Truck Arrival Management Systems at Liquid Bulk Terminals

Case study for a new set-up of Truck Logistics at Vopak Terminal Vlaardingen

I.A. van den Brink

Master Thesis

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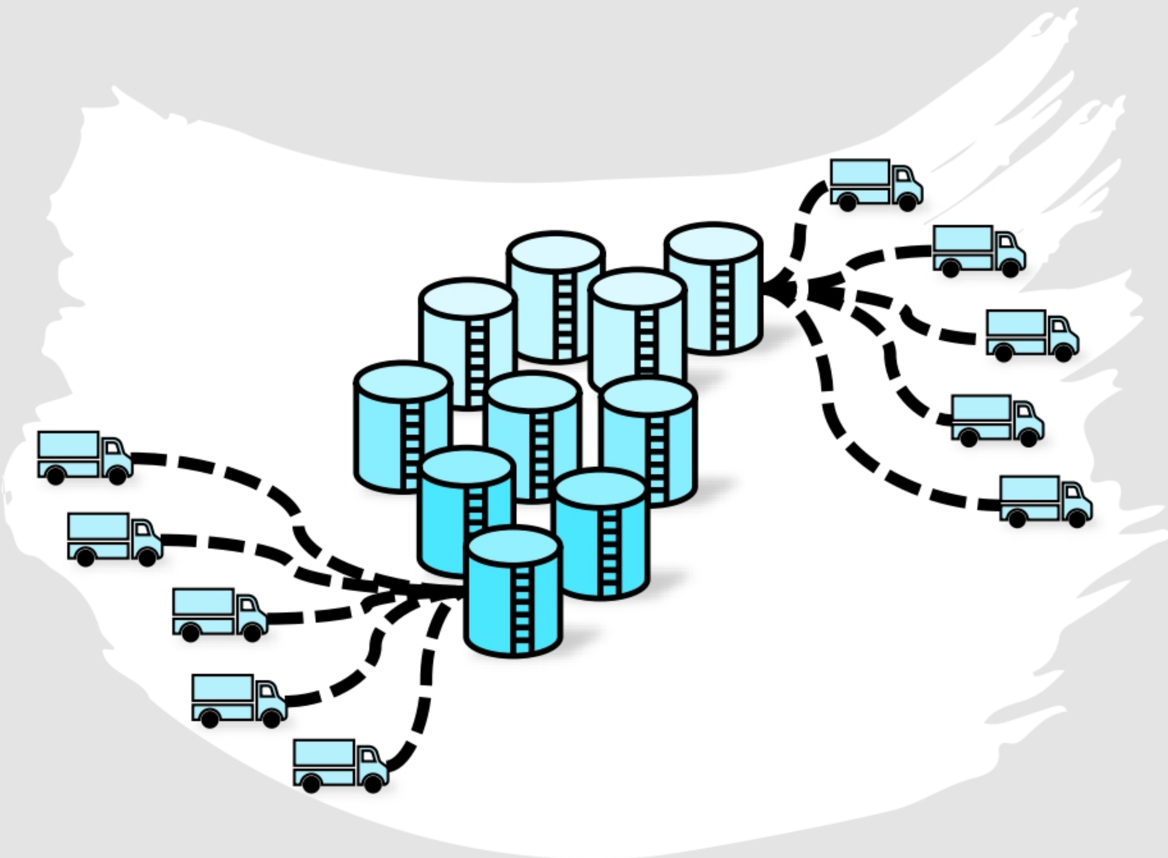

TU Delft

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Master Thesis

by

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TUDelft

Preface

Dear reader,

This master thesis shows a graduation research on the development of a complementary Truck Arrival Management system in order to handle an increased number of incoming trucks at Vopak Terminal Vlaardingen B.V. The research is conducted under supervision of Delft University of Technology and was initiated by the company Vopak Terminal Vlaardingen.

I am grateful for the opportunity Vopak offered me. I have always been interested in logistics, so this research was a wonderful challenge. For the last year, I worked on this project with enthusiasm. In particular, I would like to thank Lianne for her comprehensive feedback and I admire her knowledge and work ethic. I also would like to thank all other employees at Vopak who took the time for me, supported me throughout the project and helped me further. I learned a lot about Vopak Terminal Vlaardingen and the processes that take place at the company, which I will bring along in my future life.

Furthermore, I would like to thank Mark for his thorough feedback on this report. I also would like to thank Dingena, your points of attention were very useful. Lastly, I would like to thank Anna-Louise Nijdam for being part of my graduation committee.

Lastly, I would like to thank my family and friends. It was not always easy, especially not during the last months which were busy and stressful. Throughout the project, they advised and supported me, provided distraction at the moments I needed it and helped me further when I encountered issues.

After all, I completed my graduation project in 10 months which included struggles and beautiful moments. It feels either great and a little bit sad to finish this part of my student life at the Delft University of Technology. With the completion of this research, my time at Vopak will also come to an end. I am going to miss the people and the company, but I am also looking forward to the next steps in my life. First I will take some time off, and who knows, maybe till next time!

Enjoy reading my thesis!

I.A. van den Brink
Delft, February 2023

Executive Summary

Nowadays, the continuously growing and changing economy requires adaptations to the worldwide set-up of supply chains [1]. Several transport modalities can be used to transport goods in these supply chains. Road transport has a dominant role and remains to play this role in the modal split, despite the obligation to move from polluting to sustainable modes of transport forced by e.g. the European Commission [2, 3]. This phenomenon is visible as well at Vopak Terminal Vlaardingen (VTV) in the Netherlands, at which a case study is performed. The influence of a complementary Truck Arrival Management (TAM) system on the system performance of a Liquid Bulk Terminal is investigated.

VTV is a Liquid Bulk Terminal (LBT) that stores and transports a range of (edible) oils and liquids. A new customer has signed a contract to store its liquids in a newly constructed tank group accompanying three newly constructed unloading bays. The new customer has established a Purchase Book that is subject to change. Therefore, the exact supply of liquids and the transport modalities are not yet known and not yet fixed. The supply chain that has been setup by the customer includes trucks from within the EU and from outside the EU. Those from within the EU are transported completely via road to VTV. Non-EU containers are transported overseas with a container ship to the harbour of Rotterdam. The containers are transported via the road for the last mile to unload liquids at VTV. The liquids are transported from VTV to the factory of the customer by barges. Therefore, the inflow and outflow of liquids are strictly separated in their transport modality. A significant increase in the number of supplied trucks to the terminal has to be considered. Nevertheless, LBTs often have a compact area layout. At VTV, too, little space is available for such an increase in incoming trucks. Moreover, truck congestion at terminals is already a common problem at terminals nowadays [4].

LBTs usually use a TAM system to control the arrivals of trucks and to aim for efficient usage of resources [5]. Various TAM systems exist, of which the Truck Appointment System (TAS) is the most used and researched system at terminals [4]. For this research, Drop and Swap (D&S) has been researched as second TAM system. All TAMs have advantages and disadvantages regarding efficiency. The goal of this thesis is to design a complementary TAM system in which two TAM systems cooperate to overcome disadvantages and to improve the system performance of an LBT. This research focused on incoming trucks and does not include other transport modalities that are encountered by LBTs. Furthermore, the research is further narrowed down to the ”additional” logistic flow that comes with the customer. The main research question that has been investigated is:

To what extent can truck logistics at a Liquid Bulk Terminal be improved by developing a complementary Truck Arrival Management system within a global intermodal supply chain?

First of all, the LBT as a system and processes taking place in this system have been investigated. The main functions of an LBT are storage and transport of liquids. Terminals can be classified according to their position in the supply chain. A terminal uses equipment to perform its functions, like jetties, tanks, pumps and pipelines, and (un)loading bays which all have to be cleaned, maintained and inspected on a regular basis. Several truck logistic processes happen at an LBT. These processes can be split into an information/communication part and a physical part. The TAM system represents the information/communication part and can be seen as the planning process. Planning happens before a truck physically arrives at a terminal in order to coordinate truck arrivals and achieve efficient usage of resources. The physical part consists of four processes, namely arriving, entering, unloading and departing. There are often two arrival peaks per day, one in the morning and one in the afternoon. Entering represents the registration part of truck drivers before entering the terminal. During unloading, a truck is discharged by a pump. Lastly, during departing, the paperwork is finished and the the truck leaves the terminal. The chance of congestion is highest during entering.

Two KPIs are defined to measure the system performance of an LBT with respect to the TAM system. KPI 1 is the number of unloaded trucks, KPI 2 is the Truck Turnaround Time (TTT) of unloaded trucks. The aim is to maximise KPI 1 and to minimise KPI 2.

This research focuses on the development of a complementary TAM system, in which TAS and D&S cooperate. In a TAS, transport operators book an appointment to (un)load their liquids at an LBT. It is based on a strict schedule which is known in advance [6]. D&S is researched chosen as it is a promising TAM system that could mitigate peaks in truck arrivals and therefore reduce congestion at terminals. It has a less extensive planning part compared to TAS and utilises a Drop and Swap Terminal (DST) that separates external and internal truck activities. At a DST, trucks that have to (un)load at the LBT drop off their container and pick up another container of the same transport operator. External Truck Drivers and Internal Truck Drivers take care of the (un)loading of containers at the LBT. External Truck Drivers and Internal Truck Drivers are familiar with the terminal [7, 8]. Both TAM systems have advantages and disadvantages. The purpose of the complementary TAM system is to overcome the disadvantages, and to improve the system performance of an LBT.

A Discrete Event Simulation (DES) has been used to model the TAM systems and the physical processes. A DES shows the system status at discrete time steps and can enable stochastic, dynamic and complex characteristics by which reality is simulated well. These characteristics are necessary for this research as the operational level of a terminal entails these characteristics.

The design of the DES is based on the case study performed at VTV. The current situation with TAS as a TAM system has been analysed and the situation for a complementary TAM system has been explained. The processes planning, arriving, entering, unloading and departing are analyses. VTV also handles trucks that need an NVWA inspection. This inspection is only necessary for some product types and needs to be executed before trucks can unload at the terminal. Furthermore, factors that influence the supply chain are studied, such as the product type, the truck type and supply scenarios.

An important characteristic of the complementary TAM system is that the arrival of trucks is separated based on the origin of the trucks. EU trucks enter the system via the TAS. Non-EU trucks enter the system via D&S. The morning is reserved for TAS, the afternoon is reserved for D&S. In the morning, D&S trucks can be transported from the DST to the LBT such that they can already be registered and be inspected if necessary. Trucks that miss their slot in the TAS can unload during the reserved D&S time and D&S trucks that are ready to unload in the morning can fill empty slots.

The model objective, requirements and assumptions have been listed. Furthermore, the model components have been discussed. The flowcharts that show the design of the system include the model components. The designs of the information system, TAS, the D&S system and the complementary system are visualised in flowcharts. The designed model has been programmed in Python with SimPy for DES features. The model is verified according to multiple tests. Three types of validation are used, namely data validation, structural validation and performance validation. For validation, historical data of VTV was used. Performance validation was done by means of a z-test.

In order to study the influence of parameters and the system performance of the complementary TAM system, an experimental plan has been setup. This experimental plan contains Truck Scenarios as input, parameters and Design Alternatives as requirements and KPIs for measuring the performance. The Truck Scenarios are derived from supply scenarios setup by the customer. The parameters can be divided into simulation and configuration parameters. Furthermore, three Design Alternatives are setup, namely a complete TAS, a complete D&S system and a complementary TAM system. The exact layout of the complementary TAM system depends on the Truck Scenario. Nine experiments have been performed which all focus on different Design Alternatives and parameters to study their influences. The parameters that have been studied are the number of parking lots, Internal Truck Drivers, External Truck Drivers and servers at registration.

The parking lot capacity, the number of Internal Truck Drivers, External Truck Drivers and servers at registration influence the system performance. Furthermore, the NVWA inspection has major influence on the system performance. When comparing the same Design Alternative and Truck Scenario, the TTT shows a decrease if the NVWA inspection is done before arriving at the LBT. Furthermore, the number of unloaded trucks increased at the same time.

An increase in KPI 1 can also be observed by comparing the complementary TAM system to a complete TAS. However, with this increase, the TTT increased as well. It can be concluded that a complementary TAM system is beneficial regarding the number of unloaded trucks, but depends on the input and system design. However, there will be a trade-off between the number of unloaded trucks and the TTT.

Samenvatting

Tegenwoordig vereist de voortdurend groeiende en veranderende economie aanpassingen in de wereldwijde opzet van toevoerketens [1]. Voor het vervoer van goederen in deze toevoerketens kunnen verschillende vervoersmodaliteiten worden gebruikt. Het wegvervoer heeft een dominante rol en blijft deze spelen in de modal split, ondanks de verplichting om van vervuilende naar duurzame vervoerswijzen over te stappen, die bijvoorbeeld door de Europese Commissie is opgelegd [2, 3]. Dit is ook zichtbaar bij Vopak Terminal Vlaardingen (VTV) in Nederland, waar een case study is uitgevoerd. De invloed van een complementair Truck Arrival Management (TAM) systeem op de systeemprestaties van een terminal voor vloeibare bulkgoederen is onderzocht.

VTV is een terminal voor vloeibare bulkgoederen die diverse (eetbare) oliën en vloeistoffen opslaat en vervoert. Een nieuwe klant heeft een contract getekend om zijn vloeistoffen op te slaan in een nieuw gebouwde tankgroep met drie nieuw gebouwde losplaatsen. De nieuwe klant heeft een aankoopoverzicht opgesteld dat aan verandering onderhevig is. Daarom is de exacte levering van vloeistoffen en de vervoerswijze ervan nog niet bekend en vastgelegd. De toevoerketen die door de klant is opgezet bevat vrachtwagens van binnen de EU en containers van buiten de EU. EU vrachtwagens worden volledig over de weg vervoerd. Niet-EU containers worden met een containerschip overzees vervoerd naar de haven van Rotterdam. De laatste kilometers naar VTV van niet-EU containers zullen ook via wegtransport plaatsvinden. De vloeistoffen worden met binnenschepen weggevoerd van VTV naar de fabriek van de klant. De toe- en afvoer van vloeistoffen zijn dus strikt gescheiden in hun vervoerswijze. Er moet rekening worden gehouden met een aanzienlijke toename van het aantal vrachtwagens dat bij de terminal moet lossen. Echter hebben terminals vaak een compacte indeling en ook bij VTV is niet veel ruimte beschikbaar voor een dergelijke toename van het aantal inkomende vrachtwagens. Bovendien is congestie van vrachtwagens bij terminals al een veel voorkomend probleem tegenwoordig [4].

Terminals maken gewoonlijk gebruik van een TAM systeem om de aankomst van vrachtwagens te controleren en een efficiënt gebruik van materieel na te streven [5]. Er bestaan verschillende TAM systemen, waarvan de Truck Appointment System (TAS) het meest gebruikte en onderzochte systeem op terminals is [4]. Daarnaast is Drop and Swap (D&S) bestudeerd voor dit onderzoek. Alle systemen hebben voor- en nadelen wat betreft efficiëntie. Het doel van dit onderzoek is het ontwerpen van een tweedelig TAM systeem, waarbij de twee aparte systemen elkaar aanvullen en kunnen samenwerken om nadelen te ondervangen en de systeemprestaties van een terminal voor vloeibare bulkgoederen te verbeteren. Dit onderzoek is exclusief gericht op inkomende vrachtwagens en heeft geen betrekking op andere vervoersmodaliteiten waarmee terminals voor vloeibare bulkgoederen te maken hebben. Bovendien wordt het onderzoek verder beperkt tot de ”aanvullende” logistieke stroom veroorzaakt door de nieuwe klant. De hoofdonderzoeksvraag die is onderzocht is:

In hoeverre kan de vrachtwagenlogistiek op een terminal voor vloeibare bulkgoederen worden verbeterd met de ontwikkeling van een complementair Truck Arrival Management systeem binnen een wereldwijde intermodale toevoerketen?

Als eerste zijn het systeem van een terminal voor vloeibare bulkgoederen en de processen die in dit systeem plaatsvinden onderzocht. De voornaamste functies van zo een terminal zijn opslag en vervoer van vloeistoffen. Terminals kunnen worden ingedeeld aan de hand van hun positie in toevoerketens. Een terminal gebruikt materieel om zijn functies uit te voeren, zoals aanlegsteigers, tanks, pompen en pijpleidingen, en laad- en losstations die allemaal regelmatig moeten worden schoongemaakt, onderhouden en geïnspecteerd. Op een terminal vinden verschillende vrachtwagenlogistieke processen plaats. Deze processen kunnen worden opgesplitst in een informatie/communicatiegedeelte en een fysiek gedeelte. Het TAM systeem vertegenwoordigt het informatie/communicatie gedeelte en kan gezien worden als het planningsproces. De planning gebeurt voordat een vrachtwagen bij een terminal aankomt om de aankomst van de vrachtwagen te coördineren en een efficiënt gebruik van de materiaal te bereiken. Het fysieke gedeelte bestaat uit vier processen, namelijk aankomen, binnenkomen, lossen en vertrekken. Vaak zijn er twee aankomstpieken per dag vast te stellen in de aankomstverdeling van vrachtwagens op een terminal. Binnenkomen vertegenwoordigt het registratiegedeelte van vrachtwagenchauffeurs voordat zij de terminal betreden. Tijdens het lossen wordt een vrachtwagen gelost door een pomp. Tenslotte wordt het papierwerk afgewerkt en verlaat de vrachtwagen de terminal tijdens vertrekken. De kans op congestie is het grootst tijdens het binnenkomen.

Er zijn twee KPIs vastgesteld om de systeemprestaties van een terminal te meten aangaande het TAM systeem. KPI 1 is het aantal geloste vrachtwagens, 2 is de Truck Turnaround Time (TTT) van geloste vrachtwagens. Het doel is om KPI 1 te maximaliseren en KPI 2 te minimaliseren.

Dit onderzoek richt zich op de ontwikkeling van een complementair TAM systeem, waarin TAS en D&S samenwerken. In een TAS boeken vervoerders een afspraak om hun vloeistoffen te lossen of the laden bij een LBT. Het is gebaseerd op een strakke planning die vooraf bekend is [6]. Daarnaast is er gekozen voor D&S omdat het een veelbelovend TAM systeem is dat pieken in de aankomst van vrachtwagens kan opvangen en daardoor bijdraagt aan de vermindering van congestie op terminals. Het heeft een minder uitgebreid planningsgedeelte vergeleken met TAS en maakt gebruik van een Drop and Swap Terminal (DST) die externe en interne vrachtwagenactiviteiten scheidt. Bij een DST zetten vrachtwagens die bij de terminal moeten lossen of laden hun container af en halen een andere container van dezelfde vervoerder op. Externe en interne vrachtwagenchauffeurs zorgen voor het afhandelen van containers op de terminal zelf. Externe en interne vrachtwagenchauffeurs zijn bekend met de terminal [7, 8]. Beide TAM systemen hebben voor- en nadelen. Het doel van het complementaire TAM systeem is de nadelen te ondervangen, en om de systeem prestaties van een terminal te verbeteren.

Een Discrete Event Simulation (DES) is gebruikt om de TAM systemen en fysieke processen te modelleren. Een DES toont de status van het systeem in discrete tijdstappen en kan stochastische, dynamische en complexe karakteristieken bevatten. Door deze kenmerken kan de werkelijkheid goed worden gesimuleerd. Dit onderzoek richt zich op het operationele niveau van een terminal, waarbij deze kenmerken van belang zijn.

Het ontwerp van de DES is gebaseerd op de case study van VTV. De huidige situatie met TAS als TAM systeem is geanalyseerd en de situatie voor een complementair TAM systeem is toegelicht. De processen plannen, aankomen, binnenkomen, lossen en vertrekken zijn geanalyseerd. VTV handelt ook vrachtwagens af die een NVWA inspectie nodig hebben. Deze inspectie is alleen nodig voor bepaalde producttypes en moet worden uitgevoerd voordat vrachtwagens kunnen lossen op de terminal. Verder zijn factoren bestudeerd die de toevoerketens beïnvloeden. Dit zijn onder andere het producttype, het vrachtwagentype en de toevoerscenario's.

Een belangrijk kenmerk van het complementaire TAM systeem is dat de aankomst van vrachtwagens wordt gescheiden op basis van de herkomst van de vrachtwagens. EU vrachtwagens komen het systeem binnen via TAS. Niet-EU vrachtwagens komen het systeem binnen via D&S. De ochtend is gereserveerd voor het TAS, de middag is gereserveerd voor D&S. In de ochtend kunnen D&S vrachtwagens vanaf de DST alvast naar de terminal voor vloeibare bulkgoederen worden vervoerd, zodat ze al geregistreerd en eventueel geïnspecteerd kunnen worden. Vrachtwagens die hun slot in het TAS missen, kunnen lossen tijdens de gereserveerde D&S tijd. Andersom kan ook: een D&S vrachtwagen die in de ochtend al klaar is om te lossen, kan een leeg TAS slot opvullen.

De doelstelling, eisen en aannames van het model zijn gedifinieerd. Verder zijn de modelcomponenten besproken. De stroomdiagrammen die het ontwerp van het systeem weergeven, bevatten deze modelcomponenten. De ontwerpen van het informatiesysteem, het TAS, het D&S systeem en het complementaire systeem zijn gevisualiseerd in stroomdiagrammen. Het ontworpen model is geprogrammeerd in Python met SimPy voor DES functies. Het model is geverifieerd aan de hand van verschillende testen. Validatie is op drie manieren gedaan, namelijk door gegevensvalidatie, structurele validatie en prestatievalidatie. Historische gegevens van VTV konden worden gebruikt voor validatie. De prestatievalidatie werd uitgevoerd door middel van een z-toets.

Om de invloed van parameters en de prestaties van het complementaire systeem te bestuderen, is een experimenteel plan opgesteld. Dit experimentele plan bevat toevoerscenario's als input, parameters en design alternatieven als vereisten en KPIs voor het meten van de prestatie. De toevoerscenario's zijn gebaseerd op scenario's die door de klant zijn opgesteld. De parameters kunnen worden onderscheiden in simulatie- en configuratieparameters. Verder zijn er drie design alternatieven opgesteld, namelijk een volledig TAS, een volledig D&S systeem en een complementair TAM systeem. De exacte indeling van het complementaire systeem hangt af van het toevoerscenario. Er zijn negen experimenten uitgevoerd die allemaal gericht zijn op verschillende design alternatieven en parameters om hun invloed te bestuderen. De bestudeerde parameters zijn het aantal parkeerplaatsen, interne vrachtwagenchauffeurs, externe vrachtwagenchauffeurs en servers tijdens registratie.

De capaciteit van de parkeerplaats, het aantal interne en externe vrachtwagenchauffeurs en het aantal servers bij registratie beïnvloeden de prestaties van het systeem. Bovendien heeft de NVWA inspectie een grote invloed op de systeemprestatie. Als hetzelfde design alternatief en toevoerscenario wordt vergeleken, blijkt dat de TTT hoger is als de NVWA inspectie op de terminal wordt uitgevoerd vergeleken met wanneer de situatie wanneer de NVWA inspectie wordt uitgevoerd voordat de vrachtwagen op de terminal aankomt. Tegelijkertijd neemt het aantal geloste vrachtwagens toe als de NVWA inspectie van tevoren is uitgevoerd.

Een toename van KPI 1 kan ook worden geconstateerd door het complementaire TAM systeem te vergelijken met een volledig TAS. In deze vergelijking nam echter ook de TTT toe. Er kan dus geconcludeerd worden dat een complementair TAM systeem gunstig is wat betreft het aantal geloste vrachtwagens, al is de verbetering afhankelijk van het toevoerscenario en het systeemdesign. Er zal echter een afweging zijn tussen het aantal geloste vrachtwagens en de TTT.

Contents

Symbols

$\mathcal{Logi}(\mu,\beta)$ Logistic distribution with location parameter μ and scale parameter β

$\mathcal{Logn}(\mu,\sigma)$ Lognormal distribution with location parameter μ and shape parameter σ

$\mathcal{N}(\mu,\sigma)$ Normal distribution with mean μ and standard deviation σ

$\mathcal{Tri}$(a,b,c) Triangular distribution with minimum a, mode b and maximum c

$\mathcal{U}$(a,b) Uniform distribution with minimum a and maximum b

$\mathcal{Wei}(\alpha,\beta)$ Weibull distribution with shape parameter α and scale parameter β

Number of...

α Significance level z-test

μ Average z-test

σ Standard deviation z-test

z^* Critical z-value

Abbreviations

ABS Agent Based Simulation. xi, 21, 22, 90

AGV Automated Guided Vehicle. 12, 15

AI Artificial Intelligence. 19, 90

ALICE Alliance for Logistics Innovation through Collaboration in Europe. xxii, 89, 90

BCP Border Control Post. 25, 26, 31, 105

CLT Central Limit Theorem. 22, 46, 53, 54

D&S Drop and Swap. v–viii, xi, xii, xxi, xxiii, 5–7, 13, 16, 17, 19, 20, 22, 23, 27–29, 34–40, 42, 45, 46, 53, 57, 61–65, 67, 69, 71–74, 80–82, 84–89, 91, 92, 104–108, 110, 111, 121, 125, 135, 136

DA Design Alternative. vi, xii, xxii, 6, 7, 53, 59, 63–75, 77, 79–83, 86, 88, 92, 107–109, 134, 141, 145, 147, 149

DES Discrete Event Simulation. vi, viii, xi, xxi, 21, 22, 38, 44, 57, 88, 91, 105, 107, 121, 135

DST Drop and Swap Terminal. vi, viii, 5, 19, 20, 22, 27, 29, 31, 34, 37, 45, 60, 62, 73, 74, 77, 80, 87, 91, 106, 108

DTAS Dynamic Truck Appointment System. xxi, 18, 19, 89

ETA Expected Time of Arrival. 18, 19, 90

ETD External Truck Driver. vi, 16, 22, 29, 31, 37, 39, 44, 45, 60, 62, 63, 65–68, 70, 71, 73–77, 79–82, 84, 86–88, 91, 106–110

EU European Union. v–viii, 3, 25, 27–29, 31–36, 39, 52, 60, 61, 63, 64, 66, 67, 69, 74, 80, 82, 85, 88, 89, 91, 105–107, 111

FCFS First Come First Serve. 5, 13, 14, 18, 89, 105

FTMaaS Freight Traffic Management as a Service. 19, 89, 90

GHG Green House Gas. 1, 89, 104

IoT Internet of Things. 18

ITD Internal Truck Driver. vi, xii, xxiii, 5, 16, 20, 22, 29, 31, 37, 44, 45, 60, 62–68, 70–77, 79–82, 84, 86–88, 91, 106–110, 141

IWT Inland Waterway Transport. 1, 92, 104

KPI Key Performance Indicator. v, vi, viii, ix, xi, xii, xxii, xxiii, 6, 7, 9, 15, 16, 21, 35, 36, 46, 51, 56, 59, 69–88, 90, 107, 109–113

LBT Liquid Bulk Terminal. v, vi, viii, xi, xxi, 1, 2, 4–7, 9–12, 14–22, 35, 37, 57, 59, 60, 63, 65, 69–74, 77, 80–82, 84–89, 104–107, 109–111

LLN Law of Large Numbers. 22, 46, 53, 83

NVWA Nederlandse Voedsel- en Warenautoriteit/Netherlands Food and Consumer Product Safety Authority. vi, viii, ix, xxi, xxii, 25–27, 29–39, 44, 46, 49, 52, 59–63, 65, 67, 69–74, 76, 77, 79–86, 88, 91, 105, 107–111, 147

PDF Probability Density Function. xxi, xxii, 46, 48–52, 54, 129–131

PIT Poort Intstructie Training/Gate Instruction Training. xxi, 25, 36, 37, 46, 48, 49, 53, 61–63, 108, 109

RFID Radio-Frequency Identification. 14

TAM Truck Arrival Management. iii, v–ix, xi–xiii, xxi–xxiii, 1, 3–7, 12, 13, 15–20, 22–24, 27–31, 34–36, 38–40, 43, 44, 51, 53, 57, 59, 60, 62–67, 69–77, 79, 81, 83–91, 104–108, 110, 111, 121, 127, 135, 136

TAS Truck Appointment System. v–ix, xi, xii, xxi, 4–7, 13, 17, 18, 22–24, 26–29, 34–41, 44, 46, 47, 51, 53, 57, 58, 61–65, 67, 69–72, 74–77, 80, 82–92, 104–111, 121, 123, 134–136

TS Truck Scenario. vi, xii, xxiii, 6, 52, 59, 60, 63–86, 88, 90–92, 107–110, 134, 141–145, 147, 149

TTT Truck Turnaround Time. v, vi, viii, ix, xxii, 4, 5, 13, 15, 16, 37, 51, 53, 54, 56–58, 69–88, 107, 109–111

TVF Time-Varying Fee. 5, 13, 89, 105

UCO Used Cooking Oil. 31

VDTW Vessel Dependent Time Windows. 5, 13, 89, 105

VTV Vopak Terminal Vlaardingen. iii, v–viii, xi, xiii, xix, xxi, xxii, 1–7, 10, 11, 16, 23–35, 37, 39, 45, 46, 49–56, 58, 60–63, 67, 69, 84, 87–91, 105–108, 111, 115–118, 120, 121

Terminology

Drop and Swap Way of handling trucks. A truck driver drops its full container at an area from where a designated driver transports the containers between the area and the actual terminal for (un)loading. The truck driver that left its container at the area picks up an empty container from the area in the same shift so that the containers are swapped [7]. v, vii, xi, xii, xvii, xxi, 5–7, 13, 17, 19, 20, 22, 23, 28, 37, 39, 40, 42, 57, 63, 89, 91, 104–106, 121, 125, 136

Expedition Counter at the gate of Vopak Terminal Vlaardingen where documentation is handled for trucks that arrive at the terminal. xii, xxi, xxiii, 24–26, 29, 31, 34, 36–38, 44–46, 48, 51, 53, 62, 63, 65–71, 73–75, 77, 79–82, 84, 86, 91, 105, 109, 141, 144

First Come First Serve Way of handling queues, works with the principle of ”First in First out”: first one entering is first one to be helped. xvii, 5, 89, 105

Monte Carlo Method of approximating an expected value using sampling [9]. xi, 22, 46, 52

Poort Intstructie Training Safety test. Necessary for everyone that enters a Vopak terminal. xviii, 25

Purchase Book Overview of purchases done by a business, which gives information about the supply of liquids. It shows the distribution product categories and origins of trucks. v, xi, 3, 6, 26, 28, 31, 60, 91, 92, 105

Slotbooking Way of scheduling transport. Usually it is an electronic system in which transport operators book a timeslot for a specific (un)loading bay to (un)load their cargo. 17

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1 Introduction

This chapter contains the introduction of research focused on improving the Truck Arrival Management at a Liquid Bulk Terminal for a global intermodal supply chain. The context, incentive for the research, research gap, problem statement, research questions and report structure are discussed.

