influence Factor level, for all on-time trucks to start their service during this service time-window. This outcome shows that despite the given time-window of 120 minutes to each truck it is still possible, and with almost 98% assurance probability, to have the trucks service start in a reasonable time from their arrival time at the plant.

Furthermore, as it has already been discussed and to the best of the authors knowledge, at the moment of writing this Master Thesis there is no other published research using of truck specific time-windows in a Truck Appointment System. Thus, this research proposes a new type of TAS which aims at achieving high system performance while overcoming the strict, not flexible and adaptable to disruptions, nature of the TAS. In more detail, four different works proposing new and improved types of TAM systems for the loading operations of a Chemical Plant or a Liquid Bulk (Chemical) Terminal are available, and consequently it is interesting to compare the performance of these different TAS under the same conditions. These TAM systems are the joint-Optimization Model for a TAS, in which the interests of the various stakeholders are accommodated, designed by Wibowo & Fransoo (2020), the Integrated Predictive and Optimization Model with the use of real-time truck ETA information introduced by Prakoso (2021), the use of an Optimization Model and real-time truck ETA data for rescheduling all trucks proposed by Vanga et al. (2022) and the combination of the TAS and the Drop and Swap developed by Van Den Brink (2023). It is worth noting that all these works have been published very recently, between 2020 and 2023. From these systems, those of Prakoso (2021) and Vanga et al. (2022) use as case-study the same Chemical Plant with this research and therefore the comparison of the systems performance is more straightforward. Nonetheless, the comparison with Prakoso's (2021) TAS is not possible as in his study synthetic data was used, while in this research real data from the plant is used. Further, for the comparison between the system proposed by Vanga et al. (2022) and the developed in this research it is remarked that exact comparison, with the use of Statistical Analysis tools, is not possible, as the experiments output data is not available. However, the assessment of these two systems' performance is conducted by comparing the mean values and standard deviations of the KPIs for both systems. From this comparison it is noticed that the proposed system, by this study, has a significantly lower trucks Average Waiting Time, 5.02 minutes compared to the 70 minutes of the other system. In addition, the standard deviation of the trucks waiting time is considerably lower in the proposed system. Moreover, the mean value of the Makespan shows a reduction of around 15% in the proposed system compared to that of Vanga et al. (2022), yet Makespan's standard deviation is notably higher in the proposed system. The difference in the performance, between these two models, is most likely due to the utilization of flexible appointment start times in the proposed system in contrast to the fixed appointment start times used in the system developed by Vanga et al. (2022).

Limitations

For the development of the Optimization and Simulation Models a few assumptions and simplifications were made. To start with, the limited contact with the Chemical Plant's side during the performance of this research is a critical limitation. Thus, their perspective and reflection on the developed models as well as on the assumptions and simplifications that were made is lacking. As a result, the values for some critical parameters were based on the author's understanding of the system and discussion with this thesis supervisors. Furthermore, in this research the contact with the carriers, companies and drivers, was not possible. Consequently, carriers' objectives on this research was based solely in literature review while data was obtained from the chemical plant's side. Further, the maintenance and the failures of the equipment are not considered despite the effect that they can have on the system's performance. Additionally, the data provided by the Chemical Plant represents 70 workdays and while some Covid measures were still in place, thus both demand and congestion levels might not be representative of the typical plant's operation. Also, each truck is considered to be able to carry only 1 Product Type, which might not be the case in the real system, as each truck has several compartments. In addition, and despite the significance of the ETA information for this research, the development of a system for obtaining them is out of the scope of this work. Thus, in the proposed system the ETA information for each truck is considered available for use. Efforts in developing such a system for real-word systems are part of the FTMAAS project, with which this research is associated too. Lastlys, in this research only a single case was examined, which despite the fact that it shows significant improvement in system's performance, it might not be sufficient for generalizing its outcomes.

9 Conclusion and Recommendations

9.1 Conclusion

The objective of this research was to design and assess the performance of a time-window based Truck Appointment System (TAS), with adaptive slot management and the use of real-time ETA information, for the loading operations in a Chemical Plant. Based on the outputs and the KPIs values obtained from the simulation, the performance of the proposed TAS on the objectives of the different stakeholders was evaluated. Furthermore, Sensitivity Analysis on the effect that the Influence Factor – truck's compliance to the proposed system– has on the system's performance was conducted, to gain a better insight and understanding of the system. From the comparison of the two TAS configurations (designs) simulation outcomes, it can be deduced that the Proposed TAS performs significantly better compared to the currently in use TAS, with the biggest improvement noted on the trucks' Gate Waiting Time (KPI 1). Regarding the effect of the proposed TAS with time-windows on the stakeholders, for the Chemical Plant the relevant KPIs are the Slot Utilization (KPI 2) and the Makespan (KPI 3), which show no and a 10% improvement, respectively, compared to the currently use TAS. Also, the effect of the Influence Factor on them is zero and marginal respectively. Regarding, the Carriers and the Authorities the related KPI is the Gate Waiting Time (KPI 1), which appears to have the highest improvement compared to the current TAS, as a reduction of around 94.5% on the mean waiting time is achieved, from 91.63 to 5.02 minutes, and its standard deviation decreased by 63%. Further, this KPI is affected positively by the Influence Factor, as the Gate Waiting Time is reduced as the compliance to the proposed system increases. Finally, it is worth noting that in the proposed TAS design, there is not a trade-off on the performance of the different KPIs, meaning that the improvement of one does not result in a deterioration of the others.