1.1. Research Context

The continuously growing and changing economy, and the growing volumes of goods that need to be handled, require adaptions in worldwide supply chain and logistic operations [1, 11, 12, 13]. Different modes of transport can be used to transport freight, such as road, rail, water and air transport. Figure 1.1 shows the European performance for freight transport between 1995 and 2020 in which the dominant role of road and sea transportation is visible. Road transport accounts for more than half of the total modal split [10].

To meet sustainability goals and reduce Green House Gas (GHG) emissions, the European Commission targets and promotes a modal shift in freight transport: from road transport towards rail transport and Inland Waterway Transport (IWT). Yet, road transport continues to play a leading role in supply chains [2, 3].

The dominant role of road transport is also experienced by Liquid Bulk Terminals. Large numbers of trucks lead to truck congestion at terminals if they are not properly handled. Truck congestion at terminals in general is a well-known and growing problem due to the rising demand from industries and the developing economy [1, 7, 8, 12]. One of the main reasons for truck congestion is the arrival pattern of trucks, and in particular the arrival of trucks at peak hours [14, 15]. This often causes congestion at gates [16]. Furthermore, terminal vehicle capacity contributes majorly to the total delay trucks experience in terminals [15]. Liquid Bulk Terminals - especially VTV - usually have a compact layout, which contributes to truck congestion [17]. Truck congestion is a complex prob-

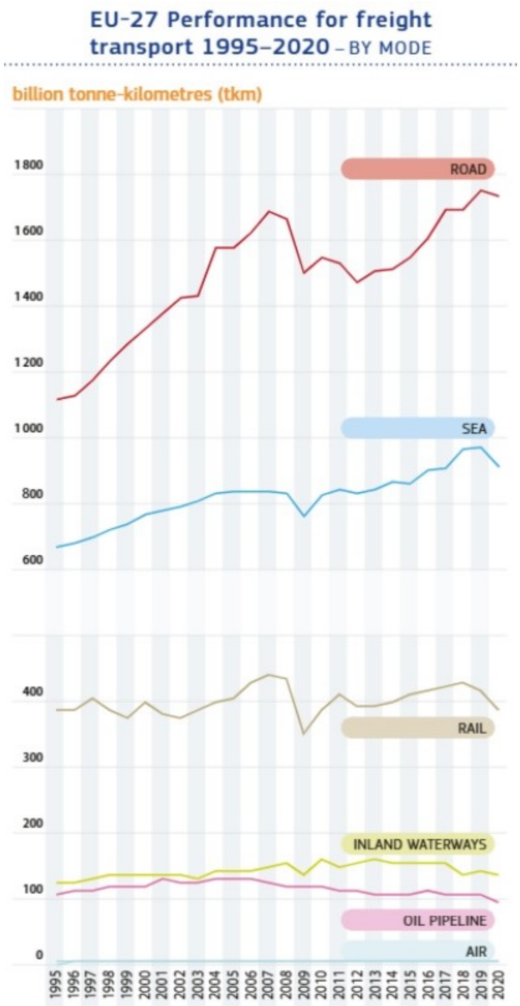


Figure 1.1: European Freight Transport by Mode [10]

lem due to several dependent components in the supply chain and due to a variety of stakeholders [8]. Moreover, congestion decreases truck productivity, causes negative environmental consequences and does not benefit terminals [1, 7, 8, 12, 16, 18, 19].

1.2. Research Incentive

This research was initiated by Vopak Terminal Vlaardingen. Vopak Terminal Vlaardingen is a Liquid Bulk Terminal (LBT): a terminal that stores (edible) oils for customers in tanks. The oils are transported via several modalities like road transport (trucks), rail transport (railcars) and water transport (vessels and barges) from and to customers. The terminal has a total storing capacity of roughly 600.000 m^3 in 300 tanks, distributed among several tank groups [20, 21]. Vopak Terminal Vlaardingen stores several liquid products. Four product categories can be distinguished: vegoils, oleochemicals, baseoils and plant- and wastebased elements of biodiesel. Vopak Terminal Vlaardingen facilitates the loading and unloading of liquids. Loading is equivalent to charging and is specified as the transshipment of liquids from a tank to a transport modality. Unloading is equivalent to discharging and is defined as the transshipment of liquids from a transport modality to a tank. Figure 1.2 gives an impression of the terminal.

Figure 1.2: Vopak Terminal Vlaardingen [22]

The leading role of road transport is also noticed at Vopak Terminal Vlaardingen (VTV). The number of trucks handled at VTV will increase tremendously in the coming year: a contract is signed by a new customer that is going to store its oils in a new tank pit that is currently under construction. Sixteen extra tanks and three extra dedicated unloading bays are constructed at the terminal. The new customer will start to discharge its liquids in these tanks in May 2023. The new tank group at VTV is constructed at the place where old tanks previously stood as can be seen in Figure 1.3. It shows the map of VTV, including jetties, pump stations, tank groups and (un)loading bays. The tank group numbers are also indicated.

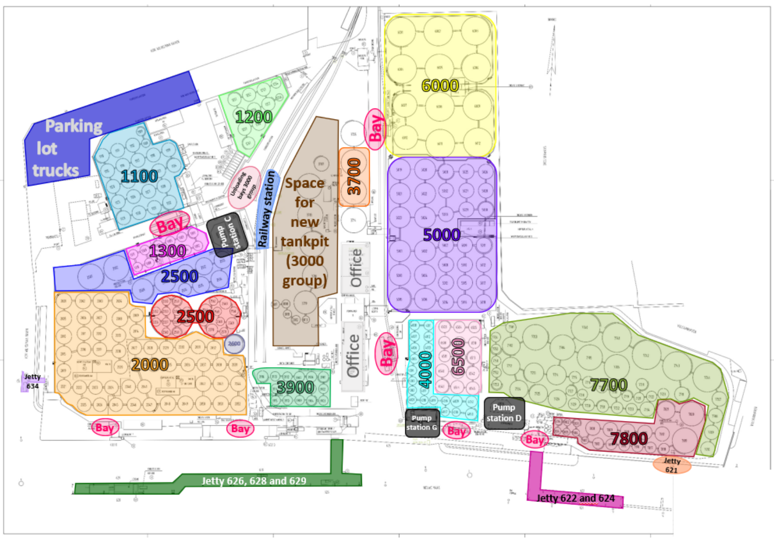


Figure 1.3: Map of Vopak Terminal Vlaardingen Including Tank Group Numbers

There is limited space to allocate to more truck logistics at the terminal and in the area surrounding it. Therefore, VTV aims at handling trucks as quickly as possible to maximise throughput and minimise congestion. Congestion is defined as: "*the presence of delays along a physical pathway caused by the presence of other users*", in which delays represent the difference between the recorded and expected service time under conditions without congestion [4]. Furthermore, VTV prefers to use a Truck Arrival Management system that can handle large peaks in truck arrivals.

1.2.1. Supply Chain and Purchase Book

The root cause of possible truck congestion can be found within the supply chain of the logistic set-up. The supply chain is shown in Figure 1.4. As can be seen, liquids will be supplied to the terminal via trucks and will be discharged, stored and blended at VTV. Thereafter, it is transported to the customer's factory via barges. Normally, VTV does break-bulk, in which large amounts of liquids are transported to the terminal via vessels. These large amounts of liquids are distributed into small quantities which are carried away from the terminal by barges or trucks. However, the logistic set-up for this new customer shows make-bulk, in which small amounts of liquids are transported to the terminal. These small amounts are blended and result in large quantities which are carried away from the terminal [23].

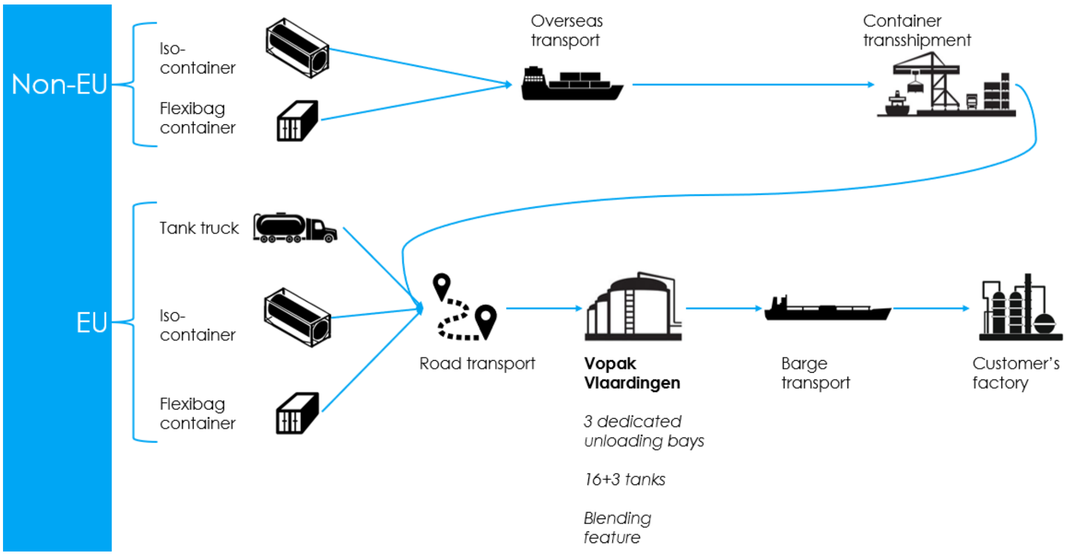


Figure 1.4: Supply Chain

The Purchase Book determines the distribution of the different liquid types and origins of purchased liquids. The exact Purchase Book of the customer is not known yet and can change over time. These uncertainties come from the fact that, in the first place, worldwide locations where liquids are available for sale have to be found. Moreover, partnerships have to be made between the new customer and suppliers that sell these liquids for which several scenarios are made.

Liquids can be purchased within the European Union (EU) and/or from outside the EU. Liquids bought outside the EU will be transported overseas, either via vessels directly to VTV or via containers on ships with a stopover at the port of Rotterdam. The last mile transportation of the containers from the port of Rotterdam to VTV will happen via trucks. Due to the stopover of containers at the port of Rotterdam, the supply chain is intermodal. Liquids bought in the EU will be transported completely via road transportation. Because of the worldwide origins of supplied trucks, the supply chain can be classified as global.

Overseas transportation causes peaks in supply, as many containers can be transported via ships and arrive at the port in one go. Transportation via road will lead to a more steady supply of liquids. Moreover, different combinations can be made in the purchase of liquids which cause variations on the supply side.

This research focuses on the prevention and mitigation of truck congestion at terminals. Therefore, only the supply via road transportation to the terminal is researched and the direct supply of liquids via vessels to the terminal is not examined.

1.2.2. Transport Modality

As previously mentioned, several transport modalities can be used to transport liquids and the new customer does so to supply liquids to the terminal to be discharged in tanks, like road and water transportation. The ratio road:water transportation depends on a couple of factors and is explained in Section 4.2. This research focuses exclusively on road transportation because the supply chain, as shown in Figure 1.4, is prone to problems due to the number of incoming trucks. Little parking space is available for trucks just outside the terminal, which might be a bottleneck. The parking lot for trucks is located northwest of the site, as can be seen in Figure 1.3.

The stored liquids from the new tank group will be loaded onto barges exclusively. The barges sail to the customer's factory on a daily basis, where new products will be produced. Hence, the unloading and loading flows are strictly separated in their transport modality, see Figure 1.5. Furthermore, because of the frequency the barges transport liquids from the terminal to the factory, it is important that supply of liquids to the terminal will not stop.

Sixteen newly constructed tanks are available for storing products for the customer at VTV. Furthermore, there are three already existing tanks available as quarantine tanks, which will only be used for storing liquids with unknown quality for a short amount of time. After quarantine and a quality analysis, the liquids will be transported to the sixteen new tanks via pipelines.

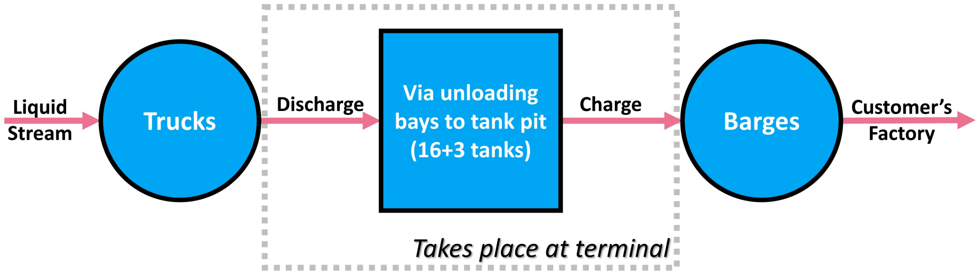


Figure 1.5: Product Flow

1.3. Research Gap

Truck logistics consist of four main physical processes: arriving, entering, unloading and departing which is elaborated on in Section 2.2. In order to maximise throughput and minimise truck congestion, the focus is mainly on the arriving and entering processes of trucks. When examining the complete truck logistic process, it becomes clear that these processes have the highest chance of queuing, as is visualised in Figure 1.6. Queuing causes waiting times which enlarge the Truck Turnaround Time. Hence, the biggest reduction in Truck Turnaround Time is gained by eliminating waiting times. A reduction in time spent on physical processes is harder to achieve [6].

Truck Arrival Management (TAM) systems contribute majorly to the arriving and entering processes of trucks. Most terminals use a TAM system in order to regulate the arrival of trucks. Various TAM systems exist which all have their own characteristics regarding the arrival of trucks and mitigation of truck congestion.

Truck Appointment System (TAS) is one of the most used and researched TAM systems at terminals

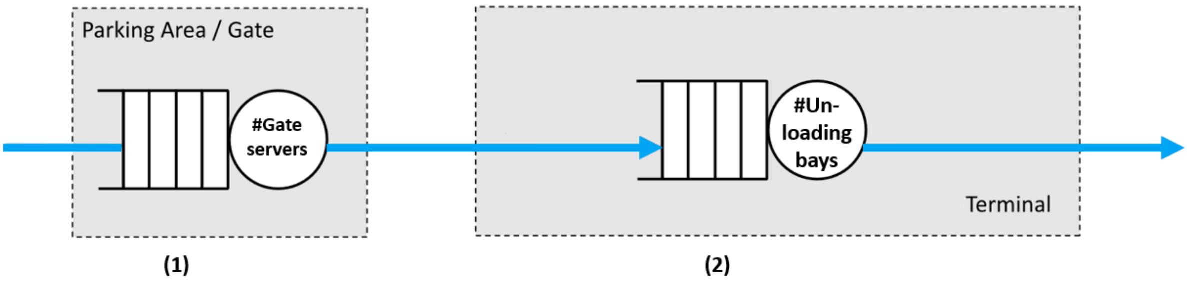


Figure 1.6: Queues at a Liquid Bulk Terminal. One at the gate and one before unloading [8].

[4, 24]. The working mechanism of a TAS is as follows: transport operators have to book a time slot for a specific (un)loading bay in which they want to (un)load their liquids. The system is usually an electronic system. TAS has advantages and disadvantages regarding efficiency. There are a maximum number of bookable appointments, as such preventing and overflow of trucks that plan to (un)load at the terminal. Furthermore, it is tried to evenly spread truck arrivals and minimise waiting times for drivers with this system [5, 14, 15, 25, 26, 27]. In practice, however, the system shows inefficiencies which are not favourable for either the terminal and transport operators. This is mainly because TAS is highly dependable on a strict schedule, while truck arrivals and equipment availability have a stochastic nature: time losses are still generated [1, 6, 15]. VTV also uses TAS as a TAM system nowadays.

A literature research is done to find out which alternative TAM systems exist. Various systems exist, like Drop and Swap (D&S), First Come First Serve (FCFS), Time-Varying Fee (TVF) and Vessel Dependent Time Windows (VDTW) [6, 7, 8, 19, 27, 28, 29]. For this thesis, it is important that the TAM can handle both trucks arriving via road transport and sea transport in an efficient way. Literature states that D&S is a robust TAM system that can handle peaks in truck arrivals. A D&S practice includes a Drop and Swap Terminal (DST) with a large storage capacity for containers. Incoming external trucks drop off their container at this area and pick up another container of the same transport operator, after which they leave the DST again. The DST acts as an extra buffer which is not present at (the parking lot of) the actual terminal. This D&S operation takes less time than the actual (un)loading operation. Thus, external trucks run through the system faster. Internal trucks take care of either the transportation between the actual terminal and the DST and the (un)loading operation. Internal Truck Drivers are better acquainted with safety and operational rules of the terminal because of routine. This results in more efficient (un)loading operations. The terminal is completely in control of truck arrivals with a D&S system. A disadvantage is that not all truck drivers visit the terminal regularly. Therefore, swapping containers is not always possible, as truck drivers cannot take containers that are not their possession [7, 8].

As becomes clear, both TAS and D&S have advantages and disadvantages regarding the arrival of trucks and containers and their processes. Furthermore, form literature it becomes clear that no research has been done yet on the combination of TAS and D&S as a TAM system. From this point of view, the question arose if TAS and D&S could work complementary to each other to handle incoming trucks at an LBT. Both systems have restrictions, for which is researched if they can be removed by combining the best of both systems. The combination of these systems therefore defines the research gap as visualised in Figure 1.7. The exact interpretation of such a system is the subject of this research.

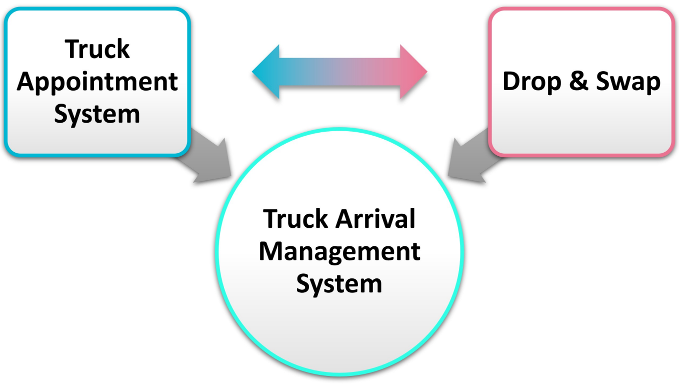


Figure 1.7: Research Gap

1.4. Problem Statement

An increase in the number of handled trucks in a compact LBT environment brings along issues in the logistic process, as there is a high risk of truck congestion which might result in high Truck Turnaround Times.

In this research, VTV is the case study examined. The number of trucks arriving at VTV will increase because of a new customer that is going to store its liquids at the LBT. The number of **extra** trucks that this customer is going to send to VTV is not yet known, but can vary from 5.000 to 19.000 extra trucks annually, depending on the Purchase Book. This comes down to 20 to 75 extra trucks per day and results in a significant increase in handled trucks. There is enough space to store the liquids, because of the new tank pit. However, there is a shortage in space around the terminal for these extra trucks coming to the terminal to perform the truck logistics and unload their liquid cargo.

Furthermore, there is only one road supply route, so if congestion happens, the flow of trucks and cars gets stuck around the terminal. In order to not disrupt this flow of trucks, a new set-up of the Truck Arrival Management is researched. Nowadays, TAS is the most used and researched Truck Arrival Management system, but has disadvantages regarding efficiency and truck throughput [4, 24]. D&S is a robust system that can handle peaks in truck arrivals. The aim is to develop an innovative TAM in which TAS and D&S work complementary to each other in a dynamic way. It is researched if this TAM can improve truck logistics at the LBT, while keeping in mind the maximisation of truck throughput and minimisation of truck congestion under unknown and changing circumstances.

For the case study, it is important to note that operations taking place at the terminal nowadays have to continue as usual as soon as the new tank group and its logistics are commissioned. The new customer and the operations for this tank group are only an addition to the existing situation at VTV. The already existing operations and this new logistic set-up will be strictly separated. The new logistic set-up, which is addressed in this research, will in the first place exclusively be applied to the logistics for the new customer: the existing operations are not taken into account while assessing the new logistic set-up. The existing logistics are only taken as a basis and as comparison material, but will further be left out of scope. Once the new TAM set-up has been researched and shows improvements, it could be applied to the existing logistics. The focus area of this research is summarised in Figure 1.8.

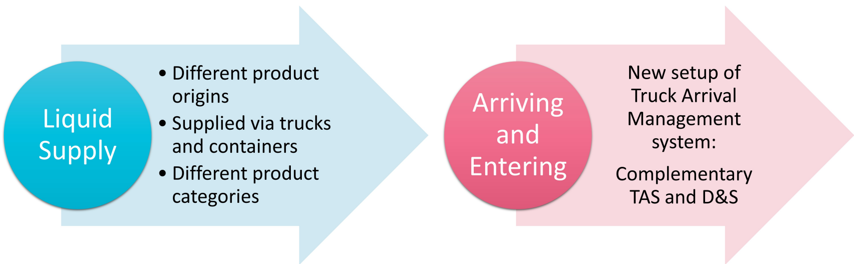


Figure 1.8: Focus Area Research

1.5. Research Questions

The main research question investigated in this project is:

To what extent can truck logistics at a Liquid Bulk Terminal be improved by developing a complementary Truck Arrival Management system within a global intermodal supply chain?

The sub-research questions investigated are:

1. *How is the system Liquid Bulk Terminal described and which truck logistic processes happen within this system?*
2. *What are the KPIs that can be measured at a Liquid Bulk Terminal with respect to its Truck Arrival Management system?*
3. *How can Truck Appointment System and Drop and Swap be specified according to literature?*
4. *Which modelling method would be appropriate for the complementary Truck Arrival Management system?*
5. *How can the truck logistics of the case study at a Liquid Bulk Terminal be described?*
6. *What does the model design of a complementary Truck Arrival Management system look like at a Liquid Bulk Terminal?*
7. *Which Design Alternatives for the Truck Arrival Management system can be researched to investigate the system performance of a Liquid Bulk Terminal for relevant Truck Scenarios?*
8. *What influences the KPIs of a complementary Truck Arrival Management system at a Liquid Bulk Terminal?*

1.6. Report Structure

The structure of the report is as follows: in Chapter 2, research questions 1 and 2 are addressed. In this chapter the Liquid Bulk Terminal as a system and its truck logistic processes are explained. Furthermore, the Key Performance Indicators and what could influence them are elaborated.

In Chapter 3, research questions 3 and 4 are discussed, in which the Truck Arrival Management systems Truck Appointment System and Drop and Swap are explained. Furthermore, the modelling method for this research is looked into.

Chapter 4 focuses on research question 5 and elaborates the case study at Vopak Terminal Vlaardingen. Subsequently, the model design is explained in Chapter 5. This chapter focuses on research question 6. The model is presented, accompanying its verification and validation.

Research question 7 is elaborated in Chapter 6. The simulation input, the parameters for the experiments and the Design Alternatives are explained. Furthermore, an overview of the experimental plan is shown. The results of the experiments are presented in Chapter 7, according to research question 8.

In Chapter 8, a conclusion is drawn. Lastly, recommendations for future scientific research and advice to the company are given in Chapter 9.

2

System Analysis Liquid Bulk Terminal

This chapter focuses on sub-research questions 1 and 2 and gives an overview of a Liquid Bulk Terminal as a system in order to get a good understanding of the problem. First, the LBT is described according to its functions, its classification and its equipment. Then, the truck logistics are explained by means of the planning process and the four physical processes: arriving, entering, unloading and departing. Lastly, the two Key Performance Indicators determined for this research are discussed.

2.1. System Description

Bulk terminals are industrial facilities that enable temporary storage of large product quantities before these products are transshipped to another transport modality and/or transported to another location [30]. LBTs are furnished to facilitate activities and services to store, handle and be in charge of cargo in liquid forms. They usually contain a variety of tank storage facilities and other technical equipment to transport the liquids, like pump stations [31]. Liquid bulk can arrive at, be transported across, and leave terminals via several modalities: road transport, rail transport, sea transport and pipeline transport are the most common ones [32]. Furthermore, an overarching goal is to both provide good quality and service to customers and to minimise costs [33].

Transportation of products across the terminal is necessary as products come from one means of transport, are stored in tanks, and will thereafter be transshipped to another means of transport. To complete these steps, a terminal consists of three different systems: seaside operations, yard operations and landside operations [23, 34]. These operations are visualised in Figure 2.1, which presents a simplified sideview of an LBT.

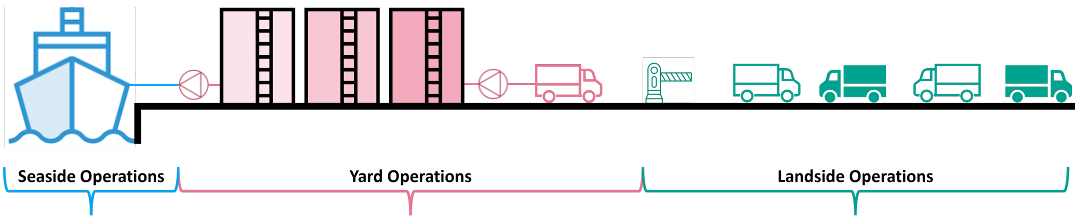


Figure 2.1: Simplified Sideview of a Liquid Bulk Terminal Including Operations [35, 36]

The seaside operations focus on barges and vessels that arrive at, berth at and depart from the terminal. The barges and vessels either have to be loaded with product or come to the terminal to discharge their liquids. Yard operations mainly consist of storing products, transporting liquids across the terminal and transshipping liquids from one modality to another. The equipment at the terminal is used for these operations. Landside operations include the arrival and departure of trucks and the processes that take place at the gate. Trucks also come to the terminal to either discharge their liquid or to be loaded with product that is stored at the terminal. Sometimes, activities at an LBT overlap these three operations [23].

2.1.1. Terminal Functions

Terminals generally have different functions. The main functions are storage, transportation and adding value in the form of blending, tank-to-tank transfers and/or adding additives [37]. Storage and transportation are the primary functions of a terminal. The last service, adding value, is a secondary service as it is mostly an optional function and can differ per terminal ranging from elaborate services to less elaborate services [23].

Next to the primary and secondary services, a terminal should ensure safety by performing activities which are focused on:

- Hazardous situations: safe working area, safety fundamentals, fire prevention
- (Toxic) emissions: odour removal, vapour treatment
- Quality of products: sampling, testing, heating, cooling and pressurising of products
- Quality of equipment: cleaning, inspection and maintenance of installations [33]

2.1.2. Terminal Classification

Several types of terminals exist. A way of classifying these types is by the position in the supply chain. Depending on its position in the supply chain, the logistic function has a more outstanding role. Four types that can be classified are strategic, industrial, import/export and hub terminals. Strategic terminals are generally used for strategic storage by governments. Industrial terminals are used to store raw materials and finalised goods at a production site. Import/export terminals fundamentally provide make or break bulk services. Hub terminals are high volume market places with many logistic services [37]. Vopak Terminal Vlaardingen can be classified as an import/export terminal because of its make and break bulk services.

Independent of their classification, an LBT has functions within the supply chain. It has to connect different transport modalities to maintain product flow. Furthermore, it has to store products to provide a buffer between different modalities. This function is necessary for strategic reasons or to compensate for scheduling differences in supply and/or demand for example. Another important aspect in the supply chain is changing product flow size by either combining or distributing products. Lastly, performing value added operations is also a function that can be placed within the supply chain set-up [23].

2.1.3. Terminal Equipment

What type of equipment a terminal has depends on the type of material a terminal handles. Container or dry bulk terminals have different tools to perform their functions compared to LBTs. Furthermore, equipment at an LBT is less flexible and more dedicated to certain products compared to container terminals, where equipment is more flexible and can be interchanged between containers more easily [23].

The equipment at an LBT enables e.g. storage, tank-to-tank transport and loading and discharging trucks, barges and vessels. Equipment necessary for these operations are jetties, tanks, pumps, pipelines and (un)loading bays. Furthermore, supporting activities like cleaning, inspection and maintenance are vital. A gate and parking, too, are necessary to handle all incoming and outgoing transport.

Jetties

Barges and vessels arrive at and depart from the terminal. This occurs on the seaside of the terminal. For the berthing of barges and vessels, jetties are present. Pipelines are connected to these jetties, which have flexible hoses or loading arms at the end to reach the ships and to account for their motion relative to the jetty [23].

Appendix B focuses on information about VTV specifically. Figure B.1 gives information about the jetties at VTV. Figure B.1a shows the terminal from above and highlights the jetties present at VTV. As can be seen, jetties have different sizes at which different sizes of ships can berth. Figure B.1b shows the jetty planning for a random day. On the left, the codes for the 10 different jetties are presented. The schedule itself shows how long a ship is docked. The colour codes give the status of a ship. The mooring layouts and requirements differ per jetty, per size of a ship and per how many ships have to be moored at the jetties at the same time [21].

Tanks

Liquids are stored in tanks. Tanks can be rented for one product or products can be mixed if multiple customers store similar products and agree on mixing. The tanks at terminals often have different capacities and different sizes. At VTV, tank capacities range from approximately 250 m^3 to 6240 m^3 [20, 21].

Furthermore, tanks can include blending systems in order to create a mixture of liquids. For some products, additional measures have to be taken, like the heating of liquids during storage to prevent liquids from solidifying, or the blanketing of tanks with nitrogen to maintain quality of a product. Heated products are stored in isolated tanks.

In Appendix B, Figure B.2, the tanks of VTV are presented. Figure B.2a highlights all tanks present at VTV. As can be seen, heights, surfaces and colours can differ per tank. Figure B.2b shows a close up of tanks at Vopak Terminal Vlaardingen. The white tanks and the silver-coloured tanks both belong to a different tank group. The tanks at the top of Figure B.2b are isolated tanks. This picture is taken from the location indicated by the arrow and star in Figure B.2a.

Pumps and Pipelines

The pipelines and pumps provide transport of liquids at the terminal, either from trucks to tanks, from tanks to tanks or from tanks to ships/trucks. Pumps often include a filter to clean (polluting) particles from the liquid. All ships also have a pump aboard, which is used to discharge liquids from the ship to the terminal.

For the lining up of equipment, a set-up procedure exists. This is important, as leakages are highly unfavourable. For example, pressure tests are executed on pipelines prior to unloading. Valves and pipes, too, are checked by multiple terminal operators to ensure that they are setup accordingly before they are in operation.

Some pipes and pumps transport heated liquids, and thus these installations are isolated as well. Moreover, different types of pipes and pumps are used for transportation. Pipes at VTV are made of carbon steel or stainless steel and have different sizes. Pump types present at VTV are e.g. the steampump and the stripperpump.

(Un)loading Bays

For the loading and discharging of trucks, (un)loading bays are present at the terminal. Some of these are dedicated to a specific product and/or tank. Some are flexible and can be used for multiple products and tanks. At several bays, a weighing bridge and/or a fall protection are integrated. The weighing bridge is able to weigh trucks before and after their (un)loading operation. The fall protection provides a safe location where truck drivers can prepare their truck for the (un)loading operation.

Cleaning, Inspection and Maintenance

The tanks, pumps and pipelines also have to be cleaned, maintained and inspected. They can be cleaned with water (with or without detergent) or with steam. If the pipes are suitable for this, they can also be pigged to remove product residue that is left after (un)loading.

Inspection and preventive maintenance of equipment is done on a regular basis to prevent failures. If, however, the equipment does break down at an unexpected moment, corrective maintenance will be necessary.

Parking Area and Gate

The parking area and gate allow visitors and trucks to arrive at and depart from the terminal. The trucks come from and go to the hinterland. The parking area contains parking places for trucks to park upon arrival at the terminal. The gate is needed to check and oversee everyone and everything entering the site.

2.2. System Processes

The processes that happen on a Liquid Bulk Terminal are explained in this section. For this research, the main focus is on landside and yard operations, which include trucks. The processes that are included start when a truck plans to arrive at the terminal and ends at the moment a truck has departed from the terminal. This will be referred to as truck logistics [7].

2.2.1. Truck Logistics

Trucks transport liquids via roads. Different types of trucks, which are shown in Figure 2.2, exist. The trucks considered do not belong to the category Automated Guided Vehicle (AGV). Figure 2.2a shows an iso-container, Figure 2.2b shows a flexibag container and Figure 2.2c shows a tank truck. Figure 2.2d shows the components of a truck with a container. These trucks consist of three components, namely: 1) the front of the truck, 2) a container and 3) a chassis. The iso-container and the flexibag container are coupled to the chassis and are removable from the chassis. The chassis is also removable from the front of the truck [8]. Tank trucks consists of one part, for which only the chassis can be uncoupled from the front of the truck.

(a) An iso-container [38] (b) A flexibag container [39] (c) A tank truck [40] (d) Components of a truck with container [41]

Figure 2.2: Truck Configurations

Trucks arriving at an LBT need to pass various stages which consist of either an information part and a physical part. The information/communication stream is defined by the Truck Arrival Management system [1, 14, 26]. The physical stream consists of the arriving at, entering of, unloading at and departing from the terminal [7, 8, 13, 34, 42, 43]. Solely unloading is mentioned, as this research is focused on the unloading rather than the loading of trucks at LBTs. Figure 2.3 visualises the complete logistic process. Figure 2.4 contains the logistic sub-processes, distributed among the information/-communication stream and the physical stream.

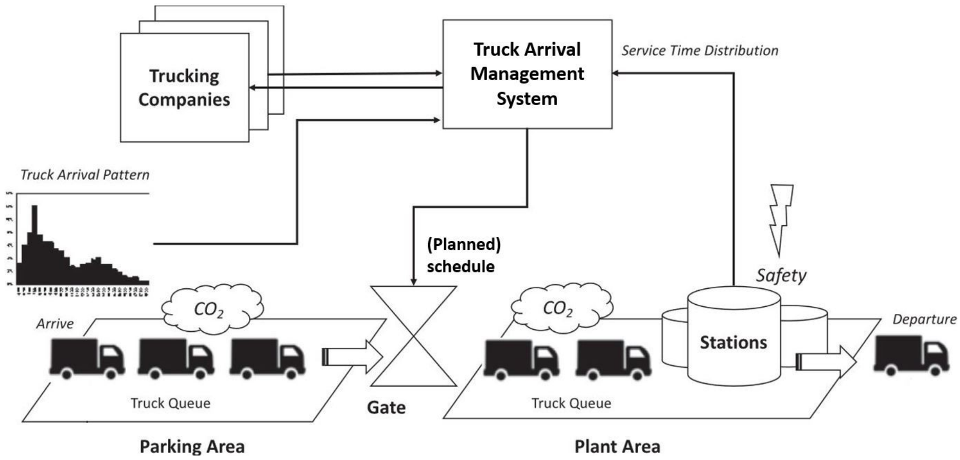


Figure 2.3: Truck Logistics at a Liquid Bulk Terminal [24]

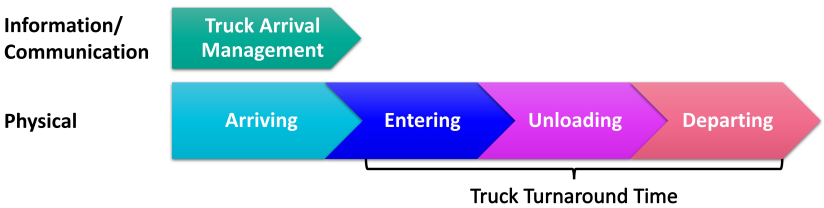


Figure 2.4: Logistic Sub-Processes [1, 5, 7, 8, 34]

As previously mentioned, one information process and four physical processes occur within the system. These processes are planning, arriving, entering, unloading and departing of trucks. The physical processes require time spent at the terminal. The longer a truck spends time within the system, the less efficient it is. Therefore, it is important that trucks run through the system as quickly as possible.

In literature, the Truck Turnaround Time (TTT) is defined in several ways and measures the time a truck is in the system. According to Carlan et al. [6], the effective unloading operation is counted as TTT. In this view, only the time a bay and employees of the terminal are dedicated to the unloading operation is counted as TTT. Another view that Carlan et al. [6] and Torkjazi and N. N. Huynh [44] present, is that the gate-to-gate process is counted as TTT. This means that time is counted from the moment a truck enters the terminal until the moment a truck leaves the terminal. A last view is that the TTT consists of time spent on the physical process: the time spent on arriving at, entering of, unloading at and departing from the terminal, is counted as TTT. This view aligns with Wibowo and Fransoo [24]. For this research it is chosen to define the TTT as the moment a truck is registered during the entering process until the moment a truck departs from the terminal as visualised in Figure 2.4 as well.

2.2.2. Planning

Before a truck physically arrives at a terminal, it plans to (un)load its liquids at a terminal. Terminals use a TAM system to coordinate truck arrivals. In this report, the focus is on Truck Appointment System and Drop and Swap. These TAM systems are further explained in detail in Chapter 3. However, there are more TAM systems, like FCFS, TVF and VDTW [6, 19, 27, 28, 29].

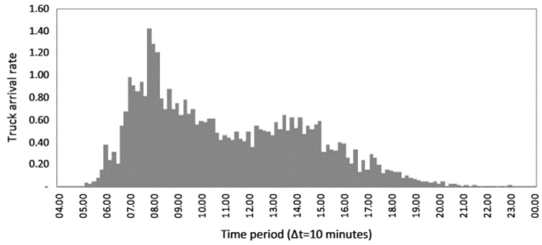
All TAM systems have their own characteristics and work differently regarding the mitigation of truck congestion. The overall aim of TAM systems is to provide a good service level to customers, align operations within the terminal and maximise terminal resource utilisation [5]. The planning process happens prior to the truck arrival, and thus it is not taken into account for the calculation of the TTT.

2.2.3. Arriving

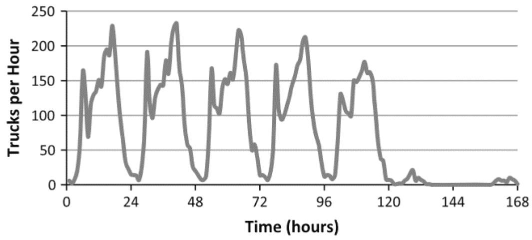
Trucks have to arrive physically at the terminal in order to unload their liquids [17]. Usually, a parking lot is located outside, but near, the gates of a terminal, where trucks can park upon arrival [8, 24]. Arriving is defined from the moment a truck arrives at the parking lot of the terminal until the moment the truck driver starts to register at the gate.

Exact arrival times of trucks at terminals are stochastic and therefore unpredictable beforehand [1, 5, 19, 34]. The fluctuations in truck arrivals can be attributed to external factors like weather conditions and traffic jams [9, 15]. These characteristics contribute to non-optimal truck logistics, as studies show that queuing length and inefficiencies can be reduced if truck arrival times are known in advance [18]. However, there are some patterns that can be observed within the arrival process. Arrival patterns can be constant or show peaks [5, 8, 15, 27, 29, 34]. Often, two arrival peaks can be experienced during the day, one in the morning and one in the afternoon [7, 12, 26, 27]. During weekends, fewer trucks arrive at a terminal compared to weekdays, according to Dekker et al. [7]. These aspects can also be seen in Figure 2.5, which visualises truck arrival patterns. Figure 2.5a shows the empirical truck arrival distribution during one day at a chemical site in the Netherlands. Figure 2.5b shows the truck arrival pattern at a terminal in the port of Rotterdam during one week. Figure 2.5c shows the hourly truck arrivals at a marine terminal in the port of New York/New Jersey during one working day. The two peaks per day are explained by the fact that truck drivers usually make two trips per working day to pick up and/or drop cargo, one in the morning and one in the afternoon, to maximise their productivity [7, 8, 12]. Afternoon operations highly depend on the accomplishment of morning operations [45]. Therefore, truck drivers prefer to arrive early at the terminal, and wait in front of the gate, to reduce the risk of being transferred to the following day [8]. At peak arrival times, dense traffic situations can occur in the area around the terminal. Too many trucks arriving at the same time can cause a capacity overload at the terminal.

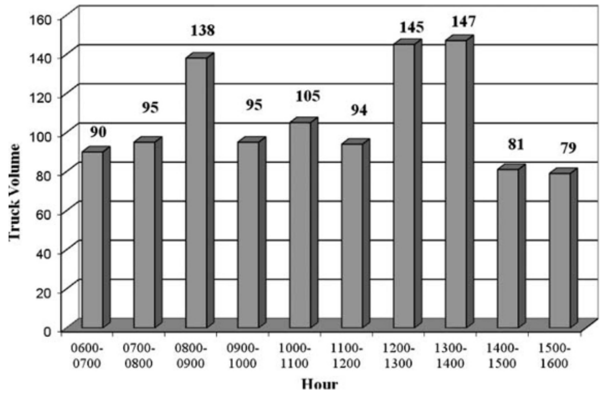
As can be seen in Figure 2.5, most operations happen during the day. Incentives have been made in order to shift truck arrivals to the night. However, these did not result in the flattening of arrival peaks as mentioned by Dekker et al. [7] and Bentolila et al. [29]. There are several reasons for this. Both terminals and transport operators have to facilitate the possibility of night operations, otherwise there will be a misalignment between supply and demand. Furthermore, truck drivers have limited driving and working hours per day. Terminal operators have limited working hours per day as well. So, if night operations would be enabled, night shifts have to be introduced in which higher wages have to be paid compared to wages for day shifts. Furthermore, at night, more safety regulations might be necessary, e.g. adequate illumination.



(a) Empirical Truck Arrival Distribution
Location: a Chemical Site in the Netherlands
Time Horizon: One Day [8]



(b) Typical Truck Arrival Pattern
Location: Container Terminal in the Port of Rotterdam
Time Horizon: One Week [7]



(c) Hourly Truck Arrivals
Location: Marine Container Terminal in the Port of New York/New Jersey
Time Horizon: One Day [12]

Figure 2.5: Truck Arrival Patterns

2.2.4. Entering

Entering is defined from the moment a truck driver starts to register until the moment a truck enters the gate of a terminal. Registration occurs just before entering the gate, as terminals often have strict visiting and safety regulations. The registration includes checks, identification and inspection, as everyone and everything that enters the site is examined [7, 8, 24, 43]. Registration at the gate often has to be done in person to prevent fraud. The check-in time depends on various factors, such as the experience of the truck driver and the type of product transported [43]. An LBT usually has one entering gate [24].

Gate congestion at terminals is a major concern [11]. The check-in process often causes queuing. The cause can be found in several reasons, e.g. limited gate capacity, a large number of truck arrivals [12]. The queues at the gate are usually handled on a FCFS basis [8, 13, 27, 46]. To make the entering process run more smoothly, automatic identification and/or online registration can be an option if implemented well regarding safety, reliability, quality and accuracy. However, this requires cooperation between transport operators and terminals to implement the necessary technologies, e.g. Radio-Frequency Identification (RFID). Furthermore, the implementation of innovative technologies might come along with extra costs, but it can be earned back if quality and efficiency increase [43]. All in all, the design of such a good working system is likely to be complex but might be worth the investment.

The parking lot where trucks park upon arrival facilitates an area where trucks have to wait until they can enter the terminal. Trucks have to wait, for example, if the unloading bay they are assigned to, is still occupied [8, 34]. The parking lot has a finite number of spaces [24, 34]. As queuing inside the gates of a terminal is unfavourable, trucks often have to wait outside the terminal [8, 27].

2.2.5. Unloading

Unloading is defined as the process that starts from the moment a truck enters the gates of a terminal until the moment a truck is unloaded and is ready to leave the terminal.

Unloading happens during opening hours of the terminal. Opening hours often variate per terminal and are limited [1, 27, 29, 47]. Unloading is seen as a continuous process [23]. Furthermore, the unloading of liquids itself takes a relatively long time and depends on product, capacity and equipment properties like viscosity, volume of the truck and pump speed [24]. The number of compartments of a truck also contributes to the the unloading time. Figure 2.6 shows trucks with a single and multiple compartments. Multiple compartments enable trucks to transport multiple products or products that have to maintain different temperatures at the same time. However, multiple compartments also means that compartment switches have to be made during the unloading of the whole truck [48]. The containers and trucks that are taken into account in this research only have one compartment.

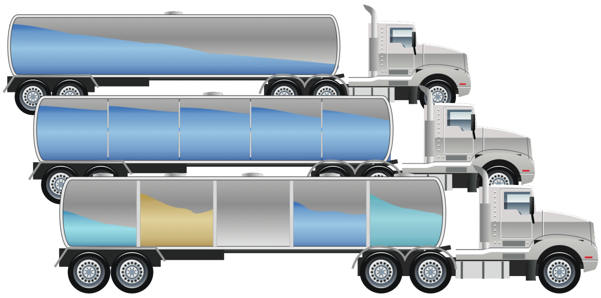


Figure 2.6: Trucks with a Single Compartment and with Multiple Compartments [49]

In order to execute operations at terminals, equipment is required. The present equipment at LBTs is usually specialised and less flexible compared to equipment necessary at container terminals. As an example: it is more common and applicable to use AGVs at container terminals than at LBTs [23]. Moreover, LBTs generally have multiple non-identical unloading bays which all serve different types of products [24]. The equipment at the terminal is never 100% guaranteed to work, as equipment also has downtime because of failures or broken parts for which corrective maintenance has to be carried out. Those failures often happen unpredictably and could lead to a jam in the unloading process [27]. Next to corrective maintenance, preventive maintenance also has to be executed. Preventive maintenance is aimed at preventing failures.

The liquid products considered in this research consist of different streams of products and are not uniform, as mentioned in Section 1.2.1. Therefore, multi-commodity applies to this research [5, 50].

2.2.6. Departing

Departing is defined from the moment a truck has finished unloading and is ready to leave the terminal until the actual passing of the gates. This process includes the preparation for the truck leaving the terminal and a final drafting and checking of documents [6, 7].

2.3. Key Performance Indicators

The system performance is evaluated by Key Performance Indicators. A Key Performance Indicator (KPI) is a measurable value that shows the progress towards an intended result and shows how well a system performs [51, 52, 53]. In this section the KPIs for an LBT regarding its TAM system are addressed.

Several KPIs exist in order to show the system performance for a Liquid Bulk Terminal. Each KPI has its limitations, as every KPI focuses on a specific part of the LBT system [37]. The KPIs for this research majorly focus on the truck logistics of discharging trucks. The following KPIs have been chosen to represent the system performance:

1. Number of Unloaded Trucks
2. Truck Turnaround Time of Unloaded Trucks

KPI 1: Number of Unloaded Trucks

The number of unloaded trucks handled by the system is important as an LBT wants to handle as many trucks as possible. Every truck that is handled generates profit. Furthermore, it shows the efficiency of the system. If less trucks than the maximum capacity are handled, it means that productivity losses are generated. Therefore, the aim is to maximise the number of unloaded trucks. For this research, a time frame of one operational month is considered.

KPI 2: Truck Turnaround Time of Unloaded Trucks

The Truck Turnaround Time is a KPI that is important as it defines how long a truck is in the system. The less time it spends within the system, the more efficient the system is. The system has a maximum capacity and cannot handle more than its capacity. Once a truck is out of the system another truck can enter the system. Therefore, the shorter the TTT is, the more trucks can be handled. Furthermore, short TTTs are highly valued by transport operators. Hence, the aim is to minimise the TTT.

Factors Influencing the System Performance

Certain factors influence the previously mentioned KPIs, which are listed below:

- **Parking lot capacity at a Liquid Bulk Terminal**
- **Number of servers at registration during entering**
- Number of unloading bays
- Number of terminal operators at unloading bays
- Downtime of equipment
- The opening hours of a Liquid Bulk Terminal

Some factors are exclusively applicable to D&S:

- **Number of Internal Truck Drivers**
- **Number of External Truck Drivers**

The majority of the previously mentioned parameters can be adjusted in the design of a system and might either influence the system performance in a positive or negative way. For this research, the focus is on the number of parking lots, the number of servers at registration, the number of External Truck Drivers and the number of Internal Truck Drivers. This is mainly done because these factors are linked to the newly integrated D&S system.

Nevertheless, what needs to be kept in mind is that productivity losses at unloading bays can never be reduced to zero. Terminals need to be flexible to manage variations in inter-arrival times or unexpected external influences like weather changes, (increased) equipment setup times and unavailability of equipment [37].

2.4. Conclusion

This chapter focuses on sub-research questions 1 ans 2. First, a Liquid Bulk Terminal is described as a system by operations taking place at the terminal, its functions, its classification and the equipment present on the LBT. Second, the processes the happen within the system are elaborated. Lastly, the KPIs of interest have been discussed.

A Liquid Bulk Terminal temporarily stores large quantities of liquids in tanks. The liquids are transported to and from the terminal via several modalities. The operations taking place at the terminal are seaside, yard and landside operations. They all cover a certain part of the terminal and might overlap. Seaside operations focus on barges and vessels, yard operations focus on tanks and the equipment on the terminal and landside operations are the connection to the hinterland. Each terminal has primary and secondary functions. Primary functions include storage, transportation and adding value. Furthermore, terminals can be classified based on their position in the supply chain. Vopak Terminal Vlaardingen can be classified as an import/export terminal. A terminal also needs equipment, in order to perform services for customers. The main equipment present on a terminal are jetties, tanks, pumps and pipelines, (un)loading bays and a parking area with a gate. Furthermore, cleaning, inspection and maintenance of equipment is necessary.

Several system processes happen on an LBT which are applicable to truck logistics. These system processes can be divided into an information/communication stream and a physical stream. The information/communication stream contains the Truck Arrival Management system. The physical stream includes arriving, entering, unloading and departing of trucks. The physical processes require time at the terminal which can be measured by the Truck Turnaround Time

The KPIs show the system performance. The KPIs set for this research are the number of unloaded trucks and the TTT of unloaded trucks. Factors that influence the system performance are amongst others the number of parking lots, the number of servers at the registration office of the terminal, the number of unloading bays, the downtime of equipment and the opening hours of a terminal.

3

Truck Arrival Management Systems

This chapter focuses on sub-research question 3 and 4. The Truck Arrival Management systems Truck Appointment System and Drop and Swap are specified according to literature. Next to that, the appropriate modelling method for these systems is researched and determined.

3.1. Truck Arrival Management System

The Truck Arrival Management system defines the information/communication stream of truck logistics at LBTs, as mentioned in Section 2.2.1. TAM systems aim at achieving good service times for customers, efficient usage of resources at the terminal and avoiding congestion inside and outside the terminal [5]. TAM systems are managed by terminals and make clear to transport operators how arriving trucks are handled [14, 18]. Arrival patterns of trucks at terminals usually show two peaks per day, as explained in Section 2.2.3 [7, 12, 26, 27]. If truck arrivals are not properly managed, it can result in long queues and might decrease the service and terminal productivity level [11].

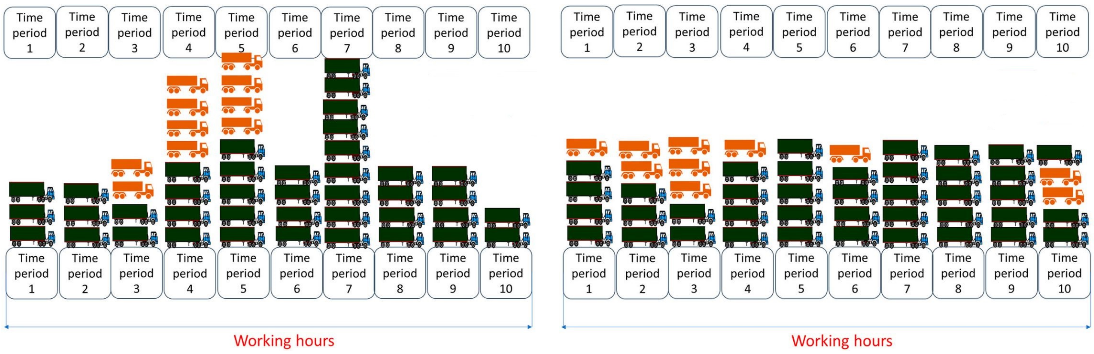
The focus within this research is on the TAM systems Truck Appointment System and Drop and Swap. TAS is focused on because it is the most used and researched TAM system at terminals [4, 24]. D&S is focused on because it has large potential to handle arrival peaks of trucks and therefore decrease congestion. Both systems have advantages and disadvantages. This research examines if the disadvantages can be overcome by letting these systems work complementary to each other.

3.1.1. Truck Appointment System

The Truck Appointment System was initiated to smooth out truck arrivals. It is usually an electronic system in which transport operators can book a time slot. These time slots are created by dividing the working day at an LBT into time windows. Often, there is a deadline the former day before which appointments can be made the latest for the following day. TAS is also known as Slotbooking and it has advantages and disadvantages regarding efficiency [1, 2, 6, 13, 15, 44].

The objective is to offer time slots that match preferred arrival times. Though, not all trucks can be served at their preferred arrival time as the system sets a maximum to the number of bookable appointments based on the LBT capacity and available equipment. If a preferred time slot is full, trucks are forced to enter the terminal at another time than their preferred time. This is done such that no overflow of trucks that plan to unload at the LBT can happen. Furthermore, it is tried to evenly spread truck arrivals and minimise waiting times for drivers [5, 14, 15, 25, 26, 27, 50]. Another advantage is that preparations and lining up equipment can be done prior to truck arrivals, as the schedule is known in advance [15]. In Figure 3.1, the theoretical difference can be seen between truck appointments without and with a TAS. In Figure 3.1a two distinctive peaks can be seen in truck appointments, whereas Figure 3.1b shows a constant flow.

However, in practice the system shows inefficiencies which are not favourable for either the terminal and transport operators. This is mainly because TAS is highly dependable on a strict schedule, while truck arrivals and equipment availability have a stochastic nature. Furthermore, the strict schedule relies on equipment availability that is 100% guaranteed, which never can be the case because of equipment reliability issues. Therefore, time losses are still generated [1, 6, 8, 15, 24]. Furthermore,



(a) Truck Appointments without Truck Appointment System [1]

(b) Truck Appointments with Truck Appointment System [1]

Figure 3.1: Difference between truck appointments without a TAS and with a TAS. Black trucks represent confirmed appointments, orange trucks represent preferable appointments [1]

truck drivers often stick to their preferred arrival time and wait before the gate until they can enter, instead of adhering to the arrival time just before their slot starts. This behaviour is incentivised by the fact that truck drivers work in a competitive environment [6, 12, 24, 29]. A mismatch can be noticed as well between the offering of time slots by the terminal and the use of time slots by trucks. Transport operators often have the opinion that there is a lack of appointment quotas, whilst terminals see that a lot of the time slots they make available are unused [2]. The schedule also suffers from no-shows or delays by trucks, such that they miss their booked time slot. In this case, the schedule has a spare time slot which might be filled by previous trucks that were too late. This replanning is done on a FCFS basis, by which the order of arrival is kept [6, 24]. As becomes clear, time windows can rather become an obstacle than a facilitation [2].

In order to overcome these disadvantages, customised TASs can be an alternative. These customised forms of the TAS are for example non-mandatory appointments systems in which making an appointment to unload is not mandatory for trucks [5, 13]. An alternative can also be an overbookable TAS to compensate for the negative consequences of no-shows [54]. A variant of this is a flexible TAS which does not set the same number of time slots during the whole day, but varies the number based on the availability of e.g. equipment [2]. Another option is to implement a cooperative system in which transport operators propose an appointment at their preferred time slot. The TAS gets these proposals and sends back appointment suggestions to transport operators based on queue length, waiting time and service time for trucks based on the workload and available capacity of the LBT [14, 18]. A visualisation of the cooperative TAS can be seen in Figure 3.2.

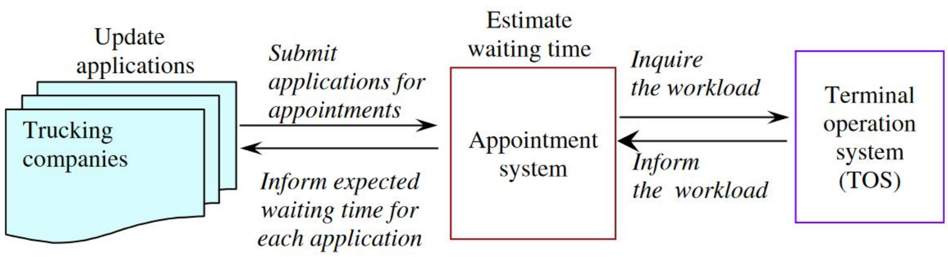


Figure 3.2: Cooperative Truck Appointment System [14]

Another form of TAS is Dynamic Truck Appointment System (DTAS) in which Internet of Things (IoT) based systems are integrated. DTAS is rather new, but breakthroughs are realised nowadays. DTAS utilises data that can be obtained by sensing systems, like traffic and weather forecasts, Expected Time of Arrival (ETA) and planning changes. Much data is already available nowadays. However, there is little coordination. In order to overcome this, an extensive amount of cooperation is necessary and business boundaries need to be overcome [1, 6, 46]. The DTAS is visualised in Figure 3.3.

The previously mentioned customised TASs both have pros and cons. Moreover, they have different characteristics regarding e.g. implementation. More research should be done in order to make them effective in flattening arrival patterns, mitigating queuing and reducing waiting times at specific

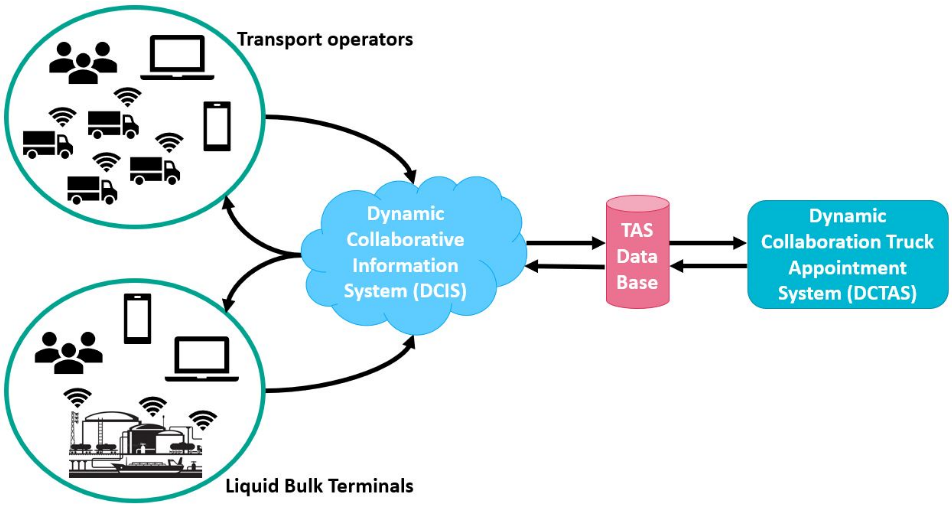


Figure 3.3: Dynamic Truck Appointment System [1, 55]

terminals. A project is setup to test the proposed system DTAS. This project is named Freight Traffic Management as a Service (FTMaaS) and is currently running [56]. Its mission is to connect traffic management systems and real-life logistics. This is done by developing, implementing and testing applications that aim for a significant impact on either traffic networks and logistic performance. The purpose is that value chains are build from data to information which either work from logistics to traffic and vice versa. Data analysis has to be done in order to produce information, this can also be done using Artificial Intelligence (AI) driven modelling approaches [57].

Within FTMaaS, projects are tested in living labs, which benefit from the interface between research and practice. One of these cases is the ”ETA driven dynamic slot re-planning at a chemical plant” [57, 58]. The aim of this case is to better utilise the storage capacity of a terminal and reduce waiting times. This is accomplished by optimising the assignment, re-planning and adjustment of slots to trucks by taking into account reliable predictions of data related to external factors, e.g. traffic jam. An accurate planning, a fast and more continuous flow of traffic and more efficient deployment of employees for executing (un)loading operations are opportunities within this case. A comprehensive data analysis is necessary to convert raw data into usable data [58]. Outcomes of this case that contribute to the reduction of truck congestion can be implemented at other terminals. No publications could be found yet about the outcomes as this project is currently running.

3.1.2. Drop and Swap

Drop and Swap is another TAM in which a drop off and pickup of respectively two containers are combined in one trip [2]. Research shows that D&S is a robust system to handle arrival peaks of trucks as visualised in Figure 3.4 [7]. The blue line shows average waiting times during a day if no D&S practice is implemented at a Liquid Bulk Terminal. The red line shows average waiting times if a D&S practice is implemented. A reduction in waiting times can clearly be seen.

A D&S practice distinguishes internal and external activities and includes a Drop and Swap Terminal (DST) with a large storage capacity for containers. Incoming external trucks drop off their container at this area and pick up another container of the same transport operator after which they leave the DST again. The DST acts as an extra buffer which is not present at (the parking lot of) the actual terminal. This D&S operation takes less time than the actual unloading operation. Therefore, external trucks run through the system faster. Internal trucks take care of either the transportation between the actual terminal and the DST and the unloading operation by which liquids are transshipped from containers to tanks. The process is visualised in Figure 3.5. Furthermore, this practice saves time at the gate because external trucks have to enter the DST once for a dual transaction. It also mitigates the number of empty truck trips [2].