Furthermore, based on this research's outcomes it can be concluded that a less strict TAS, compared to the typical one, can improve significantly the system's performance. In addition, these results dictate that some of the severe problems that logistics terminals, like chemical plants, face due to congestion and trucks arrival uncertainty, can be notably improved with the proposed design. Specifically, the remarkable reduction of trucks' average waiting time has a positive effect on the reduction of truck queues length at the plants gates, as well as the number of trucks waiting with their engines idling in the parking area. Also, congestion around logistics sites can be reduced as the number of trucks waiting on the roadside and in queues, affecting the roads flow, will be diminished. Additionally, the reduction of trucks' waiting times increases their Utilization, as their turn-around time is decreased, and reduces their fuel consumption, as they wait for shorter time with their engines idling. Moreover, the environmental footprint of the loading facility -estimated indirectly from the trucks Gate Waiting Time (KPI 3)- is expected to be significantly improved. Indeed, trucks waiting outside the plant's gate or in queues in order to get into the plant are considered in the literature to have a significant contribution on the terminal's environment footprint. Thus, as air pollution and congestion are expected to be reduced the livability of the terminal's surrounding area will be improved. Lastly, the flexible start-times, of the proposed TAS design, improve significantly the system's resilience against the trucks' arrival time uncertainty.

9.2 Recommendations for Further Research

The preliminary results of the proposed TAS appear to be very promising. Consequently, further research is required in order to establish the benefits of this TAS. As this system has been designed to improve system's resilience against disruptions it is critical to be tested under different congestion scenarios and assess its performance. This is even more important as the construction work on Antwerp's Ring Road is expected to begin and thus to increase the congestion. Also, sensitivity analysis regarding the effect of increased demand on the system's performance is another intriguing topic. Moreover, the research of possible correlations between the different parameters of the proposed TAS, namely Assured Service Start Time, Assurance Probability and Session Length, is another interesting topic, as a better understanding of the system parameters and the effect they have on the system's performance can be obtained. Finally, the acceptance and the effect that this system is expected to have on the truck drivers is also a fascinating topic for research as it will also give an indication of the actual compliance level from their side to the system.

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Appendix B

In this section some screen captures from the simulation model, while it is running, are presented. These screen captures are used to show the values of some performance measures, like the number of trucks waiting at the plant's gates, the number of trucks that are being served, the number of trucks in the plant, etc., which are used for the operational graphics validation of the simulation model.