Several types of D&S exist, either by the Drop and Swap practice and by the time management. The D&S practice can differ in a way that only the container can be taken from the truck or the whole chassis including container can be decoupled from the truck. The advantage of decoupling only containers is

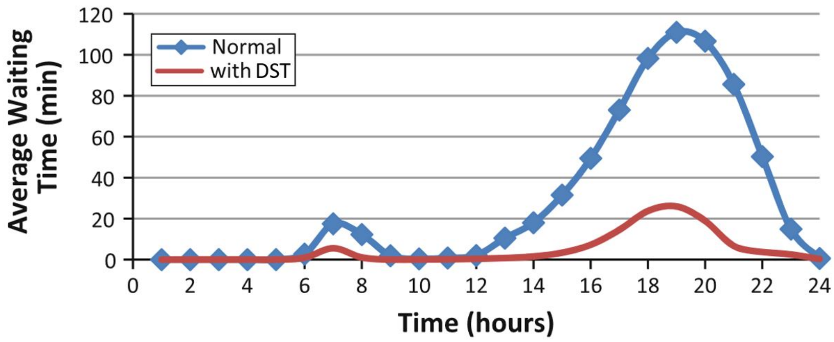


Figure 3.4: Simulation of differences between waiting times with and without a Drop and Swap Terminal. Drop and Swap type: chassis. Time management: Execute Drop and Swap during the whole day [7]

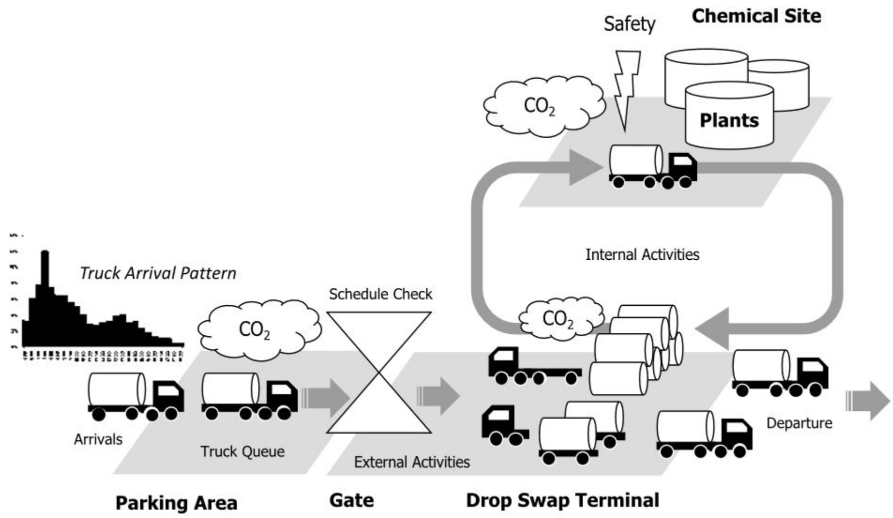


Figure 3.5: Explanation of a Drop and Swap terminal [7]

that they are stackable. However, a reach-stacker is necessary for this operation. The advantage of decoupling the whole chassis is that this D&S operation is executed faster than executing D&S with only containers. However, a chassis is not stackable and this form thus requires a larger surface for the DST [7, 8].

Internal Truck Drivers take care of the internal activities and are better acquainted with safety and operational rules of the terminal because of routine, compared to truck drivers that visit the terminal not so often. This results in more efficient unloading operations. Furthermore, the terminal is completely in control of truck arrivals with a D&S system as they have an overview of the DST and the actual terminal and can easily see which trucks/containers can be unloaded at the terminal for efficient utilisation of the terminal. A disadvantage is that not all truck drivers visit the Liquid Bulk Terminal regularly. Therefore, swapping containers at the DST is not always possible, as truck drivers cannot take containers that are not their possession [2, 7, 8].

3.2. Modelling Methods

In order to grasp logistic problems and possible solutions, modelling methods are used. Queuing theory, mathematical optimisation and simulation are forms of modelling methods that are applicable to logistic problems.

3.2.1. Simulation

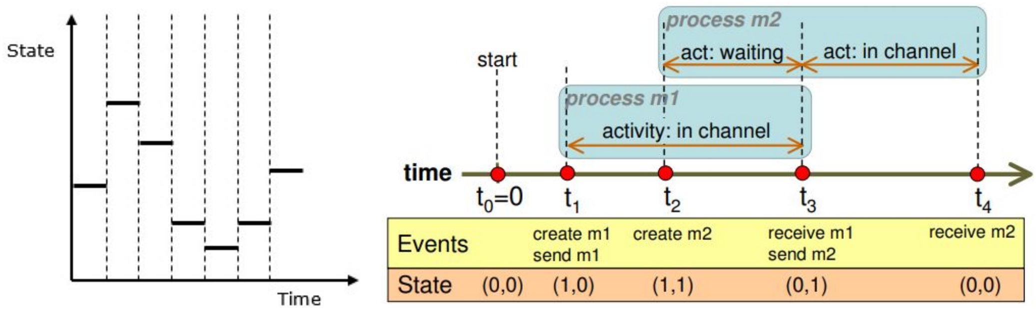
For this research a simulation is the most appropriate modelling method. Truck logistics at LBTs are rather stochastic than deterministic. Simulations enable it to include stochastic, dynamic and complex characteristics of logistic processes, whereas mathematical optimisation and queuing theory focus more on the optimisation level of a system and do not enable it to include stochastic characteristics [46, 50, 59, 60]. Deterministic models use known and fixed data. Stochastic models take distributions and uncertainties into account in used data making the data variable [44, 50]. Furthermore, simulations focus on the operational level of a system [29, 50]. This characteristic is beneficial for this research as all processes mentioned in Figure 2.4 can be included in a simulation. Furthermore, the KPIs as mentioned in Section 2.3 also focus on the operational level of an LBT. Simulations contain much information and usually show more pessimistic outcomes, compared to the queuing theory and mathematical optimisation. Furthermore, simulations can represent results relatively quickly in order to understand the behaviour of the system and to develop and analyse what-if scenarios. Simulations can model congestion management well and they can be seen as a digital twin of the physical infrastructure. Simulations are often build based upon flow diagrams [13, 60].

A simulation needs information prior to running. This information includes the boundaries of the system, resource constraints, which operations at the LBT have to be modelled and which layouts are used. Moreover, the arrival and handling processes can be modelled using distributions, by which the stochasticity is taken into account [5, 7, 13, 16, 26, 29, 50]. Once the inputs are set, bottlenecks can be tracked down and adjustments to bypass these bottlenecks can be implemented. The more actions and states are included in a simulation, the more complex it becomes. Though, it better represents reality. On the other hand, simplifications can be done in order to reduce computational time [7, 9].

3.2.2. Agent Based Simulation and Discrete Event Simulation

Agent Based Simulation (ABS) and Discrete Event Simulation (DES) are two simulation methods that are applicable to model truck logistics. DES is already paid great attention to in literature, ABS is relatively new and is not widely applied to truck logistic systems [1, 54]. Whereas DES focuses on a network level, ABS focuses on an agent level. An agent is described as an entity that is able to perceive and react to its environment [59]. Therefore, ABS analyses a system by the interaction between individuals. Individual behaviour, interactions, communication and operational sequences can also be taken into account [1, 16, 29, 54, 61]. These characteristics allow for heterogeneity to be better modelled by ABS. The results of ABS can be presented in a way that the influence of interactions and impacts of parameters can easily be noticed in the system performance [54].

DES works with discrete states, in which instantaneous jumps can be made from one state to another during a time span [62, 63]. Figure 3.6 shows an overview of DES. Figure 3.6a visualises the instantaneous jumps that can be made within the simulation. Figure 3.6b shows in detail the reciprocity of events, states and time in a DES. The states of a system in a DES depend on the input and influence the output of the system. States can differ at every point in time and only a finite number of state changes can happen during a time interval. The states in which a system can be in are defined prior to the simulation [46, 60, 63]. Events are triggered bases on states. Events define a change in state and affect the system performance. Only changed states are shown as a result, as these contain the most important information. During events, only computational time is utilised and no model time passes [46, 59, 63].



(a) Discrete Event Simulation [64]

(b) Discrete Event Simulation, detailed [63]

Figure 3.6: Overview of Discrete Event Simulation

The outputs of ABS and DES are comparable with respect to the simulation of logistic processes, especially regarding the level of detail. The major difference is that ABS takes individual behaviour into account to a larger extent than DES, in which autonomy is hard to distinguish. Moreover, if the same input is set, DES gives the same output, while for ABS every simulation is unique. DES focuses more on macro level and the computational time is shorter compared to ABS. However, ABS is more flexible and better represents reality [59]. Though, DES is a good trade-off between computational time and interesting information of the logistic process.

3.2.3. Monte Carlo Simulation

In order to get a good understanding of the system performance, Monte Carlo simulation is used. Monte Carlo simulation uses the Law of Large Numbers (LLN) and the Central Limit Theorem (CLT) to approximate the average outcome. The LLN asserts that the mean of the sample approaches the average of the population it is taken from as the size of a sample increases [65, 66]. In addition, the CLT states that the distribution of sample means converges to a normal distribution as the sample size increases, regardless of the shape of the population distribution. A sample size that is sufficiently large predicts the characteristics of a population precisely [65, 66, 67].

The larger the number of samples, the better the approximation. All simulations in this research are therefore run a couple of times, in order to attain a range of outcomes. The simulations often have slightly different initial parameters [8, 9, 13, 54].

3.3. Conclusion

A Truck Arrival Management system defines the information/communication stream of truck logistics at Liquid Bulk Terminals. TAM systems aim at providing good service to customers and at properly managing truck arrivals. Though, truck arrivals usually show two peaks per day which result in long queues and decrease terminal productivity. The TAM systems that are researched are the Truck Appointment System and Drop and Swap.

This chapter focuses on sub-research questions 3 and 4. These questions cover how TAS and D&S can be specified and which modelling methods would be appropriate for modelling an LBT system with a complementary TAM.

Truck Appointment System is usually an electronic system in which transport operators can book a time slot for unloading. The working day of a terminal is divided into time windows and together with equipment availability during the day, time slots for unloading are generated. If slots are full, trucks are forced to book another slot. This should decrease the number of trucks arriving at the same time. However, this system is not as efficient as it may seem. It is majorly based on a strict schedule, while arriving trucks and equipment availability have stochastic characteristics. Several incentives have been taken in order come up with customised TASs. More research should be done on these customised systems and if they are more effective in reducing congestion at LBTs. Therefore, this research uses the standard TAS for the development of the new TAM set-up.

D&S is another form of TAM. With this system, truck drivers drop off their full container and swap it for an empty container of the same transport operator at the Drop and Swap Terminal. This saves time, as External Truck Drivers do not have to enter the actual terminal. Internal Truck Drivers take care of the actual unloading operation, as they are more familiar with (operations taking place at) the terminal. This is a robust system which is able to catch peaks in the truck arrival pattern. Therefore, D&S is used in the development the complementary TAM system. However, it is only beneficial for transport operators that come to the terminal on a regular basis.

Lastly, to get a grip on the problem and its possible solutions, a modelling method is used. Several modelling methods exist, like queuing theory, mathematical optimisation and simulation. Simulation has properties that are advantageous for this research, as it takes into account dynamic, stochastic and complex characteristics of the problem. Simulations require information prior to running. Two types of simulation are discussed, namely Agent Based Simulation and Discrete Event Simulation. ABS is focused on the interaction between agents and what influence they have on each other. DES works with states in which a system can be. These states can change at every point in time through an event. The output of ABS and DES are comparable regarding the simulation of a logistic process. Though, DES takes less computational time and is therefore used as a modelling method for this research. With a Monte Carlo simulation, the simulation is executed several times with different initial parameters. This creates a range of possible outcomes that approximates the outcome even better.

4

Case Study Vopak Terminal Vlaardingen

In this chapter, the focus is on sub-research question 5. First the truck logistics with a Truck Appointment System at Vopak Terminal Vlaardingen is explained. This represents the TAM system that is currently used at VTV. Then, the truck logistics with the complementary TAM system is elaborated. This is focused on the additional supply chain setup by the new customer and how the truck logistics at VTV will be arranged accordingly. Subsequently, the factors that influence the new set-up of the supply chain are explained.

4.1. Truck Logistics at Vopak Terminal Vlaardingen

The case study of this research is the truck logistics at Vopak Terminal Vlaardingen. The processes that are discussed in Section 2.2 also happen at VTV. Therefore, the truck logistics with a Truck Appointment System and the truck logistics with a complementary Truck Arrival Management system are explained in this section. The complementary TAM system consists of Truck Appointment System and Drop and Swap.

4.1.1. Truck Logistics with a Truck Appointment System

In Figure 4.1, the map of VTV is shown with indicators. This figure is referenced in the text.

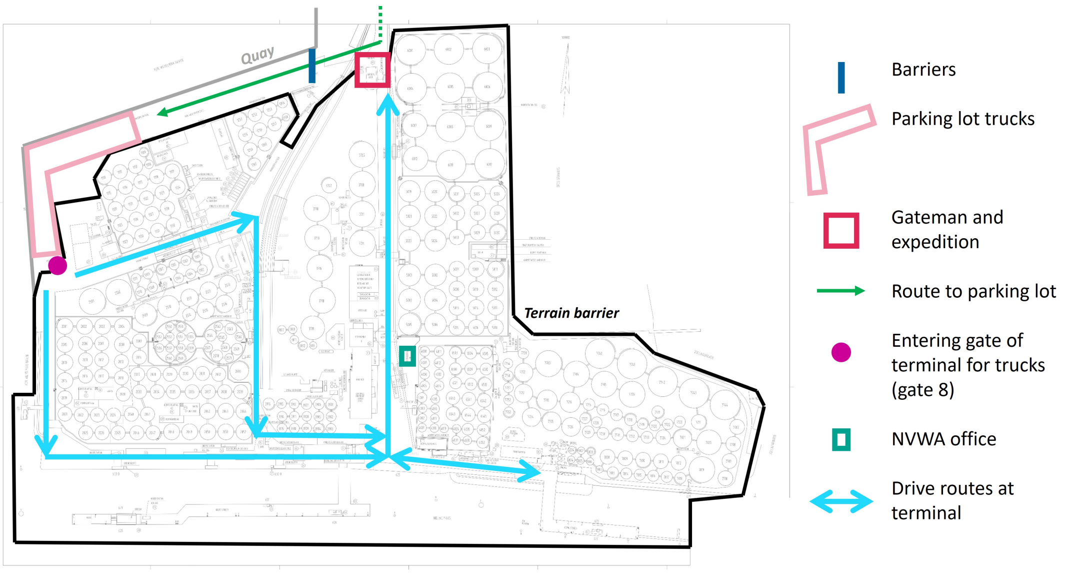


Figure 4.1: Map of Vopak Terminal Vlaardingen with important truck logistic indicators. Truck Arrival Management System: Truck Appointment System

Truck Appointment System as Truck Arrival Management System

Nowadays, VTV works with a TAS which means that transport operators book a slot for discharging trucks. A maximum number of slots is set per day and this number is the same for every unloading bay. Slots have a time length of 45 minutes. The first slot starts at 7:30 am, the last slot ends at 11 pm. A working day includes three breaks for terminal operators. The resulting number of slots per bay per day is therefore 18. Furthermore, for every booked slot, a terminal operator has to be present to be able to serve trucks. The slots are presented in Table 4.1. Not all slots are set available, to account for failures of equipment and to have some tolerance in the schedule. A restriction is that time slots have to be booked at least 24 hours in advance [68].

Table 4.1: Slotnumbers and Start Times

Slotnumber	Start Time
1	07.30 am
2	08.15 am
Break	09.00 am
3	09.30 am
4	10.15 am
5	11.00 am
Break	11.45 am
6	12.30 pm
7	01.15 pm
8	02.00 pm
9	02.45 pm
10	03.30 pm
11	04.15 pm
12	05.00 pm
Break	05.45 pm
13	06.30 pm
14	07.15 pm
15	08.00 pm
16	08.45 pm
17	09.30 pm
18	10.15 pm

The TAS of VTV does not include many ”smart” features. A feature that will be implemented in the coming year is that only available slots are shown to transport operators that are consecutive to former planned trucks, if possible.

Figure 4.2 shows the difference between the original planning and the actual execution of planned trucks at VTV. As can be seen, more trucks plan to arrive during morning shifts than that are actually arriving. Furthermore, more trucks are handled during afternoon shifts than were planned. This phenomenon can be explained by the fact that trucks have a preference for morning slots but are not able to reach the terminal in time, because of external factors like traffic jam. Therefore, these trucks are moved to afternoon shifts. Research shows that approximately 15% of the truck drivers miss their time slot.

Overall, it can be seen that slot usage is higher in the morning than in the afternoon. This trend is supported by the daily pattern that is shown in Appendix B, Figure B.3.

Truck Appointment System: Arriving Process

It is the intention that truck drivers drive to the terminal before their time slot starts. At the moment they arrive at the barriers, the barriers open automatically and trucks can drive to the parking lot for trucks. Truck drivers have to park their truck and walk to Expedition. Expedition is located in the same building as the gateman, as can be seen in Figure 4.1.

Truck Appointment System: Entering Process

Once arrived at Expedition, truck drivers have to register and arrange the paperwork. This must be done physically prior to the time slot booked, because of hardcopies that are necessary to execute checks. Truck drivers have to be present at the gatehouse at least 30 minutes prior to the start of their time slot in order to not lose their reserved time slot [68]. However, in practice if it is more beneficial for the terminal and the truck driver to still unload its liquids although the truck driver was too late, the unloading of the liquids is still done. An important condition is that any truck that has booked the time slot after the truck driver that was too late, may not be negatively impacted.

The first thing that has to be done by every truck driver before it can be served by a member of Expedition is fill in a guidance form upon at Expedition. This form contains information about e.g. the license plate, the transport operator, the product transported, the number of compartments and the last time the truck was cleaned. After filling in the form, the truck driver lines up to be served by a member

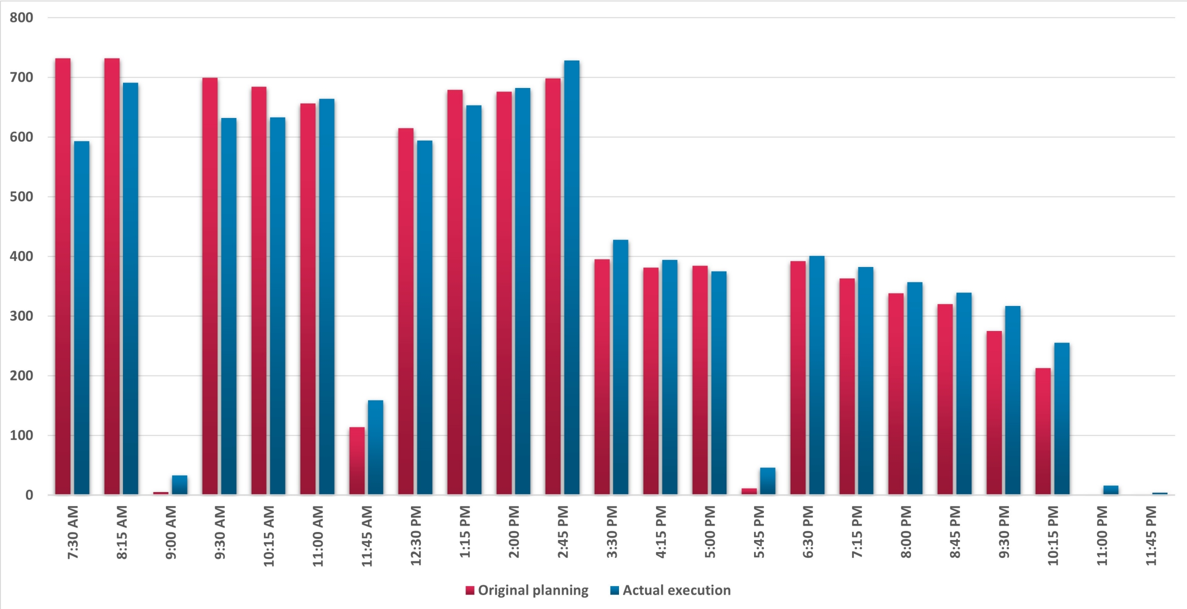


Figure 4.2: Original vs. Actual Planning of Trucks that have to be Loaded [69]

of Expedition. Once a truck driver is served by Expedition, the rest of the paperwork is arranged. The amount of paperwork depends on several factors. These factors include, but are not limited to, the number of times the truck driver visited Vopak before, the origin of the product and the type of the product. Expedition checks the information on the documents filed by the truck driver. The information that is being checked covers for example the product, the origin, the destination, the transporter, the license plate and the number of compartments in the truck. This information is found on documents like the guidance form, transport document and cleaning certificate. Furthermore, a Poort Intstructie Training/Gate Instruction Training (PIT) is necessary if a truck driver enters a Vopak terminal for the first time or if the PIT has expired, which happens after two years. The PIT has to be done under supervision of a safety guard or Vopak employee [68]. Two failures are allowed for a PIT. After the first failure, the PIT may be redone straightaway. After the second failure, the truck driver has to return the next day. If the PIT is failed again, the truck driver has to leave and access to the terminal is denied for the next two months [68].

Another important and slightly explicit inspection is the Nederlandse Voedsel- en Warenautoriteit/Netherlands Food and Consumer Product Safety Authority (NVWA) inspection. This is an inspection executed by a veterinarian of the NVWA and has to be done on animal byproducts. Animal byproducts are categorised into three categories: Category 1, Category 2 and Category 3 [70]. Category 1 and Category 3 products are handled by VTV. The inspection exclusively has to be carried out on products that are imported from outside the EU. The inspection has to be done at VTV as the terminal has a license for being a Border Control Post (BCP) [71]. Other companies and customers can also use this BCP, which means that inspections on products for customers that do not store their liquids at VTV can also be done at this BCP.

The NVWA inspection can be executed between 7 am and 6 pm [72]. However, the veterinarian that has to do the inspection is not present the whole day at the BCP at VTV. This results in the fact that the NVWA inspection can be booked a couple of weeks before, but is confirmed only 4 pm the day before the inspection was planned to be executed. At that moment it is known at what times the veterinarian is present at the BCP at VTV. The NVWA inspection itself consists of taking a sample of the liquid product and preparing papers, which is done at the NVWA location at the terminal as indicated in Figure 4.1. In order to take a sample, the product has to be in a fluid state. Therefore, solidifying products have to be heated prior to the execution of the NVWA inspection. The complete process of the NVWA inspection takes approximately 30 minutes up to 2 hours and depends on the veterinarian and the number of trucks that have to be inspected. If multiple trucks have to be inspected on the same day, they are often combined in one appointment.

Furthermore, imported containers can come in batches. Per non-EU country agreements have been made if imported containers can arrive in batches, and if so, how many containers are allowed to be in a batch. If containers are allowed to come in a batch, only one container of such a batch has to be inspected by the NVWA. The other containers will automatically be approved as well if the inspection of the first container is approved. The other containers do not have to be present at the parking lot of the terminal at the time of inspection.

The inspection can either be approved or rejected. After approval of the first container, the other containers are released and can unload their liquids at the terminal without inspection. However, if that first inspected container is rejected, all containers from the same batch have to come to the parking lot of the terminal and have to be inspected individually. If containers are not allowed to come in a batch due to agreements, every container has to be inspected individually.

In the event of a rejection, the container has to be sealed and has to stay at the same location as it was sealed, which is the parking lot of VTV as this is the official BCP. Containers can be re-inspected after rejection if the problem that led to the rejection is fixed. Problems that might cause a rejection are wrong product stickers or wrong information on documents for example. Preparing for re-inspection might take a couple of hours up to 24 hours. If the re-inspection is approved, the containers are allowed to unload their liquids at VTV. If the re-inspection is also rejected, the import of the container has failed and the NVWA decides what has to happen with the containers. Most of the times they have to return to the harbour depot. For the modelling of the system, the possibility that NVWA containers from the same country are allowed to arrive in batches is not taken into account. The reason for this is that the Purchase Book is not yet known. Hence, every container has to be inspected individually.

Without NVWA inspection, it takes approximately 5 to 30 minutes to handle a driver at Expedition. After the completion of the inspection and the paperwork at Expedition, the driver walks back to its truck and waits up to 15 minutes prior to its time slot starts to enter the terminal via gate 8, as indicated in Figure 4.1. Hence, a truck occupies a spot at the parking lot from the moment it arrives at the terminal until the truck enters gate 8.

Sometimes a time slot is missed and the driver has to shift to another slot in consultation with the planning department. A time slot is missed if registration is not finished 15 minutes prior the the start of the time slot. This results in trucks occupying a parking space for a longer time. Therefore, these parking spaces are not available for other trucks that want to register.

Employees at Expedition start working at 7 am. Every truck driver that arrives before this time has to wait until 7 am to be served by the employees of Expedition.

Truck Appointment System: Unloading Process

After entering, the driver drives its truck to a weighing bridge for an initial weighing. Weighing is important in order to settle the right amount to the customer and for customs regulations. After weighing, the truck driver drives on to its unloading bay of which three are present at the terminal nowadays. The truck can be prepared at a fall protection to get ready for unloading. Preparation consists of e.g. opening manholes. The fall protection is present at the unloading bay. Preparing the truck is important such that the truck or container is not vacuumed when unloading [68].

In advance, the pipes and pump necessary for unloading are prepared and lined up by terminal operators such that unloading can start immediately. The operator at the unloading bay checks the paperwork and starts the unloading in case everything is correct. The duration of unloading depends on a couple of factors, namely the used equipment and the characteristics of the liquid product, e.g. the viscosity. The average pumptime to unload a truck is approximately 35 minutes.

If a tank switch needs to take place in between two trucks that have to be unloaded, one time slot is reserved in order to complete this tank switch by terminal operators. A tank switch is necessary if the former truck and the current truck do not carry products that have to be unloaded in the same storage tank.

Truck Appointment System: Departing Process

Once the liquid is discharged from the truck, the truck driver drives to the last weighing bridge for a final weighing [68]. After weighing, the truck driver drives to the main street, parks its truck aside and has to go out of its truck to go to Expedition again. At Expedition, the truck driver receives its final paperwork. After this step, the truck driver can leave the terminal.

4.1.2. Truck Logistics with a Complementary Truck Arrival Management System

The logistic processes that happen within the complementary Truck Arrival Management system and its configurations are elaborated in this section. For the new customer that stores its liquids in the new tank pit, the procedure described in Section 4.1.1 still applies to a large extent, especially for the TAS part of the complementary TAM system. However, some modifications are explained in this section. The map of VTV in the new situation is shown in Figure 4.3.

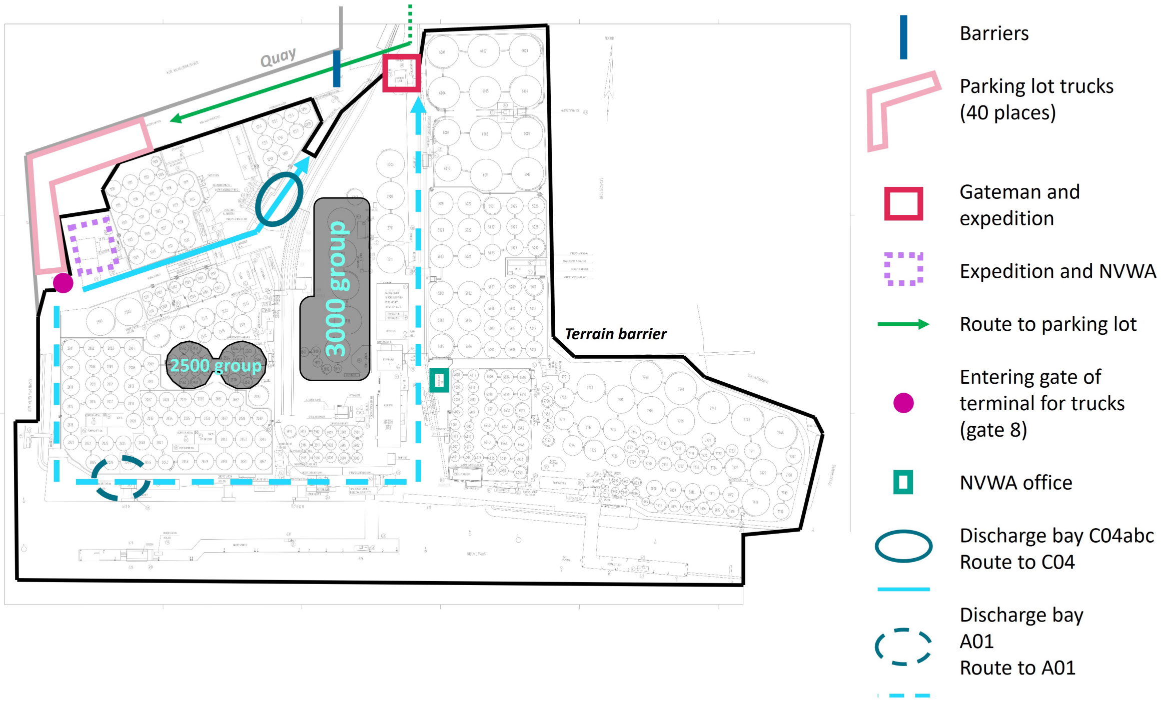


Figure 4.3: Map of Vopak Terminal Vlaardingen with important truck logistic indicators.
Truck Arrival Management System: Complementary Truck Arrival Management System

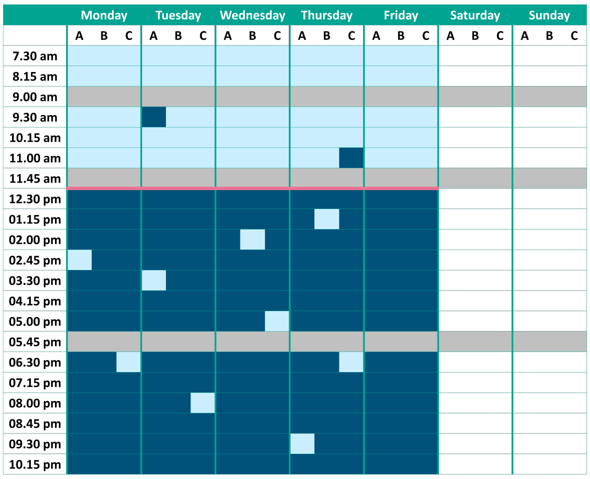
Complementary Truck Arrival Management System

In order to improve the arrival process, the research gap as described in Section 1.3 is converted into a set-up that is explained in this section. The improvement in the TAM system is that a combination between Truck Appointment System and D&S is made. Trucks that are from within the EU are handled in the first place via the TAS. Trucks from outside the EU are handled in the first place via D&S. This distinction is done based on the origin of the trucks. Trucks from within the EU completely use road transportation and are planned in the TAS. Whereas containers from outside the EU arrive at the port of Rotterdam via sea transportation and use road transportation for last mile delivery. The port of Rotterdam is used as DST in the D&S system.

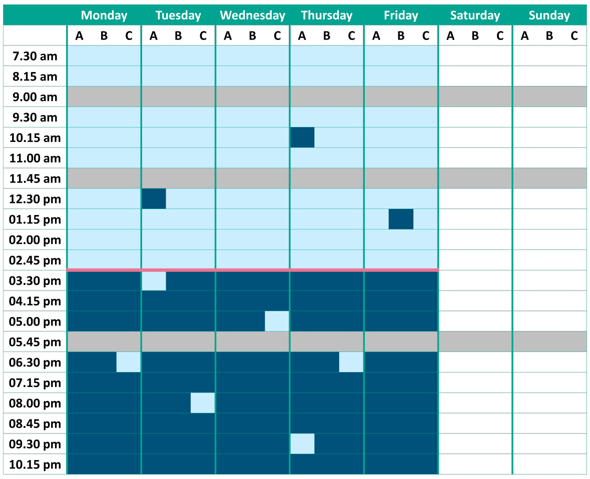
In Figure 4.4, **examples** of the previously mentioned TAM set-up are shown for a week. It shows the week, the unloading bays at VTV (C04a, C04b and C04c) and which time slots are available for TAS and which times are reserved for D&S. Figure 4.4a shows the set-up with ratio 3:7, Figure 4.4b shows the ratio 5:5 and Figure 4.4c shows the ratio 7:3 for TAS:D&S per day. Figure 4.4d explains the colour use.

As can be seen, the aim is that the morning is used for TAS and the afternoon is used for D&S. This means that EU trucks will be unloaded in the morning and non-EU trucks will be unloaded in the afternoon. The idea behind this set-up is that non-EU trucks can already be placed at the parking lot of VTV in the morning such that the NVWA inspection can take place, after which they can be unloaded in the afternoon. As stated in Section 4.1.1, only imported containers that carry Category 1 or Category 3 products have to have an NVWA inspection. Therefore, only the non-EU containers of the new customer have to have an NVWA inspection. This is because these trucks are imported and EU trucks are not imported. Furthermore, daily patterns show that the majority of the slots is used in the morning compared to the afternoon, as can be seen in Figure 4.2.

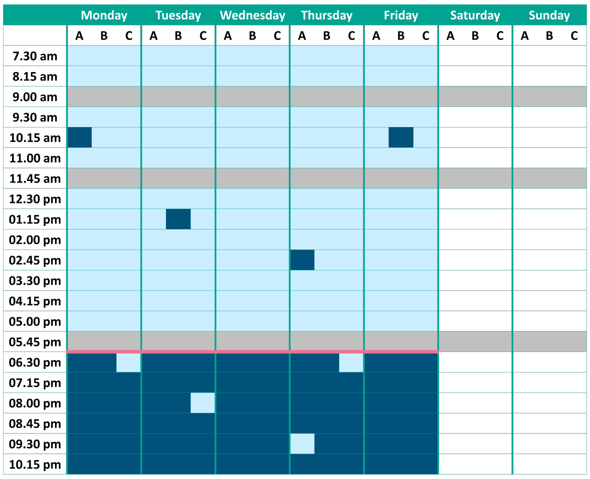
In Figure 4.4a, Figure 4.4b and Figure 4.4c, some light blue blocks can still be seen in the dark blue area, and vice versa. These blocks have been put there because some EU trucks might still miss their time slot in the TAS. Therefore, trucks that have missed their time slot can be unloaded in between D&S trucks if necessary. This is possible because the terminal is more in control of truck arrivals when D&S is used as explained in Section 3.1.2. If a slot is empty in the TAS or an EU truck misses its time slot, a non-EU truck that is ready to unload can also use that time slot to unload before the D&S part starts.



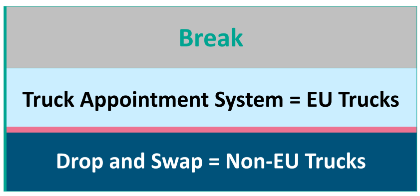
(a) 30% Truck Appointment System, 70% Drop and Swap



(b) 50% Truck Appointment System, 50% Drop and Swap



(c) 70% Truck Appointment System, 30% Drop and Swap



(d) Explanation of used Colours

Figure 4.4: Examples of Week Overviews of a Complementary Truck Arrival Management System

The exact implementation of this set-up is subject to this research. The required ratio between TAS and D&S at a day depends on the Purchase Book of the customer. It might even be the case that no separation between TAS and D&S is necessary, because either a day can fully be TAS or fully be D&S. A simulation model is build in order to research the complementary TAM system, which is explained in more detail in Chapter 5.

Saturday and Sunday are left empty in Figure 4.4. Normally, no unloading operations take place on Saturday and Sunday as can be seen in Appendix B, Figure B.4. For the new customer it is also the aim that during weekends no unloading operations take place. However, if it seems not achievable to unload all trucks during weekdays, it can be considered to unload during weekends.

Researched data from within VTV shows that it is hard to prevent tank switches as explained in Appendix B, Section B.5. Most days can not be optimised regarding an algorithm that is applied to data from the last couple of years. Moreover, days that can be optimised show that at most one or two tank switches can be eliminated, for which much flexibility is required from truck drivers. Truck drivers have to be present at least two time slots before their scheduled time slot, but can also be placed two time slots later than their scheduled time slot. This set-up is not favourable as truck drivers are not willing to wait this long. Therefore it is decided that the optimisation of tank switches is left out of the TAM system that focuses on the TAS part. Within the D&S set-up it is easier to prevent tank switches, as the terminal is to a certain extent in control of truck arrivals. Hence, it is easier to decide which containers have to be unloaded at a specific day to prevent tank switches. The containers that have to be unloaded can be prepared and grouped as well before they arrive at VTV.

Complementary Truck Arrival Management System: Arriving Process

Containers imported from outside the EU arrive at the port of Rotterdam, where they are unloaded from the ship onto the DST. From this DST, the containers can be transported to the parking lot of VTV. Trucks from within the EU are directly arriving via road transportation at the parking lot of VTV. This process is visualised in Figure 4.5.

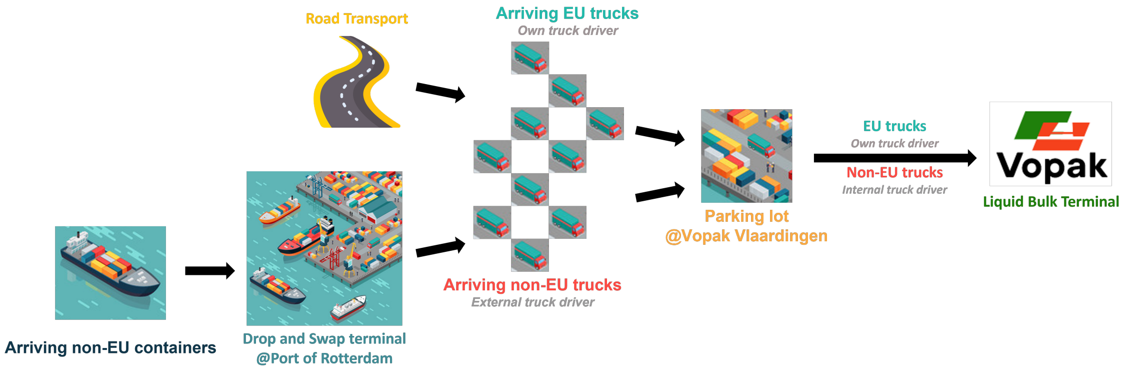


Figure 4.5: Arriving of Trucks for Complementary Truck Arrival Management System [73, 74, 75]

From the parking lot at VTV, the EU trucks can enter the terminal with their own driver. The non-EU trucks are transported by other truck drivers. An External Truck Driver transports containers from the DST to the parking lot of VTV. The Internal Truck Driver transports the containers between the parking lot at VTV and the unloading bays at the terminal with a terminal tractor. The Internal Truck Driver also takes care of the entering process at the gate for these containers.

It is the idea that containers from outside the EU that transport solidifying products are heated at the DST. Trucks from inside the EU do not have to be heated after they left their origin country as they lose approximately 2°C per 24 hours. VTV can not facilitate a heating service to trucks before they enter the terminal [76].

At the parking lot of VTV, 25 parking spots are reserved for trucks of the new customer. A separation is made as well at the parking lot for trucks that are handled via the TAS and trucks that are handled via the D&S system. The initial configuration is that 15 parking lots are reserved for TAS and 10 parking lots are reserved for D&S. This is the initial set-up and changes during the experiments based on the executed research.

Complementary Truck Arrival Management System: Entering Process

For the complementary TAM system, the entering process at VTV might change. Firstly, Expedition is probably moving to near the entrance gate for trucks (gate 8 in Figure 4.3). The new office for Expedition might then also include the NVWA office. The relocation is not yet decided by VTV, but plans are made. The advantage is that Expedition and NVWA are closer to the actual entrance gate of the terminal for trucks [76].

Additionally, a separate member of Expedition is dedicated to handling all truck drivers that arrive for the new customer. This means that the logistics for the new customer and the current logistic operations at the terminal do not interfere at this point.

Another scenario that is considered by the new customer, is to execute NVWA inspections at the container terminal in Rotterdam where imported trucks arrive with the container ship. This could relieve many (scheduling) complications with trucks that have to be inspected by the NVWA at VTV before unloading.

Complementary Truck Arrival Management System: Unloading Process

There are three designated newly built unloading bays with integrated fall protection and weighing bridge at which the trucks can discharge at VTV, see Figure 4.3. This means that some routes change and that preparing the truck and the initial and final weighing will be done at the unloading bay itself, instead of at a separate location. Furthermore, it is agreed with the new customer that only single-compartment trucks should be used. Therefore, trucks only have to pass one unloading bay per visit. Single-compartment trucks are also safer and more efficient [68].

A dotted route and unloading bay can be seen in Figure 4.3, this shows an unloading bay which can be added to the logistics for the new customer. A fifth unloading bay can also be added. However, this is not favourable as the new customer and the existing operations at the terminal interfere at that moment. The fourth and fifth unloading bay are only set into operation if the incoming number of trucks reach a certain level [76]. These levels are shown in Table 4.2.

Table 4.2: Unloading Bays Operational Set-up [76]

Number of Incoming Trucks per Year	Number of Operational Unloading Bays
9200	3
13500	4
19000	5

After all, the agreement is made that the logistic set-up is first done for the three dedicated unloading bays. Therefore, the fourth and fifth unloading bay are left out of scope.

The three dedicated unloading bays are connected to the sixteen newly built tanks in the 3000 group. Furthermore, there are three tanks in the 2500 group which are already present at the terminal nowadays. These tanks will be connected to the newly built unloading bays. Products of unknown quality have to go in quarantine in these three tanks. After sampling and some days of quarantine, the liquids can be transported to the sixteen tanks of the 3000 group [76].

The three dedicated unloading bays are named C04A, C04B and C04C. Some differences exist between the unloading bays regarding the product flows. The main product flows that will be unloaded at VTV for the new customer are animal byproducts, which include Category 1 and Category 3 products, non-categorised and waste products. Category 1 products can exclusively be unloaded at unloading bay C04C and cannot be unloaded at unloading bay C04A or C04B [76]. This is because Category 1 products have to be disposed as waste due to the fact that it is categorised as animal byproduct [70]. Therefore, this product stream may not concatenate with any other non-waste products and should strictly be separated from the other product streams. If liquid that is not Category 1 product comes in contact with Category 1 product, the liquid has to be degraded to Category 1 product.

The overview of unloading bays and connected tanks is given in Table 4.3. Unloading bays A and B are connected to the same tanks. It is even possible to unload two trucks simultaneously at unloading bays A and B. Unloading bay C is connected to the Category 1 tanks. Furthermore, a blending feature is present in the tanks, excluding the possibility of blending Category 1 product with any other products. As previously mentioned, the additional unloading bay A01 is set on hold for now. It can be connected to 5 tanks in the 2000 group in the future [76].

The maximum technical availability of the unloading bays and the accompanying equipment is set to

Table 4.3: Unloading Bays Connected to Tanks [76]

Unloading Bay	Number of Connected Tanks in 3000 Group	Number of Connected Tanks in 2500 Group	Number of Connected Tanks in 2000 Group
C04A	16	3	0
C04B	16	3	0
C04C	6	0	0
A01	0	0	5

80%. The other 20% accounts for technical unavailability and (unplanned) maintenance. Furthermore, the assumption is made that it takes maximum 45 minutes to unload trucks [76]. This does include the preparation, pumptime and finishing process of the truck. Preparation has to be done at the dedicated unloading bays, as the fall protection and weighing bridge are integrated in the unloading bay.

Complementary Truck Arrival Management System: Departing Process

The aim is that truck drivers do not have to visit Expedition after unloading, but that they will receive the final paperwork of the operator at the unloading bay. This saves leaving time of a truck and therefore, the next truck can start unloading quicker.

After unloading, the Internal Truck Driver (ITD) that is in charge of the non-EU trucks at the terminal drives the trucks back to the parking lot of VTV. From the parking lot of VTV, an External Truck Driver (ETD) takes care of the transportation of containers back to the DST in the port of Rotterdam. From there, the containers are transported back the their origin or to another location with container ships. The EU trucks leave the terminal with their own truck driver and return to their origin or leave for another destination completely via road. This process is visualised in Figure 4.6.

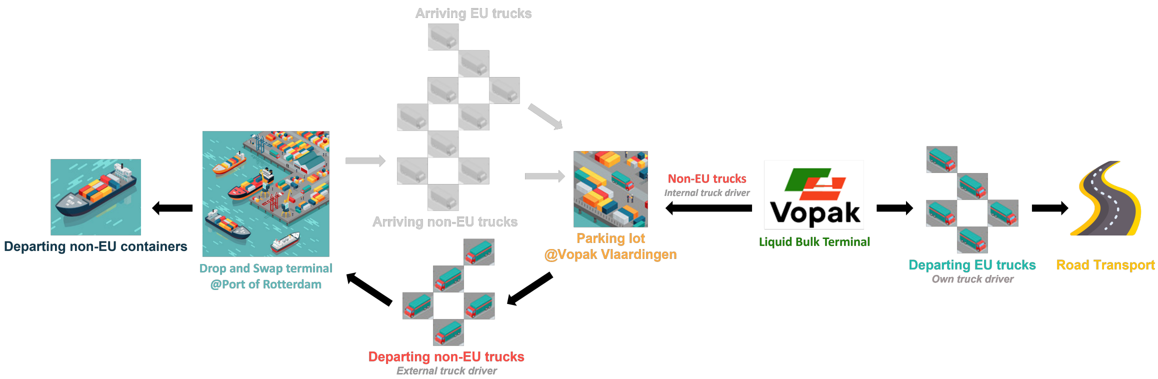


Figure 4.6: Departing of Trucks for Complementary Truck Arrival Management System [73, 74, 75]

4.2. Factors Influencing the Supply Chain

This section focuses on factors that influence the supply chain that has been setup by the new customer of VTV for unloading liquids in the newly built tank group. The supply chain is visualised in Figure 1.4. The factors that influence the supply chain play an important role, as future changes in the Purchase Book affect scenarios that happen within the supply chain. It is in line with expectations that the Purchase Book will change over time, as product resources are not inexhaustible. Therefore, other locations and sources have to be addressed. Additional to purchasing products from other locations, is the fact that the supply route to the terminal changes, which affects the truck arrivals.

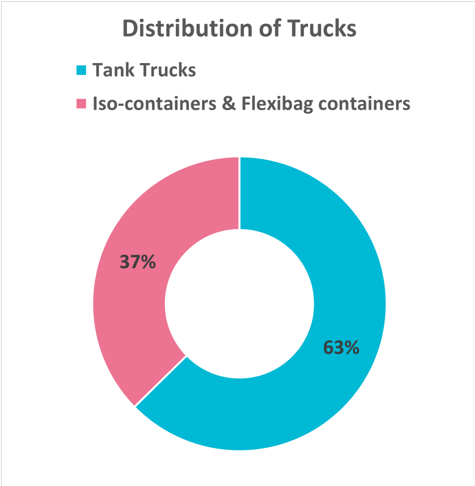
4.2.1. Truck Type and Product Type

The supply chain and Purchase Book interact with each other. The Purchase Book contains products that are and will be purchased including their origin locations. Furthermore, it contains the distribution of numbers of how products are transported, either via bulk, barge, flexibag, iso-container or tank truck [77].

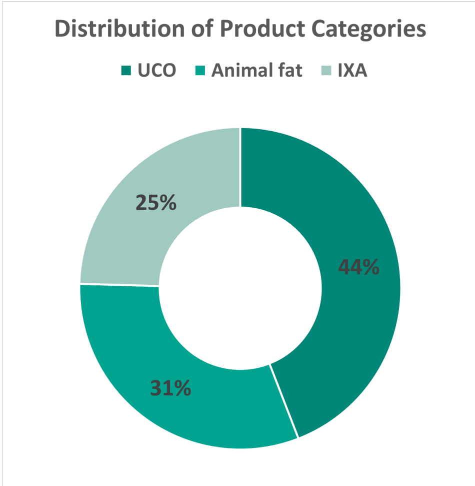
Figure 4.7 shows basic assumptions about the Purchase Book of the new customer at VTV. This research focuses on the truck supply exclusively, therefore only information about trucks is shown. Figure 4.7a shows the supply distribution among different types of trucks, namely the tank trucks on one hand and the container trucks on the other hand. Figure 4.7b shows the supply distribution among different product categories, which are Used Cooking Oil (UCO), animal fat and IXA lipids (acids). Figure 4.7c shows which part of the container trucks that will be supplied has to be heated and which part has to be inspected by the NVWA.

Animal waste products from outside the EU need to be inspected at the import location by the NVWA. The import location is VTV in this case, as this is an official BCP [71]. An appointment made at the NVWA is always confirmed or rejected the day before the appointment at 4 pm. This confirmation or rejection is passed on late and therefore brings along uncertainties within the unloading schedule.

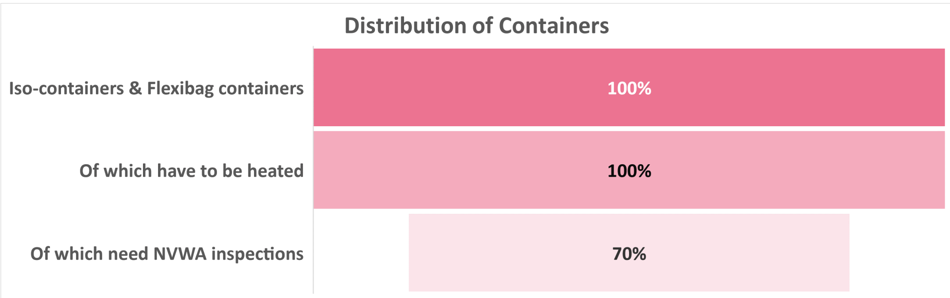
Furthermore, some liquids have to be heated before they can be unloaded, otherwise the liquid has a solid form. This characteristic depends on the liquid properties. Some liquids take longer to heat, or are not properly and/or completely heated upon arrival at the terminal. This leads to extra complications within the supply of the liquids.



(a) Supply Distribution among Truck Types



(b) Truck Supply Distribution among Product Categories



(c) Distribution Heating and NVWA Inspections among Container Trucks

Figure 4.7: Basic Assumptions for Purchase of Book New Customer at Vopak Terminal Vlaardingen

4.2.2. Origin

As mentioned in Section 1.2.1 liquid products can be bought in- and outside the EU, which leads to different supplies to the terminal. Liquids bought outside the EU will be transported via overseas transport. Due to local aggregation which is explained later on, the transport of these liquids can either be done via vessels, which go directly to VTV and fall outside the scope of this research. The other option is that liquids are transported via containers on ships, which will go to an import location at the port of Rotterdam. Thereafter, the containers will be transported via the road to VTV. Liquids bought inside the EU will completely be transported via road transportation to VTV. The difference in transportation will cause a difference in supply. With overseas container transportation, a large number of containers will arrive at the port of Rotterdam at once. Hence, peaks in supply can be experienced. Regarding liquids from inside the EU that are completely transported via the road, the flow will be more steady as it is supplied on a more regular basis [78].

4.2.3. Supply Scenarios

Figure 4.8 shows the different scenarios that the customer has setup regarding the supply of liquids. The first scenario consists of partnerships with majorly large suppliers from within the EU with additionally partnerships with big non-EU suppliers. This results in a reliable feedstock quality and regular

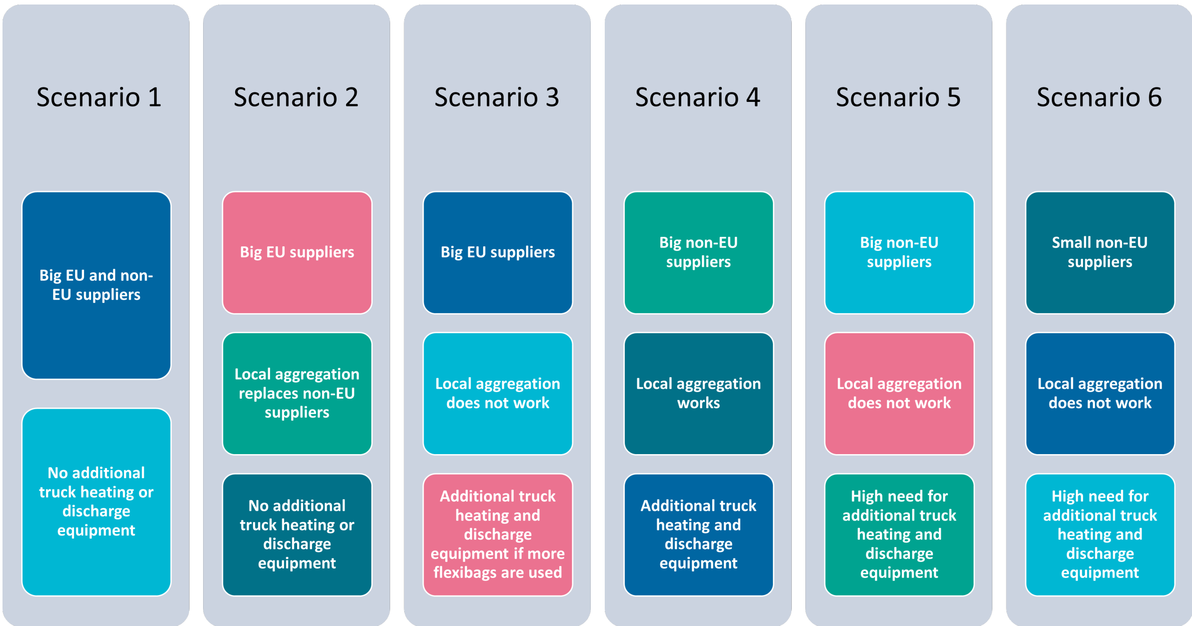


Figure 4.8: Explanation of Supply Scenarios [78]

influx of liquids. A benefit is that liquids supplied from within EU do not need to be heated an extra time before they arrive at VTV, as the heating is done locally before trucks leave their origin. Liquids will still be fluid at the time of unloading at VTV. Moreover, no NVWA inspections need to be done for liquids from within the EU. NVWA inspections bring along uncertainties in the schedule because of the late confirmation for inspection. NVWA inspections are elaborated in Section 4.1.1. There will still be a part of the supply that comes from outside the EU. However, partnerships are made with big suppliers which makes importing easier, compared to importing with small non-EU suppliers [78].

Other scenarios are also visible in Figure 4.8. These might include several smaller suppliers or more suppliers from outside EU, which requires more alignment in the supply chain and more import formalities and veterinary inspections. Furthermore, quality parameters are less reliable and the resource has to be sizeable to secure a big enough supply in one go as economies of scale increase cost-efficiency. Another option can be to locally aggregate the supply. Local aggregation can be done either in- and outside the EU and is done in order to merge the supply from containers. The liquids in containers will be transshipped to vessels locally, from this location it will directly be transported to VTV. Therefore, local aggregation decreases the number of trucks that have to come to VTV. It relieves last mile coordination, but requires more coordination for local aggregation. If local aggregation does not work, there is an increased focus on last mile coordination because of the extra incoming trucks at VTV.

Table 4.4 shows the values that apply to the different scenarios for the truck supply. It can be seen that the succeeding of local aggregation and the partnerships with big suppliers majorly influence the number of trucks that will arrive per day at VTV. Furthermore, whether or not there will be partnerships with EU or non-EU suppliers influences the ratio of non-heated:heated trucks. The more trucks originally come from within the EU, the less trucks need to be heated before they unload at VTV.

Table 4.4: Values Supply Scenarios

Scenario	Estimated Number of Trucks per Day	Ratio Non-heated vs. Heated trucks
1	40	70/30
2	40	70/30
3	55	54/46
4	20	0/100
5	55	0/100
6	75	0/100

The idea for the improvement in the TAM system is mainly focused on the difference between EU and non-EU trucks, as previously explained. EU supply causes a more constant flow, which makes it easier to plan these trucks with TAS. Non-EU supply causes a more peak flow, because of container ships that arrive at the port of Rotterdam. Therefore, the idea is to let these trucks arrive via a D&S system with the container terminal at the port of Rotterdam as DST.

4.3. Conclusion

In this chapter sub-research question 5 is answered. The truck logistics of the case study are discussed. For the case study, the truck logistics with Truck Appointment System as Truck Arrival Management have been discussed first. This represents the existing truck logistics at Vopak Terminal Vlaardingen. Subsequently, the truck logistics with a complementary TAM system have been explained. This represents the new situation that is investigated in this research. Lastly, the factors that influence the newly setup supply chain are elaborated.

For the truck logistics at Vopak Terminal Vlaardingen with TAS as TAM, a schedule in which 18 slots of 45 minutes are set available per day. Slots in the morning are preferred above slots in the afternoon. Once trucks arrived at the parking lot, they have to be registered at Expedition before they can enter the terminal. Some imported trucks might need an NVWA inspection. There are three unloading bays present at the terminal nowadays. Preparation of the truck is done before entering the unloading bay. The unloading takes approximately 35 minutes, after which truck drivers have to leave via the main street and often have to return to Expedition to finish the paperwork.

The truck logistics at VTV with a complementary TAM system is the main subject of this research. The complementary TAM consists of two systems that can work together to control truck arrivals, namely TAS and D&S. For the incoming trucks that unload for the new customer at VTV, a distinction will be made between trucks based on their origin. Trucks from within the EU arrive via TAS and trucks from outside the EU arrive via the D&S system. The result is that during the morning, trucks arriving via the TAS are handled and trucks via the D&S sytem are handled in the afternoon. Preparation of the truck for unloading will happen on the unloading bay. Unloading for the new customer happens on three dedicated newly built unloading bays into 16 newly built tanks. The finishing of paperwork will also happen on the unloading bay.

Factors that influence the supply chain for the new customer include amongst others the truck type, product type, origin of the product and whether or not local aggregation is possible. Several supply scenarios have been setup by the customer. The number of trucks coming to the terminal per day ranges from 20 to 75, with different ratios regarding their origin.

5

Model Design

This chapter focuses on sub-research question 6 which focuses on the design of a simulation model of a complementary Truck Arrival Management at a Liquid Bulk Terminal. The model objective, requirements and the assumptions made for the model are elaborated. Then, the model components and flow charts are presented. Several flowcharts are presented, all for a different subset of the model. Subsequently, the model implementation, verification and validation are presented. Validation is done in three parts, namely data validation, structural validation and performance validation. For data validation and performance validation, historical data of Vopak Terminal Vlaardingen has been used.

5.1. Model Objective

The objective of the simulation model is to investigate if limitations of TAM systems at LBTs can be overcome by developing a complementary TAM system. By means of the simulation model, a good understanding of the truck logistic processes at an LBT is gained and inefficiencies can be traced. The two TAM systems that work complementary are TAS and D&S, for which two logistic flows had to be developed in the simulation model. Inefficiencies that can be thought of are e.g. a time slot has been missed by a truck in the TAS which could be used by a truck from the D&S system that was ready to unload at the slot start time. The model is based on a case study performed at VTV for a newly setup global intermodal supply chain. The TAS is based on the existing TAM system at VTV. A D&S system has not been integrated at a large scale at VTV yet.

As mentioned, the goal is to see if the system performance of an LBT regarding incoming trucks with different origins can be improved by a complementary TAM system, before implementing it in the real world. The system performance is measured by the KPIs as stated in Section 2.3. As formerly mentioned in Section 4.1.2, a separation is made in incoming trucks in the complementary TAM system. EU trucks arrive via the TAS and non-EU trucks arrive via the D&S system.

In the simulation model, both TAM systems can work separately and complementary. There are two reasons for either enabling the systems to work separately and complementary. The first one is to be able to compare the system performances of a complete TAS, a complete D&S system and a complementary TAM system for several inputs and parameters. Therefore, the NVWA inspection is incorporated in all flowcharts, despite the fact that in a complementary TAM system only non-EU trucks arrive via the D&S system. The second reason is that in case no non-EU trucks enter the system, a complete TAS has to be available and at the moment no EU trucks arrive, a complete D&S system should be available.

5.2. Model Requirements

The model requirements are necessities that have to be present in the model to represent the truck logistics at the terminal in a realistic way. The following requirements are set:

- The model must be easily adaptable.
- The model has to include a working TAS.
- The model has to include a working D&S system.

- The model must be able to let the TAS and the D&S system work complementary to each other.
- The physical processes processes arriving, entering, unloading and departing of trucks have to be included in the simulation model.
- The model has to be able to handle all possible truck types.
- The model must include the NVWA inspection.
- At least three three unloading bays have to be included in the simulation model.
- The model must be able to run for more than one day.
- The KPIs have to result from the simulation.