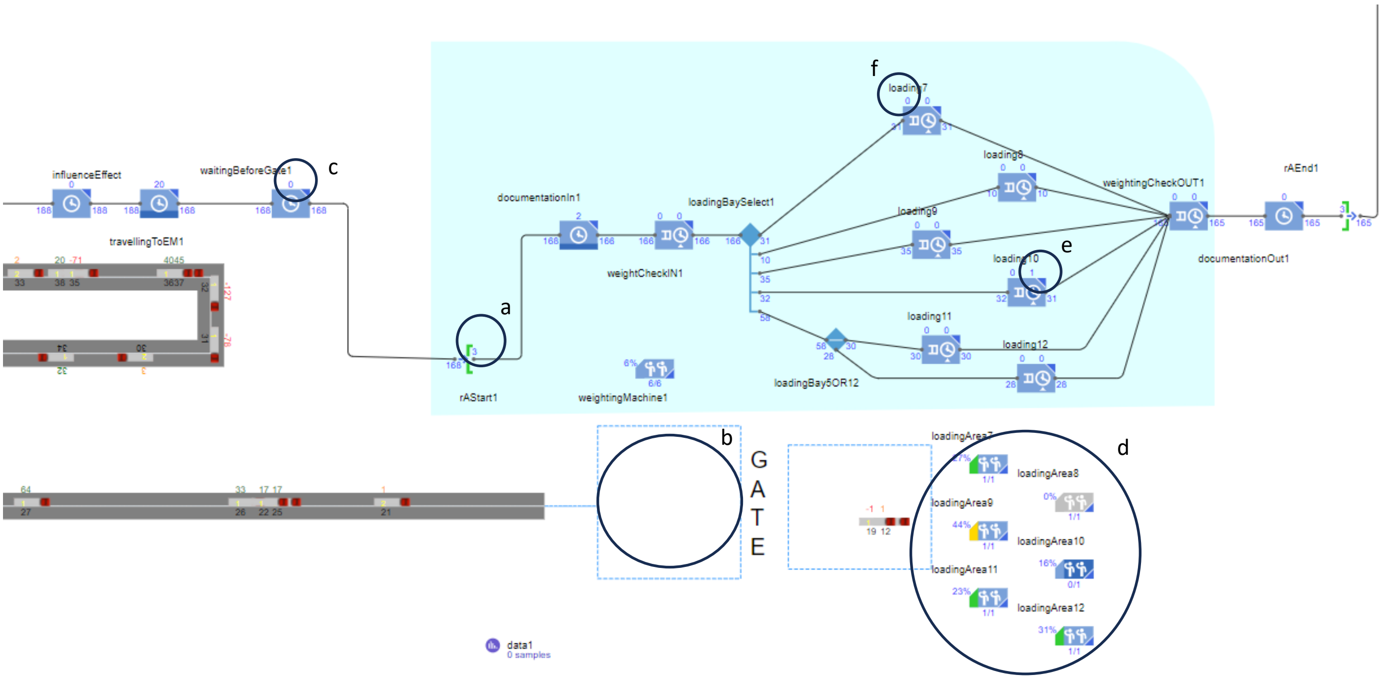

Figure B-1: Operation Graphics Validation example

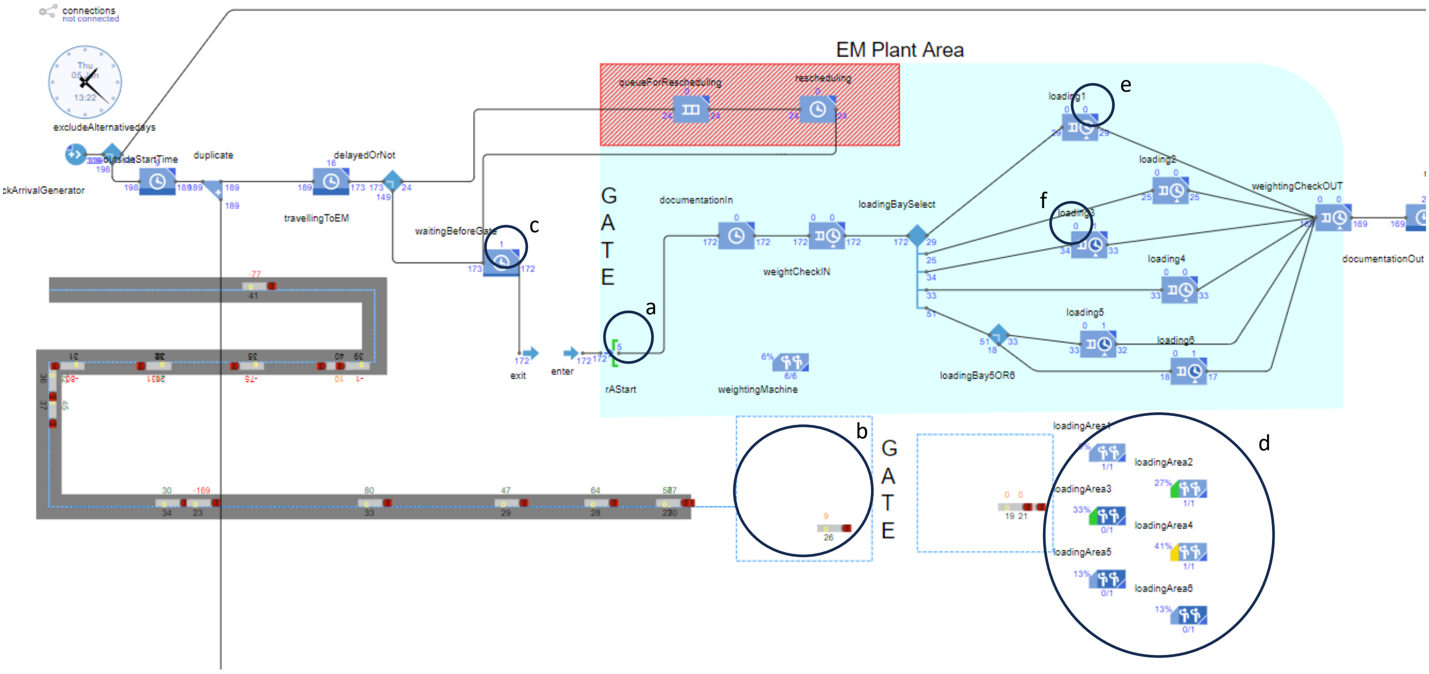

Figure B-3: Operation Graphics Validation example

In more detail, in Operational Graphics Validation, the values of different performance measures are represented graphically during the simulation's model execution. The aim of this dynamic representation, of the system's performance measures, is to ascertain that the simulation's model behavior depicts correctly (sufficiently) the actual system's behavior (Sargent, 2010). In the context of this research, the various performance measures, shown graphically during the simulation, are explained based on Figure B-1 and Figure B-3. To start with, the number of trucks in the plant at each moment is tracked, as can be seen in the circle (a). Also, the number of trucks waiting before the plant gates is displayed both with animation, see circle (b), and as a number, see circle (c). Further, the loading bays utilization for each day is illustrated, in circle (d), along with their condition servicing a truck (1) or being idle (0), see circle (e). In addition, the case of a truck waiting in front of a loading bay, to become empty and then entering, is depicted too, see circle (f). Based on this information and the historical data of the plant operations, the behavior of the simulation model is assessed and validated.