5.3. Model Assumptions

Model assumptions also have to be made in order to let the model work. The assumptions are made about facets of the model, in order to realistically represent the truck logistics. The following **general** assumptions are made:

- Weekends are not incorporated in the simulation.
- The initial value for the number of Expedition members is one. Every PIT at Expedition succeeds with a chance of 60%.
- All registrations at Expedition succeed.
- NVWA (re-)inspections succeed with a chance of 90%.
- Preparing for an NVWA re-inspection takes 2, 4 or 24 hours, with equal chances to happen.
- Removal of trucks that are rejected by the NVWA takes 0, 6, 12, 18 or 24 hours, with equal chances to happen.
- There is only one NVWA veterinarian.
- NVWA trucks are often inspected in "groups". The veterinarian inspects two to four trucks at the same time. The group size is automatically determined by the simulation. All trucks of such a group are released once the last truck of the group is inspected.
- The regular number of slots per day is 18 and the regular slot length is 45 minutes.
- The maximum capacity per day of the TAS is:
  $18\ slots \cdot 3\ unloading\ bays \cdot 1\ operational\ day = 54\ trucks$
  This is equivalent to a maximum capacity in one operational month of:
  $18\ slots \cdot 3\ unloading\ bays \cdot 21\ operational\ days = 1134\ trucks$
  The calculated capacity is used for determining the occupancy rate of unloading bays.
- Every unloading bay has a terminal operator available at the moment a truck enters the unloading bay.
- Unloading bays C04A and C04B are interchangeable, such that trucks can switch to the other unloading bay if their planned unloading bay is occupied with another truck.
- If the number slots per day available is set to the regular number of slots available per day, all trucks automatically enter the system via the TAS, independent of their origin.
- If the number slots per day available is set to 0, all trucks automatically enter the system via D&S, independent of their origin.
- If the number slots per day available for TAS is smaller than the regular number of slots per day, TAS and D&S work complementary as TAM. EU trucks automatically enter the system via the TAS, non-EU trucks automatically enter the system via D&S.
- If TAS and D&S work complementary, TAS trucks are unloaded in the morning and D&S are unloaded after the TAS schedule for a specific day is finished. This is done such that NVWA inspections can be executed in the morning for D&S NVWA trucks.
- A predefined tank swap is executed once the system switches from unloading planned TAS trucks to D&S trucks.
- If the TAM systems TAS and D&S work complementary, all TAS trucks that missed their planned time slot and which cannot be unloaded in another time slot the same day are allowed to stay at the parking lot until they can be unloaded during time reserved for D&S trucks. They are prioritised above D&S trucks when D&S time shift has started. This is due to the legal working hours of the TAS trucks drivers. If they have to wait till D&S trucks have been unloaded in the evening, their legal working hours are not respected.

- If a truck has to overnight at the terminal, e.g. because of waiting for a slot the next day, the overnight time is not taken into account in the prepump time and TTT.

For the Truck Appointment System specific:

- The schedule for the TAS is made before the physical processes at the LBT start.
- The number of slots opened for TAS are equal for unloading bay C04A, C04B and C04C.
- Technical unavailability of slots happens with a chance of 20%.
- NVWA trucks make appointments for NVWA inspections. The NVWA inspections are grouped by appointment time if they lie within half an hour from each other.
- NVWA appointments are planned approximately 2 hours before their planned time slot.
- If TAS trucks are too late, an empty slot is searched in the schedule. This is done at the moment registration at Expedition has finished. At least one slot has to be in between the moment a truck is ready to enter the terminal and a slot can start, due to possible tank swaps.
- If a truck is replanned to the first or second slot the next day and there is a complete TAS, the truck is allowed to stay at the parking lot during the night. Otherwise, the truck has to leave the parking lot and return the day of the replanned slot.
- Technical unavailability of unloading bays is integrated in the schedule before trucks are scheduled. This is done to account for planned maintenance. Furthermore, unplanned technical unavailability results in more computational time of the simulation. The chance of a slot being unavailable is represented by the percentage that is set as technical unavailability.
- Tank swaps at unloading bays are planned as well before trucks are scheduled. This is done as the exact distribution of trucks discharging in specific tanks is not yet known. Moreover, it again takes more computational time to simulate unpredictable tank swaps. The chance of a slot being reserved for a tank swap is represented by the number of tank swaps that are set as input parameter, divided by the regular number of slots, which is 18.
- Tank swaps cannot be planned during the first or the last slot of a day. Neither they can be planned consecutively in the schedule without a slot in between.

For the Drop and Swap system specific:

- All generated D&S containers are available at the DST, which comes down to assuming that a ship with containers arrived at the port of Rotterdam before the simulation starts.
- The initial value for the number of ETDs is two and they start at the DST.
- The DST in the port of Rotterdam where the containers arrive with container ships, is approximately a 30 minute drive to VTV.
- The prioritisation of containers that have to be transported from the DST to VTV is based on if the container needs an NVWA inspection (Yes/No) and the unloading bay of the container (C04A, C04B or C04C). An ETD automatically decides which available container is prioritised.
- Containers are transported from the DST to VTV based on if the container needs to be inspected by the NVWA. The total number of arriving NVWA containers is divided by the number of days the simulation runs, with a maximum value of 10 containers per day. Hence, an equal maximum number of NVWA containers may arrive at the terminal every day. NVWA containers are transported to the terminal in the evening such that they are ready for inspection in the morning. Except for the first morning of the simulation, then NVWA containers are transport in the morning as well.
- NVWA containers do not make appointments with the NVWA for an inspection, but wait at the parking lot of VTV till a ”group” can be made that goes through the NVWA inspection in one go.
- Containers are transported from the DST to VTV based on their assigned unloading bay, in the order ABC-ABC-ABC...
- The initial value for the number of ITDs is one. Every ITD has its own terminal tractor.
- ITDs are always familiar with the terminal and never have to do a PIT in the simulation.
- ITDs start at the parking lot of VTV in order to start with the registration of containers.
- Technical unavailability of unloading bays happen with a chance once a truck enters the unloading bay. There is a 10% chance that the unloading bay is unavailable for 1·45 minutes. There is a 5% chance that the unloading bay is unavailable for 2·45 minutes.
- Tank swaps at unloading bays happen with a chance as well once a truck enters the unloading bay. The chance of it happening is represented by the number of tank swaps that are set as input parameter, divided by the regular number of slots, which is 18.

5.4. Model Components

Flowcharts are build with model components, which are explained in this section. The flowcharts hold as a basis for the simulation model. The model components consist of several shapes, which are explained in Figure 5.1. As can be seen, the model components that have been used are connector, information, resource, terminator, process, decision and extractor blocks.

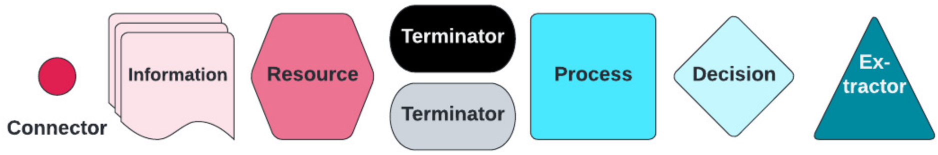


Figure 5.1: Explanation of Model Components

Connectors have the shape of a circle and join flow lines. Prior to the start of the simulation, it needs to receive **information**. This information comes from the Truck Arrival Management system, the input and the parameters. **Resources** that are present at the terminal, also need to be integrated in the simulation and are therefore present in the flowcharts. Some resources are active, like the Expedition members. Others are passive, like the parking spaces. Start- and endpoints are indicated with **terminators**. These show how to either start or end the simulation. **Processes** that happen on the terminal are indicated by squares with convex corners and contain the description of the processes. **Decisions** are indicated by triangles and lead to different paths through the flowcharts. **Extractors** are represented by triangles and show when a process splits into parallel paths.

The flowcharts for the physical processes are constructed according to a swimlane diagram. In the left vertical coloured bar, employees are indicated. Processes that belong to these specific employees are indicated in their ”own” swimlane. The swimlanes itself are presented by the right horizontal grey bars.

5.5. Flowcharts

For the design of the system, multiple flowcharts have been made. These flowcharts show the design of the information and physical processes. All flowcharts serve as a basis for the complete model design and are connected in the DES. First the information processes are shown. Then, the flowchart for a complete TAS is shown, followed by the flowchart for a complete D&S system. Lastly, the flowchart for a complementary TAM system is shown.

5.5.1. Information Processes

The information processes are shown in Figure 5.2. The information processes have been split into an information process for a TAS and a D&S system.

In Figure 5.2a, the information process that happens prior to the physical processes within a TAS is shown. The main purpose of this information flow is to schedule trucks based on the transported products while also taking into account the preference for slots based on historical data. In this process, the number of slots opened for the TAS is considered, as well as the technical unavailability and the tank swaps within the TAS. The arrival times of trucks within the TAS is based on historical data and NVWA appointments, if necessary.

Figure 5.2b shows the information process which happens prior to the physical processes within a D&S system. The aim of this information process is to get an overview of the trucks that have to be unloaded at the terminal and to order them based on the product transported and whether or not a an NVWA inspection is necessary.

As can be seen, the information process within a D&S system is less extensive compared to a TAS. This can be explained by the fact that less information is necessary for a D&S, as the arrival of trucks is more or less decided during the physical processes taking place at the terminal.

5.5.2. Physical Truck Appointment System Processes

In Figure 5.3, the flowchart of the physical processes for the TAS is presented. The flowchart is enlarged in Appendix C, Figure C.1. The information produced in the information process for TAS is used as input in this flowchart. The information process for TAS is visualised in Figure 5.2a. This flowchart is based on the existing truck logistics at Vopak Terminal Vlaardingen. It can be seen as the base case for the research on a complementary TAM system.

For the EU trucks that arrive via the TAS, no NVWA inspection is necessary. However, as previously mentioned, for being able to compare the system performance of a complementary TAM to the existing situation at VTV, the NVWA inspection has been integrated.

5.5.3. Physical Drop and Swap System Processes

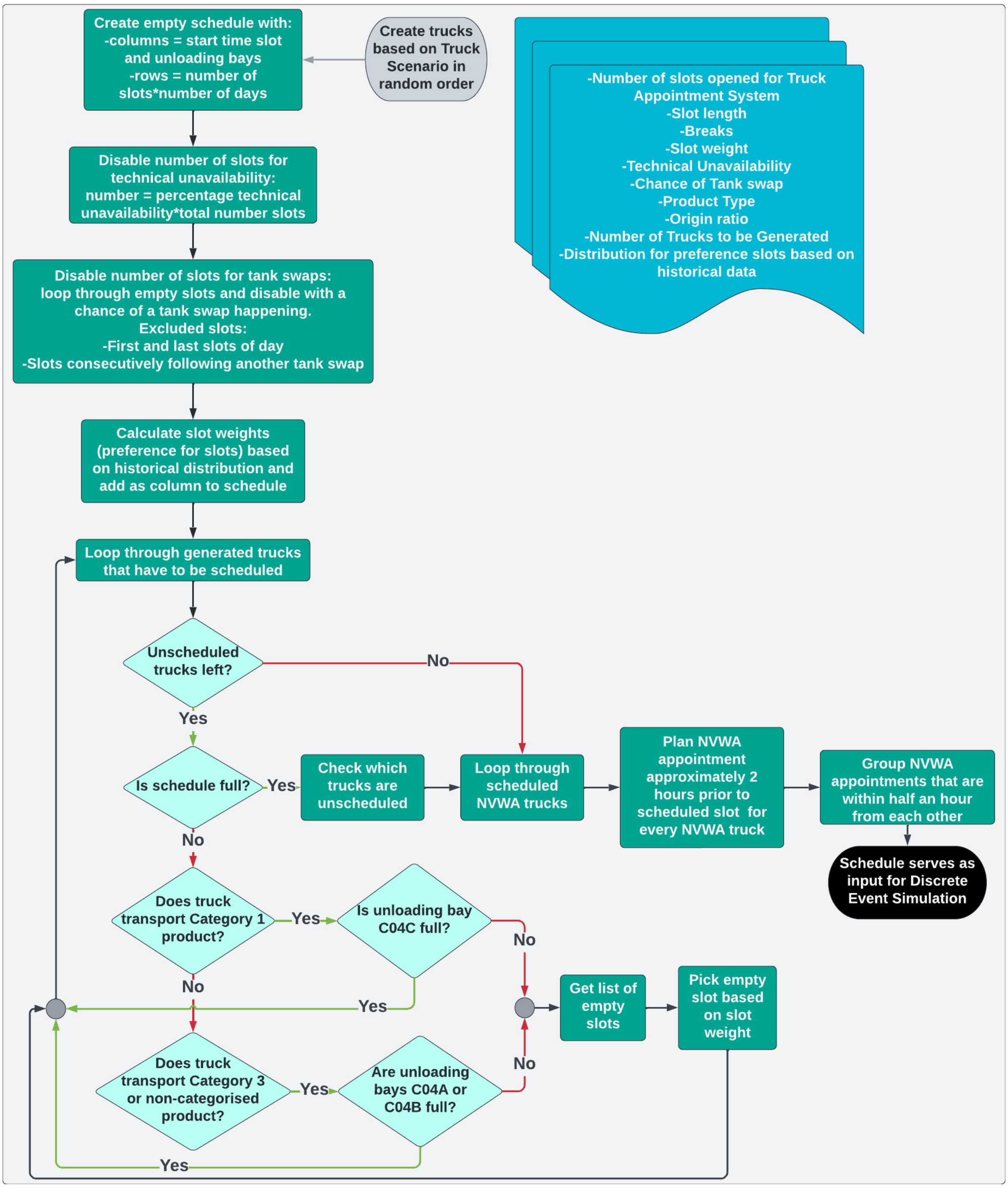
In Figure 5.4, the design of the D&S system is shown. The enlarged flowchart is presented in Appendix C, Figure C.2. The information produced in the information process for D&S is used as input in this flowchart. The information process for D&S is visualised in Figure 5.2b.

The arrival of containers is an extended process compared to the arrival process for TAS, as visualised in Figure 5.3. The reason for this is that the arrival of containers is more or less decided during the physical processes, as they depend on ETDs and the unloading rate at the terminal. Whereas in the TAS, every truck has its own truck driver that arrives at its planned or preferred arrival time.

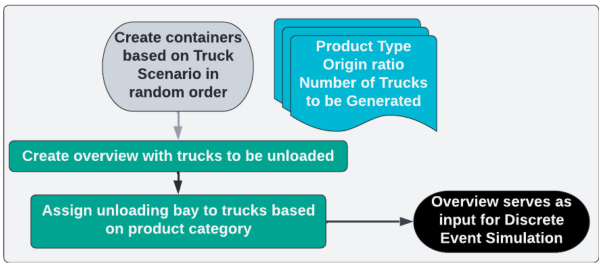
5.5.4. Physical Complementary Truck Arrival Management Processes

In Figure 5.5, the flowchart for the complementary TAM system is visualised. The enlarged flowchart is presented in Appendix C, Figure C.3. Both the information produced from the information processes for TAS and for D&S are used as an input in this flowchart.

In the complementary TAM system, the TAS is used for incoming EU trucks. The D&S system is used by non-EU trucks.



(a) Information Process Prior to Physical Process Truck Appointment System



(b) Information Process Prior to Physical Process Drop and Swap

Figure 5.2: Information Processes Complementary Truck Arrival Management

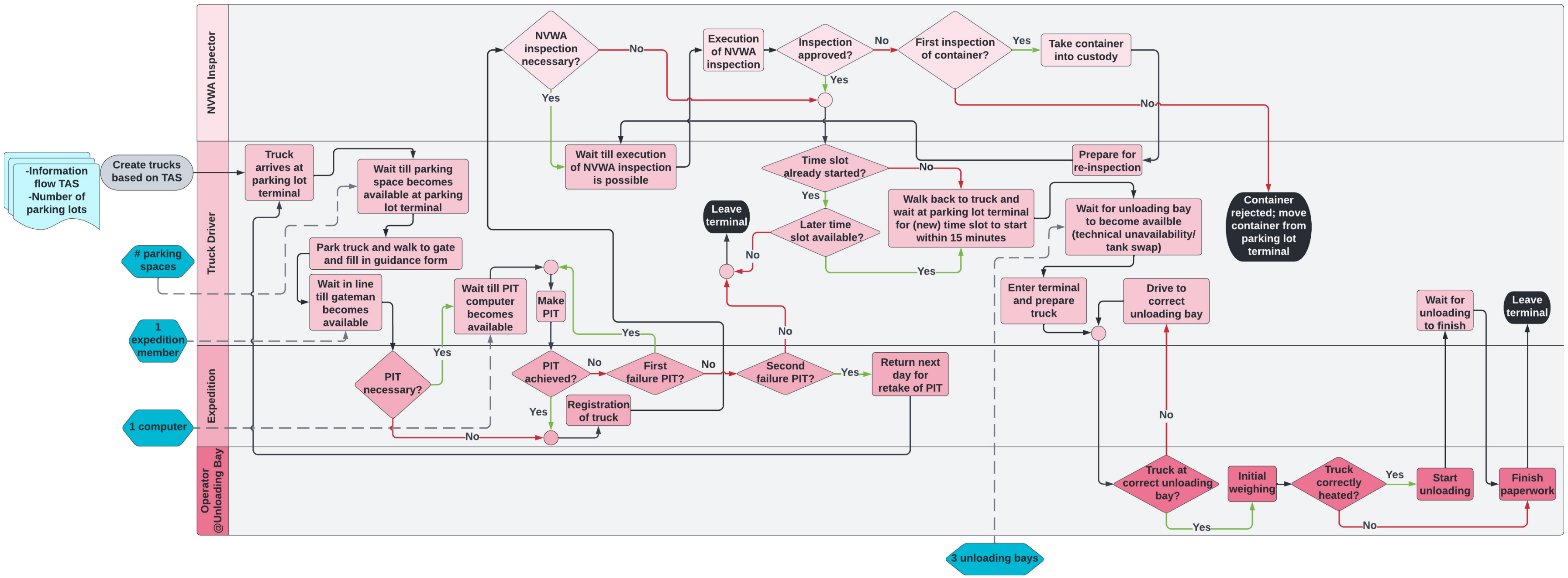


Figure 5.3: Flowchart of Physical Processes Truck Appointment System

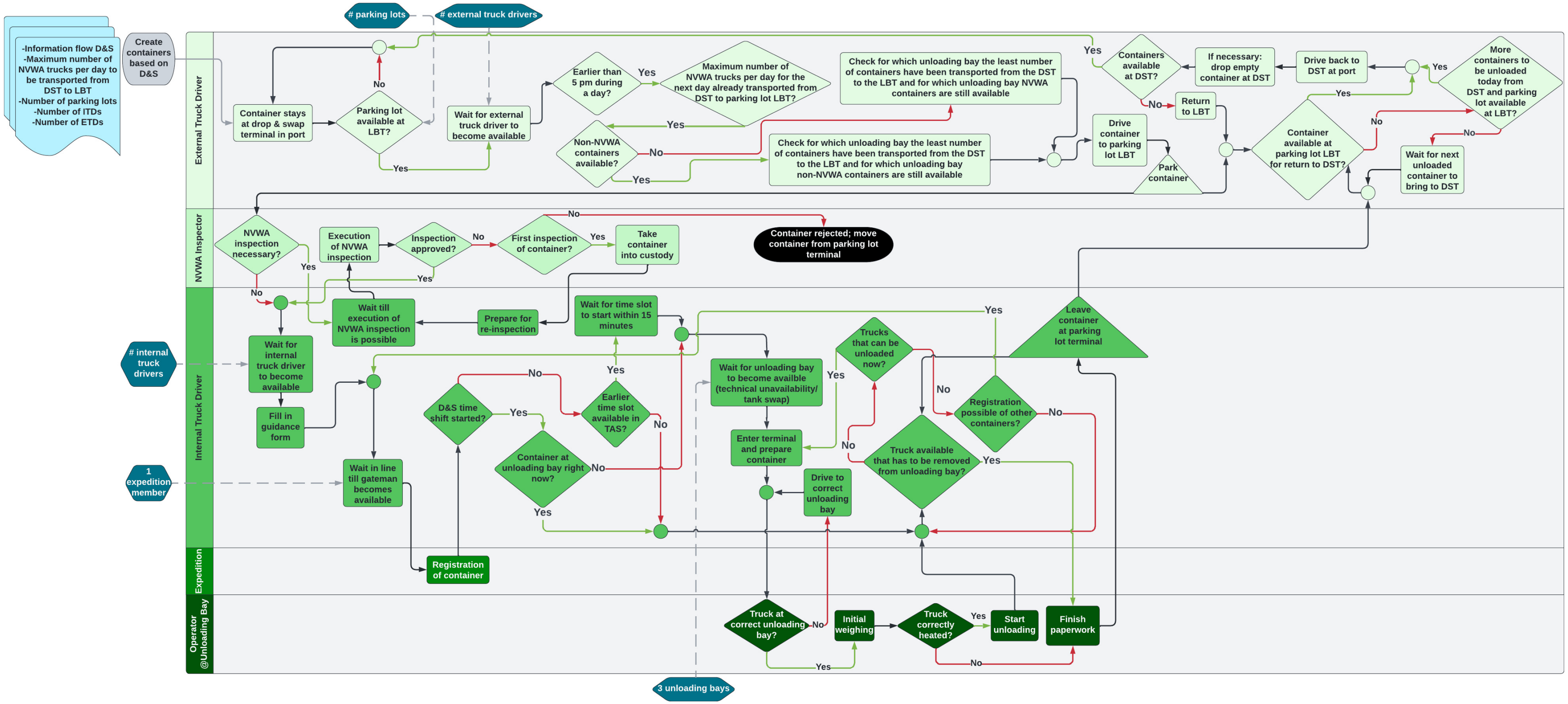


Figure 5.4: Flowchart of Physical Processes Drop and Swap System

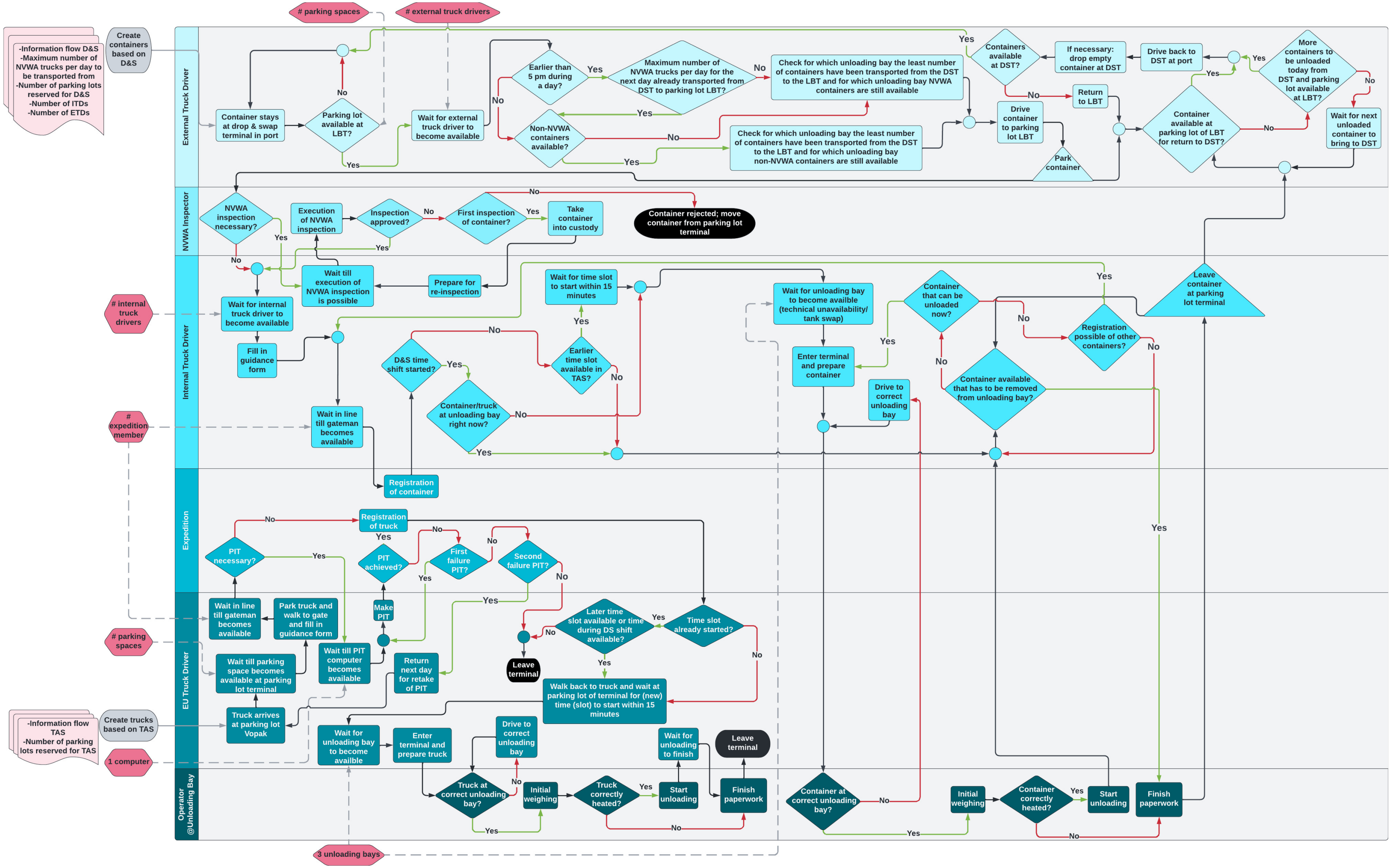


Figure 5.5: Flowchart of Physical Processes Complementary Truck Arrival Management System

5.6. Model Implementation

The simulation model as previously described is programmed in Python version 3.7.9. It is run in Spyder version 4.1.5 via an Anaconda platform. Several libraries and packages have been imported, like dill, pickle, pandas, numpy, seaborn, matplotlib, random, math, os, time, sys and scipy. DES aspects are created using SimPy version 4.0.1. SimPy contains features like environments, timeouts, resources and processes which are well applicable to this model [79].

5.7. Model Verification

The model verification is done in order to check if the model is build correctly and according to the flowcharts as presented previously. The verification is done while building the model, such that mistakes could easily be detected and in order to reach error-free implementation. Strange model behaviour, results or errors were checked regularly such that they could be prevented. Furthermore, the code consists of several classes and functions for a modular design. Lastly, the model was first implemented roughly, the details were added later. The verification is done in multiple ways, which are described below [80].

Run-time Checking and Visualisation

In the simulation several checks are implemented such that 'automated verification' was done. Furthermore, events that happen in the model are traced and event orders and times were checked. Moreover, graphical and numerical results are presented at the end of every simulation, such that outstanding results could easily be identified and rectified.

Verification Test Runs

While building the model, several verification test runs were executed to test the model. These test runs include continuity tests, degeneracy tests, consistency checks and fault injection tests. In a continuity test, slightly different parameters were tested against each other. In the degeneracy test, parameters were given extreme values. The simulation could often not handle these values. The consistency check showed changes in parameter values create a similar change in the outcome of the simulation. During the fault injection tests, invalid inputs were detected by the model. Furthermore, deterministic runs were executed in which all deviations were set to zero. This resulted in the fact that every simulation generated the same outcome. Simple tests were also executed to be able to compare results to theoretical models.

Truck Generation

The number of generated trucks must be an integer, as no partial trucks can be generated. Trucks are generated before the physical processes start. This is important for the TAM systems, as information has to be assigned to trucks before they can physically arrive at the terminal.

Flow Conservation

The number of trucks being generated, arrived and unloaded is checked at the beginning and at the end of the simulation. The total number of trucks that enters the system should also leave the system. Therefore a summation is done to see if all trucks are being processed.

Scheduling

For the TAS, it is important that no trucks that have to unload at the same unloading bay are scheduled at the same time. Therefore, only available slots for available unloading bays are presented during the scheduling of trucks.

Working Times

The working times of active resources, like ETDs, ITDs, Expedition and the NVWA veterinarian are checked before requesting them and before making them available for request again. This is done to make sure that the simulation aligns the operational working hours of the terminal.

External and Internal Truck Drivers

In the truck logistics of the D&S system, it is constantly monitored which ETD and which ITD are performing which actions at what times. This is implemented to make sure that no pending tasks are taken up by two ETDs or ITDs at the same time.

For the ITDs, it is checked every second which task can be executed. ITDs can perform the following tasks which are prioritised in the order named: remove a truck from an unloading bay after it finished unloading, bring a truck to the unloading bay to start unloading, register trucks at Expedition.

ETDs check that the parking lot at VTV does not become too overloaded. This is done every time an ETD transports trucks between the Drop and Swap Terminal and the parking lot of VTV.

Generated Service Times

As described in Section 5.8.1, service times are generated from distributions. These distributions are based on historical data. For distributions in which negative values can be generated, it is checked that the generated values are not smaller than zero. If the value is smaller than zero, the generated time is multiplied by -1. Another option was to generate a new time. However, this requires more computational time.

Furthermore, generated times are checked at the end of the simulation. It is verified that they still follow valid distributions and that they do not diverge too much from the parameterised distributions.

Occupancy Rate Unloading Bays

For every run it is checked that the occupancy rate of unloading bays is not larger than the maximum operational capacity. This is calculated in Appendix D Section D.1 in more detail.

5.8. Model Validation

Validation is done in order to check if the simulation gives the correct results. Three types of validation are used. First data validation has been done. Thereafter, structural validation and performance validation have been performed.

Data validation is executed with historical data of VTV. Distribution fitting was executed by means of EasyFit software, to parameterise arrival and service times. Structural validation is done based on expert opinions and face validity. Performance validation is done by comparing KPIs of historical data with outcomes of the simulation. Monte Carlo simulation is used together with the Law of Large Numbers and Central Limit Theorem, to check if the model is valid and works according to the situation in the real world. It was only possible to validate the performance of the TAS model with data from VTV, as TAS is used nowadays at VTV. For the D&S system, no historical data was available for validation. However, it has been checked that no very outstanding values resulted from the simulation [81].

5.8.1. Data Validation

Data validation is necessary in order to paramterise data that can be used in the simulation model. For this simulation model, the data validation is mainly executed on arrival and service times. The historical data that has been analysed is retrieved from a database of VTV [82]. The data of various service times is compared to distributions through EasyFit.

EasyFit is a software program that automatically fits distributions to data [83]. It ranks possible distributions based on Goodness of Fit tests. For this research, the distributions are ranked based on the Chi-Squared test. The Chi-Square test checks if sample data matches a distribution of a particular population [84]. Appendix C, Figure C.4 shows various distributions used in the software. In Appendix C, Figure C.4a, possible Probability Density Functions are shown. In Appendix C, Figure C.4b, the Probability Density Function (PDF) of a normal distribution is shown in detail.

The subjects that have been validated are the peaks in arrival times and preferences for time slots in the TAS, the time necessary for a guidance form, the service time at Expedition, the PIT time, the NVWA inspection time, the preparation time, the pumptime and the post pumptime. The definitions of the validated times are visualised in Figure 5.6.

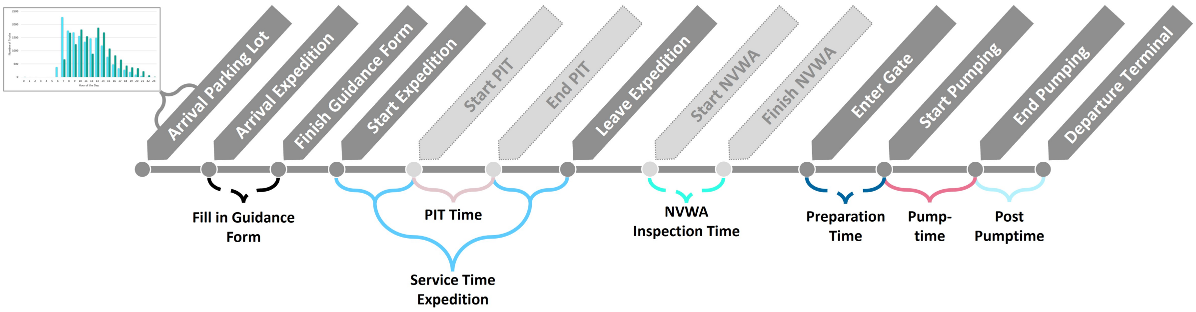


Figure 5.6: Data Validation in Truck Logistic Process

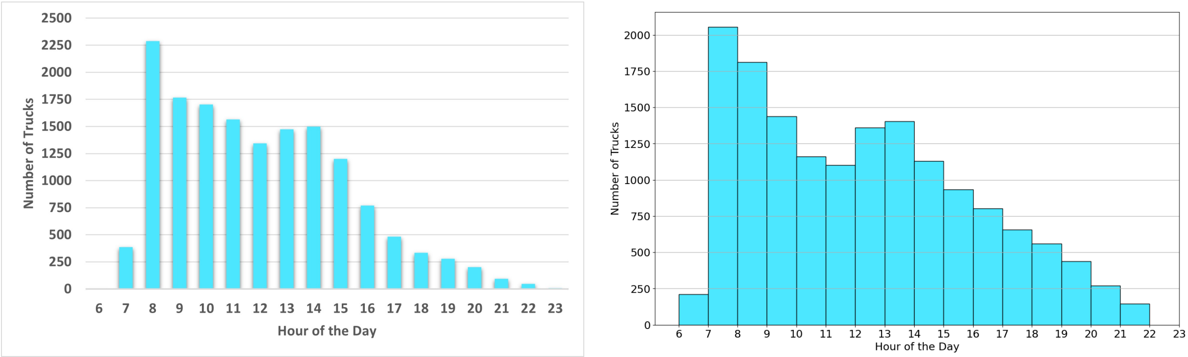
For the guidance form, the service time at Expedition and the PIT time, time measurements have been done at Expedition. The preparation time and NVWA inspection time are not based on data but expert opinions. The peaks in arrival time and preferences for time slots, the pumptime and post pumptime are validated using historical data from VTV.

VTV has a data storage system in which much data is being stored. The data for this research is filtered on the modality *trucks* and on the direction *in*, which means that only data of discharging trucks is taken. Data of the data storage system of VTV covers a couple of years. A total number of 15435 trucks has been analysed.

Truck Arrival Peak

In order to determine arrival times of trucks in the simulation, arrival times had to be analysed in the historical data of VTV. The arrival time of a truck in the historical data is equal to the start time of handling at Expedition. The validation is shown in Figure 5.7.

From Figure 5.7a, certain peaks in the arrival time can be determined, which are at 7 am and



(a) Histogram of Arrived Trucks based on Historical Data [82]

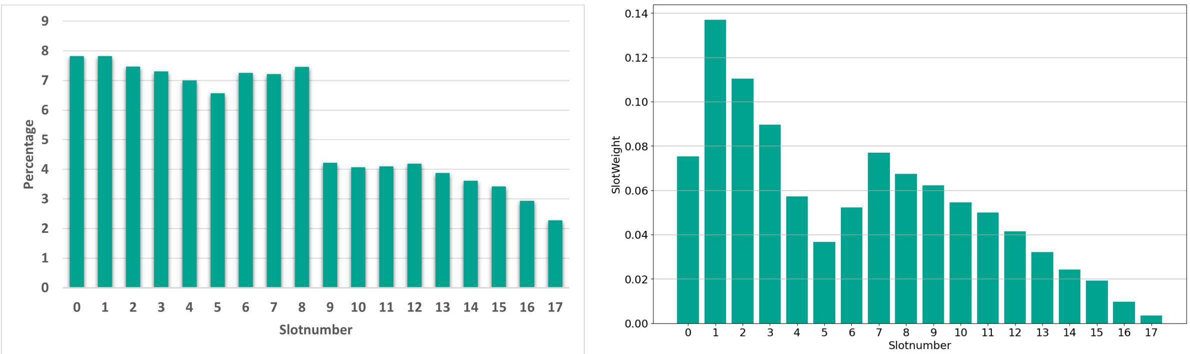
(b) Double Triangular Distribution of Arrival Times in Simulation

Figure 5.7: Data Validation Arrival Times

a smaller peak at 1 pm. This was converted to a distribution that is implemented in the simulation to determine arrival times of trucks. The established distribution is a double triangular distribution, partly derived from Wibowo and Fransoo [8]. A triangular distribution is defined by three parameters: $\mathcal{Tri}$(a,b,c). The minimum is represented by a, b represents the mode and c represents the maximum [85]. The arrival times are generated according to $\mathcal{Tri}$(6.7,7.15,14) and $\mathcal{Tri}$(11,13.25,22.5), in hours. Figure 5.7b presents the distribution used in the simulation. In the TAS, the distribution stays the same independent of the number of slots available per day.

Slot Preference

The historical preference for slots was also analysed in order to use it in the simulation model. The preference for slots is based on the original planning as discussed in Section 4.1.1. The validation is shown in Figure 5.8.



(a) Histogram of Slot Preference based on Historical Data [82]

(b) Double Triangular Distribution of Slot Preference in Simulation

Figure 5.8: Data Validation Slot Preference

From Figure 5.8a, it can be seen that more trucks are planned in the morning slots compared to the afternoon slots. The slotnumbers align with Table 4.1. However, the slotnumbers do not range from 1 to 18 but from 0 to 17. The slot preference is captured in a distribution. This distribution is used in the simulation to plan trucks. The established distribution is again a double triangular distribution, partly based on expert opinions. The probability a truck is assigned to a certain slot is generated according to $\mathcal{Tri}$(0,1,7) and $\mathcal{Tri}$(6,7,17), in slotnumbers. The distribution is presented in Figure 5.8b. In the TAS, the distribution again stays the same independent of the number of slots available per day.

Expedition Service Time

For the service time at Expedition, time measurements have been done for 64 arriving trucks. The first thing truck drivers have to do is fill in the guidance form upon arrival Expedition. This process has roughly been monitored. The decision is made to model this process with a normal distribution: $\mathcal{N}(\mu,\sigma)$. In which the average is defined by μ and the standard deviation is defined by σ. μ and σ correspond to the location and the scale parameter, respectively [85]. The distribution for filling in the guidance form is determined as $\mathcal{N}(4,1)$, in minutes. This is visualised in Figure 5.9.

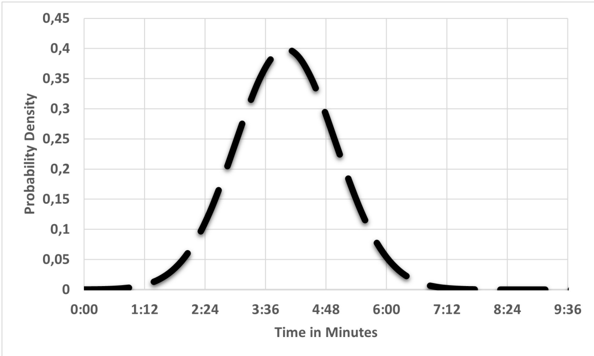
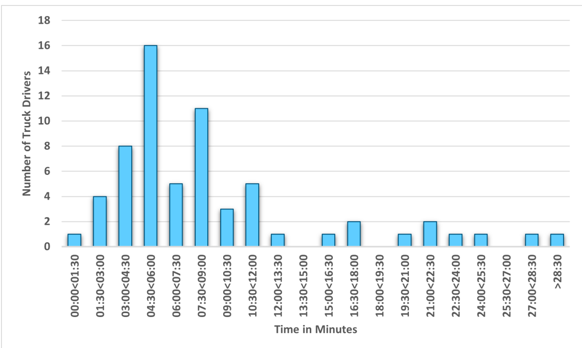


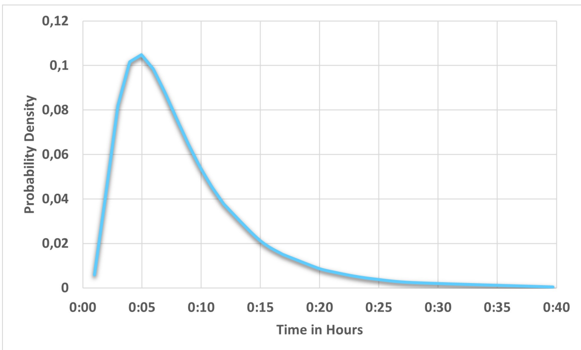
Figure 5.9: Normal Probability Density Function Fill in Guidance Form

The validation of the service time by a member of Expedition is shown in Figure 5.10. Figure 5.10a shows a histogram of the service time measurements at Expedition. Based on Easyfit, a lognormal distribution is appropriate for this dataset [85]. The EasyFit graph can be found in Appendix C, Figure C.5.

The parameters for the lognormal distribution are μ and σ: $\mathcal{Logn}(\mu,\sigma)$. These parameters represent the location and the shape parameter, respectively. μ represents where on the x-axis the graph is located. σ is also known as the standard deviation of the lognormal distribution [85, 86, 87]. If the data of a lognormal distribution is transformed by taking the natural logarithm of the data values, the transformed values follow a normal distribution [86]. The result for the distribution is $\mathcal{Logn}(1.9768,0.64858)$ in minutes, which is visualised in Figure 5.10b.



(a) Histogram Expedition Service Time based on Time Measurements



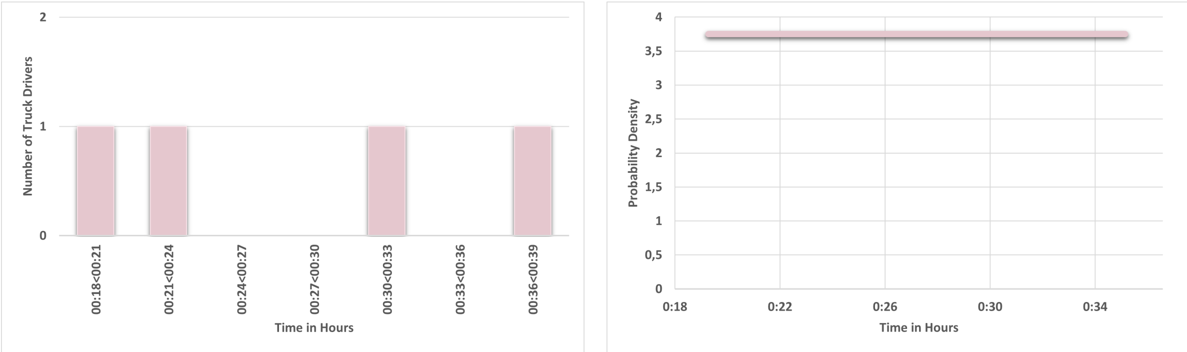
(b) Lognormal Probability Density Function Expedition Service Time

Figure 5.10: Data Validation of Expedition Service Time

PIT Time

During the time measurements at Expedition, four truck drivers had to take a PIT, which comes down to 6.25%. Times that were measured for taking a PIT were 20, 21, 32 and 36 minutes. The data is shown in Figure 5.11. Figure 5.11a presents the histogram of the time measurements.

EasyFit could not be used to check for an appropriate distribution, because there were too little measurements [85]. For now, a uniform distribution is chosen to model the PIT time based on the form of the histogram. In Figure 5.11b, the uniform PDF $\mathcal{U}(20,36)$ in minutes is shown. Though, for a more accurate representation, sufficient data should be gathered on the duration of a PIT.



(a) Histogram PIT Time based on Time Measurements

(b) Uniform Probability Density Function PIT Time

Figure 5.11: Data Validation of PIT Time

NVWA Inspection Time

Extensive historical data of the NVWA inspection time is not available. However, based on employees of VTV, the NVWA inspection per truck lasts approximately 30 minutes. The distribution of the NVWA inspection time is determined as $\mathcal{N}(30,2.5)$ with μ = 30:00 minutes and σ = 2:30 minutes. It is distributed as a normal distribution, for which approximately 95% of the generated times is between 25:00 and 35:00 minutes. The PDF is shown in Figure 5.12.

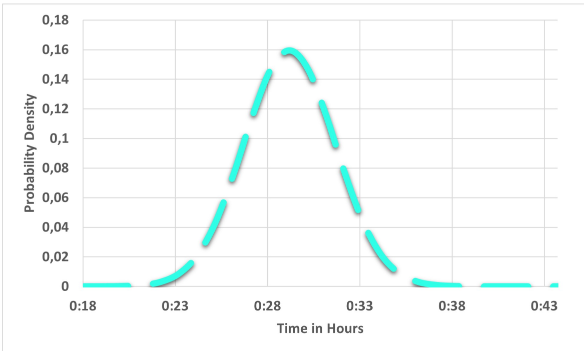


Figure 5.12: Normal Probability Density Function NVWA Inspection Time

Preparation Time

Data of the preparation time as defined from the moment a truck enters the terminal for preparing the truck till the start of pumping at the unloading bay, is not available at VTV. However, truck drivers have 15 minutes to prepare their truck before unloading. Most truck drivers finish the preparation within 15 minutes. Therefore, the distribution of the preparation time is chosen as $\mathcal{N}(10.5,1.75)$ with μ = 10:30 minutes and σ = 1:45 minutes. It is distributed as a normal distribution, for which approximately 95% falls within the time range of 7:00 till 14:00 minutes. The PDF is shown in Figure 5.13.

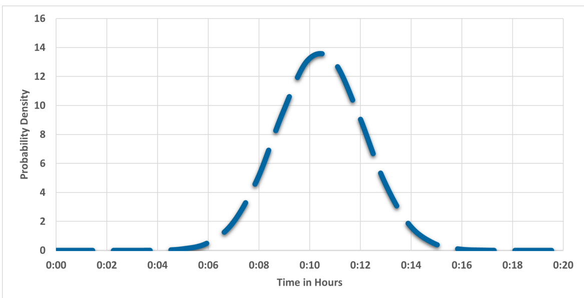
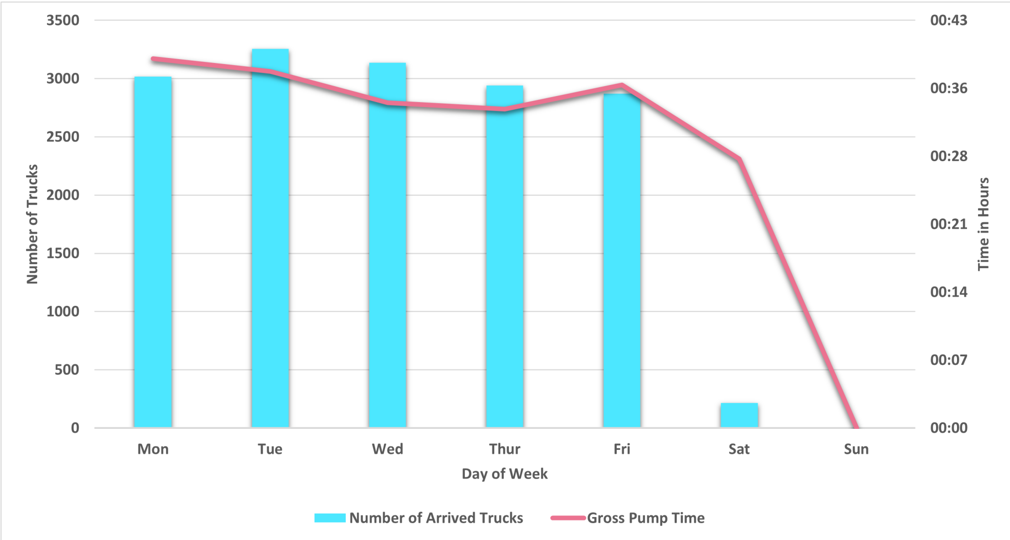


Figure 5.13: Normal Probability Density Function Preparation Time

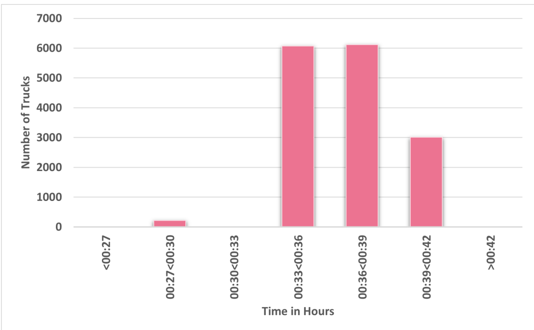
Pumptime

The pumptime represents the time the pump discharges the truck. The validation of the pumptime is shown in Figure 5.14. The number of arrived trucks per weekday has been plotted accompanying the average pumptime per day in Figure 5.14a. In Figure 5.14b, a histogram of the pumptime is shown. EasyFit was used to find a suitable distribution for the pumptime, which resulted in a logistic distribution [85]. The EasyFit graph can be found in Appendix C, Figure C.6.

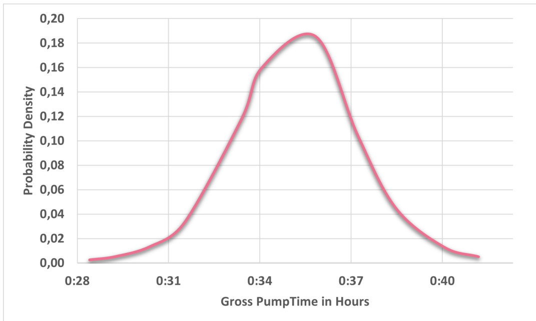
A logistic distribution is defined by the parameters μ and β: $\mathcal{L}ogi(\mu,\beta)$. These parameters represent the location and the scale parameter, respectively. μ shows where the distribution is centred on the x-axis. β gives information about the spread of the distribution and is proportional to the standard deviation [85, 88, 89]. The result for the distribution is $\mathcal{L}ogi$(35.68,1.2565) in minutes, which is visualised in Figure 5.10b.



(a) Arrived Trucks and Pumptime per Day of the Week based on Historical Data [82]



(b) Histogram Pumptime based on Historical Data [82]



(c) Logistic Probability Density Function Pumptime

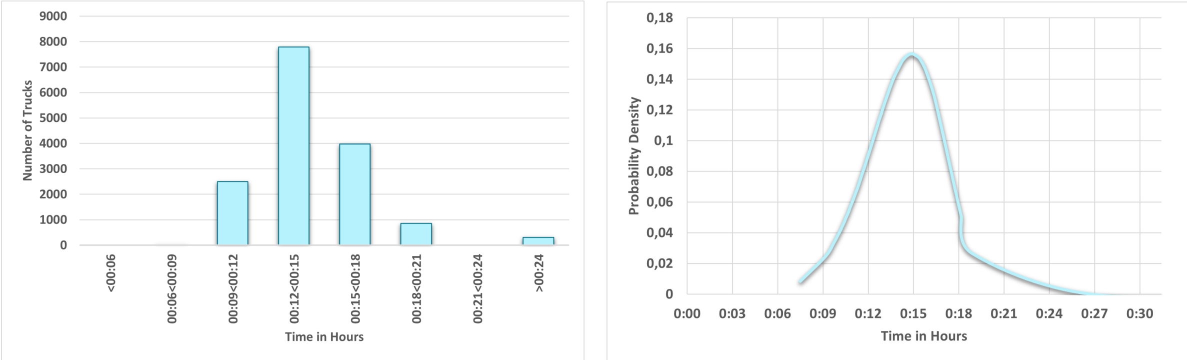
Figure 5.14: Data Validation of Pumptime

Post Pumptime

The post pumptime is the time from the moment the pump stops till the moment the paperwork is finalised. The validation of the post pumptime is shown in Figure 5.15. In Figure 5.15a, a histogram of the post pumptime is shown. The EasyFit software determined that a 2-parameter Weibull distribution is appropriate for this dataset [85]. The graph can be found in Appendix C, Figure C.7.

A 2-parameter Weibull distribution is defined by α and β: $\mathcal{W}ei(\alpha,\beta)$. These parameters represent the shape and the scale parameter, respectively. α is known as the Weibull slope or the threshold parameter. β is also called the characteristic life parameter [85, 90]. The result for the distribution is $\mathcal{W}ei$(6.4784,15.403) in minutes, which is visualised in Figure 5.15b.

The previously mentioned data of the post pumptime is for the existing truck logistics at VTV, as described in Section 4.1.1. In the existing situation, truck drivers have to leave the terminal via the



(a) Histogram Post Pumptime based on Historical Data [82]

(b) 2-Parameter Weibull Probability Density Function Pumptime

Figure 5.15: Data Validation of Post Pumptime

main street and sometimes they have to visit Expedition again in order to finalise the paperwork. In the new situation as described in Section 4.1.2, the paperwork is finished at the unloading bays for truck drivers that discharge at unloading bays C04A, C04B or C04C. After finalising the paperwork, trucks can immediately leave the terminal. Therefore, it is assumed that the post pumptime still follows a 2-parameter Weibull distribution, but alpha and beta are reduced. The value of the post pumptime in the simulation for the complementary TAM is determined as $\mathcal{Wei}$(2.49169,5.92423), in minutes. Figure 5.16 shows the Weibull distribution for the post pumptime in the complementary TAM.

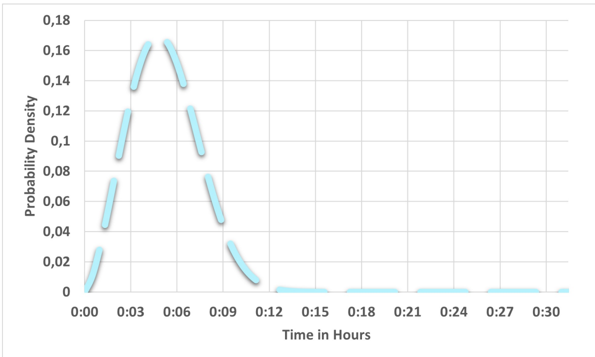


Figure 5.16: 2-Parameter Weibull Probability Density Function Post Pumptime - Complementary Truck Arrival Management System

5.8.2. Structural Validation

The simulation model is validated by experts, in the form of employees at VTV. Furthermore, face validity is done in an iterative way. For several test runs it is checked that the simulation measures what it is intended to measure.

5.8.3. Performance Validation

The subjects that are performance validated are the number of trucks that miss their time slot, the TTT and the prepump time that results from the TAS. The validation is done with a z-test.

The TTT aligns with KPI 1 as discussed in Section 2.3. Furthermore, the prepump time is validated, which is defined as the time between the moment of registration at Expedition till the moment a truck starts to unload at its unloading bay. The definitions of the TTT and the prepump time that are validated are visualised in Figure 5.17.

To perform the validation, input, parameters and the system design have to be defined. These subjects are explained in more detail in Chapter 6. For now, only the subjects that apply to the validation runs are explained.

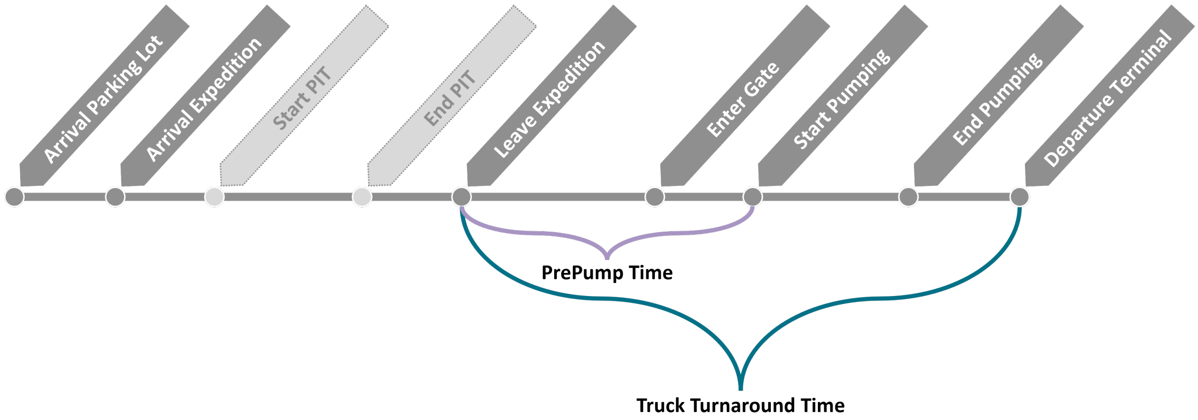
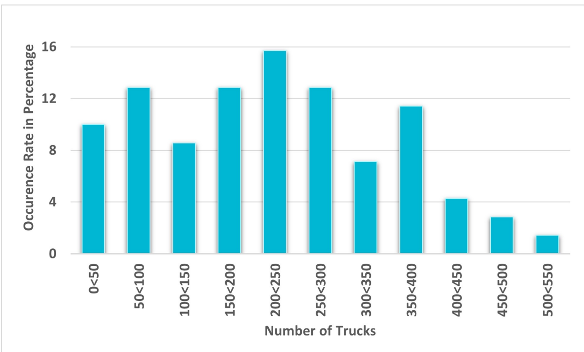


Figure 5.17: Performance Validated Times

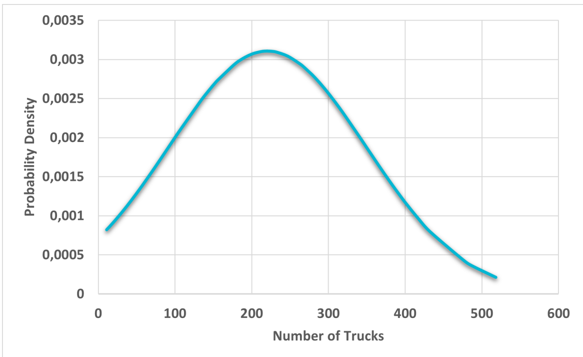
Input for Validation

First, a Truck Scenario (TS) is defined, which is considered to be the input for the simulation. The trucks in a TS can be distributed among several trucktypes, which are presented in Table 6.1. For validation, the TS that enters the system is based on historical data and can be classified as TS 0 from Table 6.2. No non-EU and no NVWA trucks are generated for validation, only trucktypes 1 to 6 are generated.

The number of trucks generated is based as well on historical data. The information about the number of trucks is presented in Figure 5.18. In Figure 5.18a, a histogram of the occurrence rate against the number of arriving trucks per operational month is presented. In Figure 5.18b, the PDF of the number of arriving trucks following a normal distribution is shown. This PDF is based on the EasyFit comparison as visualised in Figure C.8, Appendix C. It has been decided to model this as a normal distribution, such that not every simulation run the same number of trucks is generated. The mean and standard deviation are μ = 220.5 trucks and $\sigma \approx$ 128.42 trucks respectively. This results in a distribution of $\mathcal{N}(220.5,128.42)$ trucks per month. In the simulation, whole trucks are generated. Therefore, the distribution for performance validation is adjusted to $\mathcal{N}(221,128)$ trucks per operational month.



(a) Histogram Number of Arriving Trucks based on Historical Data [82]



(b) Probability Density Function Number Arriving Trucks

Figure 5.18: Performance Validation of Number of Arriving Trucks. Data of Vopak Terminal Vlaardingen

Parameters for Validation

The parameters are divided into simulation parameters and configuration parameters. Two simulation parameters are set, namely the number of runs and the length of the simulation.

To average out results, the number of runs of the simulation is set to 30. As explained in Section 3.2, a Monte Carlo simulation is important to get a range of outcomes and decrease the influence of outliers and randomness of the parameters. For every simulation run, it was checked that the number of generated trucks differed from the other runs. The length of the simulation is set to 21 operational days. The value of 21 days has been chosen as it approximately represents an operational month. An overview of these values is given in Table 5.1.

Table 5.1: Simulation Parameters Validation

Parameter	Value	Unit
Number of Replications	30	Runs
Length of Simulation	21	Days

An overview of the configuration parameters for validation is presented in Table 5.2. The configuration parameters are divided into four categories. Table 5.2a shows the general parameters. Table 5.2b shows the parameters for the time distributions. These values are based on the data validation described in Section 5.8.1. Table 5.2c presents the values for the operational hours parameters. Lastly, Table 5.2d gives an overview of the resource parameters.

Table 5.2: Configuration Parameters for Validation

(a) General Parameters

Parameter	Value	Unit
Number Slots for TAS	18	Slots
Number Generated Trucks	$\mathcal{N}(221,128)$	Trucks
Technical Unavailability	20%	-
Chance of Slot being Reserved for a Tank Swap	$\frac{1}{18}$	-
PIT Pass Rate	60%	-

(b) Time Parameters

Parameter	Value	Unit
Arrival Times	$\mathcal{T}ri(6.7,7.15,14)$ and $\mathcal{T}ri(11,13.25,22.5)$	Hours
Slot Preference	$\mathcal{T}ri(0,1,7)$ and $\mathcal{T}ri(6,7,17)$	Slotnumbers
Fill in Guidance Form	$\mathcal{N}(4,1)$	Minutes
Expedition	$\mathcal{L}ogn(1.9768,0.64858)$	Minutes
PIT	$\mathcal{U}(20,36)$	Minutes
Preparation Time	$\mathcal{N}(10.5,1.75)$	Minutes
Pumptime at Unloading Bay	$\mathcal{L}ogi(35.68,1.2565)$	Minutes
Post Pumptime	$\mathcal{W}ei(6.4784,15.403)$	Minutes

(c) Operational Hours Parameters

Parameter	Start	End	Comment
Expedition	7 am	10 pm	Last request accepted at 10 pm

(d) Resource Parameters

Parameter	Value
Expedition Members	1
PIT Computers	1
Total Number Parking Lots	25

System Design for Validation

The system design concerns the layout of the TAM system. For performance validation, the TAM system had to match the existing situation at VTV. Currently, VTV uses a complete TAS. Therefore, the number of slots is set to 18. The D&S system is not integrated in the TAM yet. This system design matches Design Alternative (DA) 1, as explained in Section 6.3.

Law of Large Numbers and Central Limit Theorem

The validity of the percentage of too late trucks, the prepump time and the TTT has been tested by comparing the mean value of the historical data to the mean value of the 30 runs of the simulation. The LLN states that the distribution of sample means converges to the population mean it is taken from, for a sufficient large number of samples [65, 66]. The CLT states that the distribution of sample means follows a normal distribution, irrespective of the shape of the population distribution [65, 66, 67].

For the 30 simulation runs, the average value for the percentage of trucks that was too late, the pre-pump time and the TTT have been calculated per run. These averages resulted in a normal distribution according to the CLT. The averages of the simulation and the average of the historical data have been compared with a z-test.

Two-Tailed Z-Test

In order to determine if the discrepancy between the simulation results and historical data is significant, a z-test has been performed in which the means have been compared. For this test, a null hypothesis and an alternative hypothesis are set. The null and alternative hypotheses are respectively [91]:

$$H_0\colon \mu_{Historical\ Data} = \mu_{Simulation\ Averages}$$
$$H_1\colon \mu_{Historical\ Data} \neq \mu_{Simulation\ Averages}$$

For the test statistics, the z-value has to be calculated. Equation 5.1 presents the equation for the z-value [92].

$$z = \frac{\mu_{Historical\ Data} - \mu_{Simulation\ Averages}}{\sigma_{Simulation\ Averages}} \tag{5.1}$$

The null-hypothesis is supported once the z-value lies within the range $[-z^*, z^*]$, in which z^* is the critical z-value. This is represented by the light blue area in Figure 5.19 [91].

Figure 5.19: Normal Probability Density Function - Two-Tailed Z-Test for Non-Directional Hypotheses [93]

To find z^*, a significance level α has to be determined. With the significance level, the confidence level can be calculated as 1-α. z^* needs to be looked up in the z-table. For this research, non-directional hypotheses have been established. Therefore, the significance level has to be divided by two to find the critical value for which z^* has to be found [91].

The z-tables for negative and positive values can be found in Appendix C, Table C.1. Table C.1a shows the negative z-values and Table C.1b shows the positive z-values. The most left column in the tables defines the z-score to the tenth's place. The column headings define the z-score to the hundredth's place. The cells in the tables represent the area under the normal distribution curve to the left of a z-value. The area represents the rejection region [91, 94].

Too Late Trucks

VTV has researched that approximately 15% of the truck drivers miss their planned time slot. No exact data for this percentage is available. The fact that trucks miss their planned time slot, influences the efficiency of the terminal. Therefore, it has been checked how the simulation lets trucks arrive.

The z-value is calculated according to Equation 5.1. Furthermore, a significance level of 1% and a confidence level of 99% are determined. z^* has been looked up in Table C.1 in Appendix C for a significance level of 1%:

$$z = \frac{15\% - 11.28\%}{1.78\%} \approx 2.09$$
$$\alpha = 1\% = 0.01$$
$$critical\ value\ z\text{-}table = \frac{\alpha}{2} = \frac{0.01}{2} = 0.005$$
$$z^* = 2.575$$

As can be concluded, $-z^* < z < z^*$. Hence, H_0 is supported for a significance level of 1%. The validation is visualised in Figure 5.20. The percentage in the simulation is smaller compared to the historical data. The assumption is that this deviation is maintained in the rest of this research.

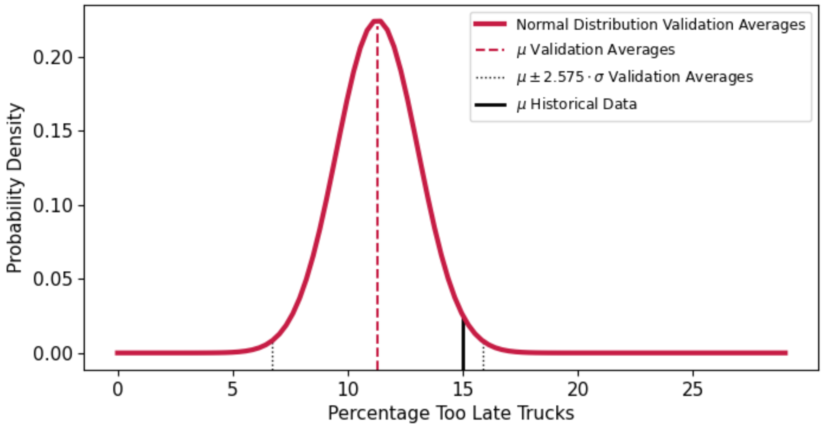


Figure 5.20: Performance Validation Too Late Trucks - Normal Distribution

The significance level is low. This has to do with the fact that the percentages from the simulation tend to be smaller compared to the historical data. The reason for this is that the exact arrival time of individual trucks and their planned slot, cannot be retrieved from the historical data. Therefore, the distributions used for the arrival time in the simulation are a good estimation, but never exactly represent the situation in the real world. However, it can be concluded that the simulation lets trucks arrive in an acceptable way, by which too late trucks are incorporated as well.

Prepump Time

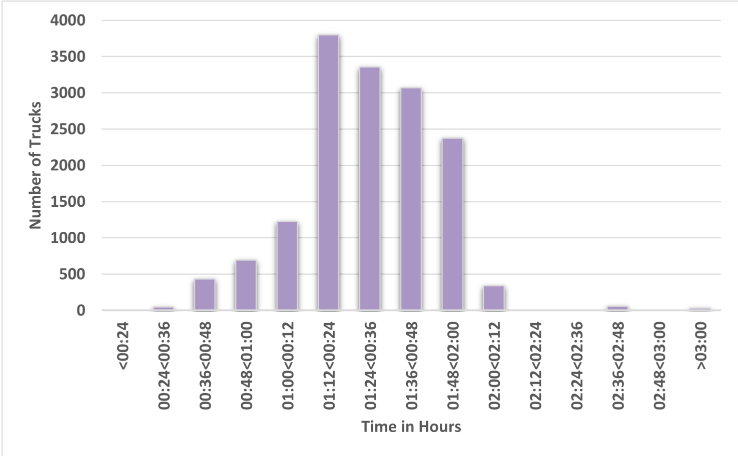
The prepump time can be retrieved from historical data. The mean of this value is compared to the averages of the validation runs. Figure 5.21 shows the historical data and the simulation data.

Figure 5.21a shows the histogram of the historical data of VTV. Figure 5.21b shows the boxplots of the historical data on the left and the averages of the simulation data on the right. As can be seen, the mean value of the simulation averages is larger than the mean value of the historical data.

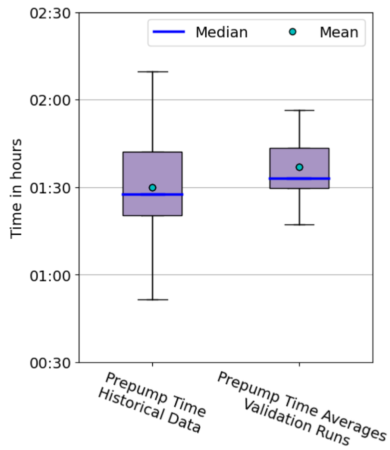
To check if the difference is significant, the z-value is calculated according to Equation 5.1. For the prepump time, a significance level of 10% and a confidence level of 90% are determined. z^* has been looked up in Table C.1 in Appendix C for a significance level of 10%:

$$z = \frac{1.497 - 1.617}{0.200} \approx -0.594$$
$$\alpha = 10\% = 0.1$$
$$critical\ value\ z\text{-}table = \frac{\alpha}{2} = \frac{0.1}{2} = 0.05$$
$$z^* = 1.645$$

The null hypothesis is supported for a significance level of 10% as $-z^* < z < z^*$. Figure 5.22 shows the distribution used for the validation. The average value of the historical data is not in the rejection region. This means that the prepump time is correctly generated by the simulation. Though, the mean value of the simulation averages is approximately 7 minutes larger than the historical average. For the rest of the experiments, it can be assumed that this deviation is retained.



(a) Histogram of Prepump Time based on Historical Data [82]



(b) Boxplots of Prepump Time

Figure 5.21: Comparison of Historical Data versus Simulation Data - Prepump Time

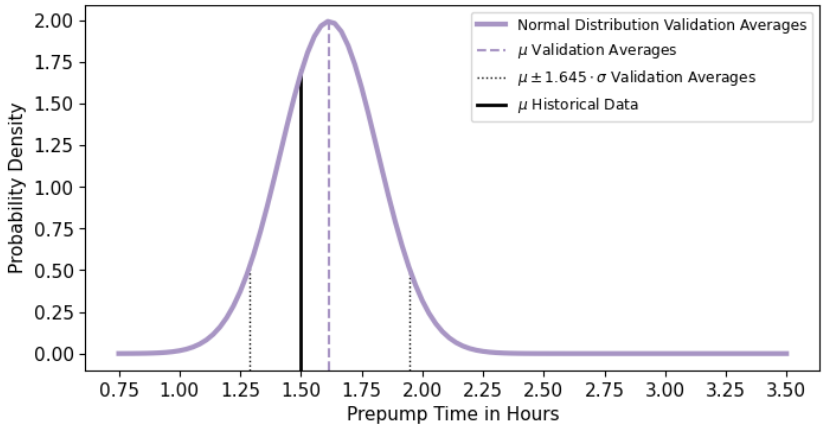


Figure 5.22: Performance Validation Prepump Time - Normal Distribution

Truck Turnaround Time

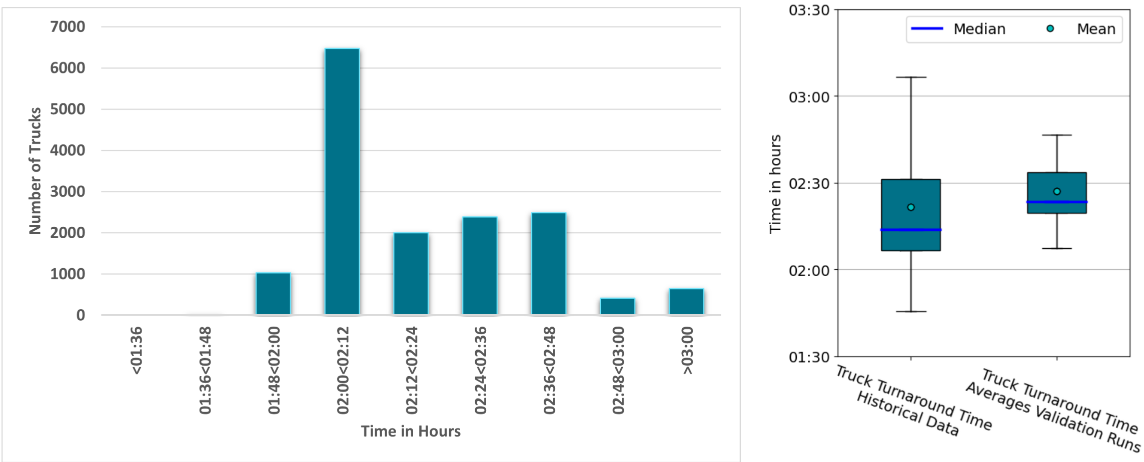
The TTT aligns with KPI 1. The TTT is retrieved from historical data of VTV. The data for the TTT ranges from the moment a truck is registered till the moment a truck departs from the terminal.

Figure 5.23 shows the historical data of VTV and the simulation data. In Figure 5.23a, a histogram of the historical data is presented. The historical data has been compared to the validation runs. Figure 5.23b shows the result in boxplots. The left boxplot shows the historical data, the right boxplot shows the averages of the simulation runs. The average of the simulation runs is again larger than the average of the historical data, as was the case with the prepump time.

In order to check if the mean values differ significantly, a z-test is performed. The z-value is calculated according to Equation 5.1. A significance level of 10% and an accompanying confidence level of 90% are determined for the TTT. The value for z^* has been looked up in Table C.1 in Appendix C:

$$z = \frac{2.362 - 2.451}{0.200} \approx -0.446$$
$$\alpha = 10\% = 0.1$$
$$critical\ value\ z\text{-}table = \frac{\alpha}{2} = \frac{0.1}{2} = 0.05$$
$$z^* = 1.645$$

For a significance level of 10%, the null hypothesis is supported. This is concluded from the fact that $-z^* < z < z^*$. Figure 5.24 shows the normal distribution used for the validation. The average value of



(a) Histogram of Truck Turnaround Time based on Historical Data [82]

(b) Boxplots of Truck Turnaround Time

Figure 5.23: Comparison of Historical Data versus Simulation Data - Truck Turnaround Time

the historical data is not in the rejection region. Therefore, the TTT that results from the simulation is valid. Though, the mean value of the simulation averages is approximately 5 minutes larger than the historical average. The assumption is made that this deviation is retained in the rest of the experiments that are done for this research.

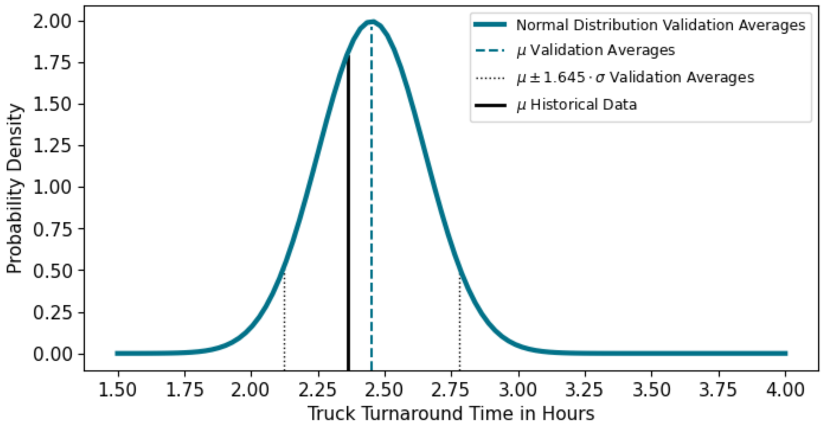


Figure 5.24: Performance Validation Truck Turnaround Time - Normal Distribution

5.9. Conclusion

This chapter focuses on research question 6 and discusses the design of the model. The model objective, requirements, assumptions and components are explained. Furthermore, flowcharts for the Truck Appointment System, the Drop and Swap system and the complementary Truck Arrival Management system are presented. Based on the flow charts, the simulation model is build. The simulation model is verified and validated.

The objective of the model is to investigate whether or not limitations of the TAS and the D&S system can be eliminated by developing a complementary TAM system. Both TAM systems can work separately of and complementary to each other. The TAM is applied to a Liquid Bulk Terminal that is subject to a global intermodal supply chain.

Furthermore, requirements and assumptions have been made, which are incorporated in the model. The model components are the so-called building blocks of the flowcharts. With the model components, flowcharts for the TAS, the D&S system and the complementary TAM system are made. The model is programmed in Python. The SimPy package is used to incorporate Discrete Event Simulation features.

The model could be verified and validated with data of Vopak Terminal Vlaardingen. Verification is done in several ways to check if the model is build correctly. Checks that have been done for example are run-time checking and visualisation, verification test runs and flow conservation. Three types of validation are used, namely data validation, structural validation and performance validation. Data validation was done by means of EasyFit software. With EasyFit, suitable distributions for arrival and service times could be determined. Distributions that are applicable to the model are the triangular, normal, uniform, lognormal, logistic and Weibull distributions. From the performance validation it can be concluded that the simulation with a complete TAS accurately follows the historical data. No significant differences in mean values could be found according to the two-tailed z-test. Hence, the simulation model is valid. The mean values for the percentage of trucks that was too late, the prepump time and the Truck Turnaround Time that resulted from the simulation slightly deviate from the historical data. The assumption is made that this deviation is retained in subsequent experiments.

6 Experimental Plan

This chapter shows the experimental plan, in which the performed experiments are elaborated. The focus of this chapter is on sub-research question 7. First, several Truck Scenarios are presented. These are considered to be the input of the simulation. Then, the parameters of the simulation model are presented. These are separated into simulation and configuration parameters. Lastly, the Design Alternatives for the Truck Arrival Management system are elaborated.

Figure 6.1 shows a simplified version of the simulation model with the input, output, requirements and performance indicated. The input is equal to the truck scenarios, the requirements are equal to the parameters and Design Alternatives. The performance is presented by the KPIs and the output is equal to unloaded trucks.

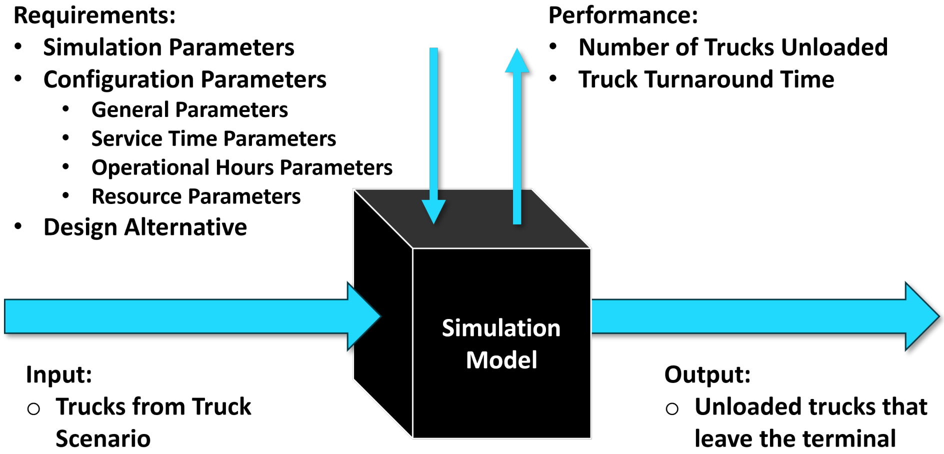


Figure 6.1: Simplified Representation of Simulation Model

6.1. Simulation Input

For the simulation, a list of truck types is made. This list includes all truck types that can be generated. The TSs consist of a combination of these truck types. TSs are the input for the simulation model and are discussed later on in this section.

6.1.1. Truck Types

The list with truck types is shown in Table 6.1. Eleven truck types can be distinguished, based on whether or not they need an NVWA inspection, their origin, if the truck driver is familiar with the LBT, what kind of product is transported and if the quality of the product is known.

Table 6.1: Truck Types in the Simulation

TruckType	NVWA	EU/non-EU	Known/Unknown Driver	Category	Quality
1	N	EU	Known	Cat1	Known
2	N	EU	Known	Cat3	Known
3	N	EU	Known	-	Known
4	N	EU	Unknown	Cat1	Known
5	N	EU	Unknown	Cat3	Known
6	N	EU	Unknown	-	Known
7	N	nEU	Known	-	Known
8	N	nEU	Known	-	Unknown
9	Y	nEU	Known	Cat1	Known
10	Y	nEU	Known	Cat3	Known
11	Y	nEU	Known	Cat3	Unknown

A striking point in Table 6.1 is that trucks with products that have unknown quality exclusively occur for imported trucks that do not transport Category 1 product. This fact has already been decided by the new customer for its Purchase Book. Furthermore, all imported trucks have a known driver. This is because imported containers arrive via containers ships in the harbour of Rotterdam. From there on, they are transported to the terminal by ETDs that are familiar with VTV. On the terminal, they are handled by ITDs that are also familiar with the terminal. Moreover, all imported containers that transport Category 1 or Category 3 product have to be inspected by the NVWA for this research. There is no distinction in whether or not containers arrive in batches.

Another point of attention is that the quality of the product is not actively considered in the simulation yet. This is because the quality of the product determines in which tank the product has to be unloaded. However, the exact distribution of which products have to be unloaded in which tanks is not yet known and can therefore not be taken into account yet. This means that tank swaps are neither examined exactly. Therefore, they are integrated as a chance of happening in order to not neglect them, as tank swaps contribute to productivity loss.

6.1.2. Truck Scenario

Based on Table 4.4 in Section 4.2, different TSs can be defined. The trucks in the TS have to be handled by the TAM and unload at the LBT. In Table 6.2, the seven different truck scenarios that serve as input for the simulation are presented. TS 0 represents the current situation at VTV and is exclusively used for validation, as described in Section 5.8.3. The other six TSs represent the future supply chain scenarios and are used as input for experiments described in this chapter.

Table 6.2: Truck Scenarios

Truck Scenario	EU Trucks	non-EU Trucks	NVWA Inspections at VTV	Number Trucks per Day	Number Trucks per Operational Month
0 Validation	100%	0%	0%	-	$\mathcal{N}(221{,}128)$
1	70%	30%	21%	40	840
1a	70%	30%	0%	40	840
2	50%	50%	35%	55	1155
2a	50%	50%	0%	55	1155
3	0%	100%	70%	[20, 55, 75]	[420, 1155, 1575]
3a	0%	100%	0%	[20, 55, 75]	[420, 1155, 1575]

As stated in Section 4.2, 70% of the imported trucks need to be inspected by the NVWA. It is stated as well that it is researched by the customer if the NVWA inspection can be executed before trucks arrive at VTV, such that the NVWA inspection is done at the port of Rotterdam. Trucks that have to be inspected by the NVWA are therefore only transported from the DST to VTV if their NVWA inspection has succeeded. Hence, TSs without any NVWA inspections at VTV are also evaluated in this research, to see what influence this has on the system performance. Important to note is that NVWA trucks (numbers 9 to 11 in Table 6.1) can still be generated in the simulation, even though they are inspected by the NVWA before their arrival at VTV.

Furthermore, the number of trucks per day is subject to change. Therefore, some experiments have been executed multiple times with a different number of trucks generated.

6.2. Parameters

In this section the parameters of the simulation are discussed. A distinction is made between simulation parameters and configuration parameters.

6.2.1. Simulation Parameters

The simulation parameters are presented in Table 6.3. The number of replications is set to five to average out results. The length of the simulation is set to 21, as this represents an operational month. Both are the same for every experiments.

Table 6.3: Simulation Parameters Validation

Parameter	Value	Unit	Same for Every Experiment?
Number of Replications	5	Runs	Yes
Length of Simulation	21	Days	Yes

6.2.2. Configuration Parameters

The configuration parameters can be divided in several subjects: general, time, operational hours and resources. Some parameters are the same for all experiments, others differ per experiment.

General Parameters

In Table 6.4, the general parameters are shown for the simulation. Except for the number of slots opened in the TAS, all parameters are the same.

The number of slots opened therefore determines the complementarity between the TAS and D&S. If no slots are opened, all trucks arrive at the terminal via D&S, whether or not their origin is EU or non-EU. On the other hand, if the number of slots opened is 18, which is equal to the maximum number of slots per day, all trucks enter the system via the TAS, independent of their origin. If the number slots opened is neither 0, nor 18, EU trucks enter the system via the TAS and non-EU trucks enter the system via D&S.

As explained in Section 5.3, the technical unavailability and the number of tank swaps work with chances instead of exact numbers. In TAS, every slot has a chance of 20% to be technically unavailable and a chance of $\frac{Number\ Tank\ Swaps}{18}$ to be reserved for a tank swap. In the D&S system, every truck has a chance of 10% that the unloading bay is technically unavailable for 45 minutes and a chance of 5% that the unloading bay is technically unavailable for 90 minutes. Trucks in the D&S system also have a chance of $\frac{Number\ Tank\ Swaps}{18}$ to have a tank swap before unloading.

Table 6.4: General Parameters

Parameter	Value	Unit	Same for Every Experiment?
Number Slots for TAS	[0,18]	Slots	No
Technical Unavailability	20%	-	Yes
Number of Tank Swaps per Day (Besides Predefined Switch from TAS to D&S)	1	Swaps	Yes
NVWA Pass Rate	90%	-	Yes
PIT Pass Rate	60%	-	Yes

Time Parameters

In Table 6.5, the parameters for the arrival and service times are presented. The distributions are based on the data validation as explained in Section 5.8.1. All distributions are the same for every experiment.

Table 6.5: Time Parameters

Parameter	Value	Unit	Same for Every Experiment?
Arrival Times TAS	$\mathcal{T}ri(6.7,7.15,14)$ and $\mathcal{T}ri(11,13.25,22.5)$	Hours	Yes
Slot Preference TAS	$\mathcal{T}ri(0,1,7)$ and $\mathcal{T}ri(6,7,17)$	Slotnumbers	Yes
Fill in Guidance Form	$\mathcal{N}(4,1)$	Minutes	Yes
Expedition	$\mathcal{L}ogn(1.9768,0.64858)$	Minutes	Yes
PIT	$\mathcal{U}(20,36)$	Minutes	Yes
NVWA Inspection	$\mathcal{N}(30,2.5)$	Minutes	Yes
Drivetime from DST to VTV	30	Minutes	Yes
Preparation Time at Unloading Bay before Start Pumping	$\mathcal{N}(10.5,1.75)$	Minutes	Yes
Pumptime at Unloading Bay	$\mathcal{L}ogi(35.68,1.2565)$	Minutes	Yes
Post Pumptime at Unloading Bay	$\mathcal{W}ei(2.49169,5.92423)$	Minutes	Yes

Operational Hours Parameters

In Table 6.6, the operational hours within the simulation are presented. The operational hours are based on the regular working hours at VTV. Again, these parameters are all the same for every experiment.

Table 6.6: Operational Hours Parameters

Parameter	Start	End	Same for Every Experiment?	Comment
External Truck Driver	7 am	10.30 pm	Yes	Last request accepted at 10.30 pm
Internal Truck Driver	7.15 am	10.15 pm	Yes	Last start of truck at unloading bay at 10.15 pm, trucks will still be removed from unloading bay when finished
Expedition	7 am	10 pm	Yes	Last request accepted at 10 pm
NVWA	8 am	3 pm	Yes	Last request accepted at 3 pm

Resource Parameters

The parameters regarding the resources are shown in Table 6.7. Except for the number of ETDs, ITDs and parking lots, all parameters are the same for every experiment. The initial values for the number of ETDs, ITDs and number of parking lots are 2, 1 and 25 respectively. These values are mainly based on the description of the complementary TAM in Section 4.1.2.

The number of parking lots reserved for TAS and therewith the number of parking lots reserved for D&S ranges between 0 and the total number of parking lots. The number of parking lots reserved for TAS depends on the number of slots opened for TAS which is described more detail in Section 6.3. This value stays the same, independent of an increase in the total number of parking lots. The total number of parking lots varies per experiment and thus has a major influence on the number of parking lots reserved for D&S trucks.

Table 6.7: Resource Parameters

Parameter	Value	Same for Every Experiment?
External Truck Drivers	[2,3]	No
Internal Truck Drivers	[1,5]	No
Expedition Members	[1,2,3]	No
PIT Computers	1	Yes
NVWA Veterinarians	1	Yes
Total Number Parking Lots	[25,35]	No
Number Parking Lots Reserved for TAS	[0,Total Number Parking Lots]	No

6.3. Design Alternatives

The Design Alternatives for the simulation apply to the layout of the TAM system. Three DAs could be established, namely the complete TAS, the complete D&S system and the complementary TAM system. Therefore, the DAs mainly differ in the number of slots opened per day for the TAS, from which automatically the remaining time for D&S results. Two DAs are always tested for every truck scenario, which are the complete TAS and the complete D&S system. The complementary TAM is based on the input ratio EU trucks:non-EU trucks in the Truck Scenario, as explained in Table 6.2. The DAs are visualised in Figure 6.2. The figure shows the TAM systems and how the trucks are unloaded.

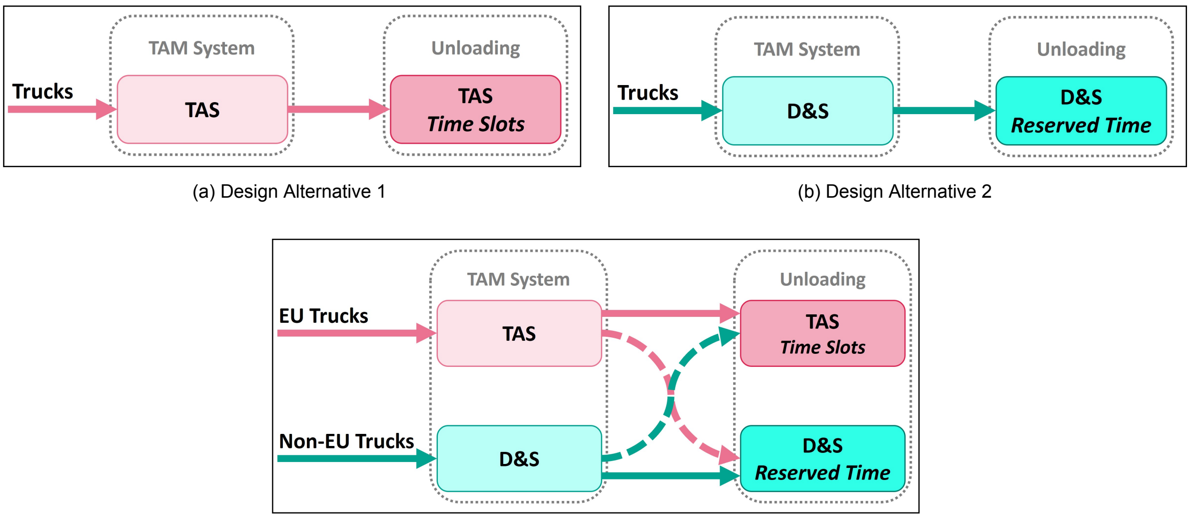


Figure 6.2: Explanation of Design Alternatives

Design Alternative 1: Complete Truck Appointment System

DA 1 is explained in Figure 6.2a. The whole day trucks are handled via the TAS in this DA, independent of their origin. Trucks arrive via the TAS and are unloaded in the TAS slots. Therefore, 18 slots are opened per unloading bay and no trucks arrive via the D&S system. This aligns with the existing situation at VTV. All parking lots available at the LBT as mentioned in Table 6.7 are reserved for TAS trucks. No ETDs and ITDs are needed for this DA.

Design Alternative 2: Complete Drop and Swap

DA 2 is visualised in Figure 6.2b. The whole day trucks are handled via the D&S system in this DA, again independent of their origin. All trucks arrive via the D&S system and are unloaded according to the D&S system. No slots are opened for the TAS. All parking lots available at the LBT are reserved for D&S trucks. Additionally, a complete D&S system needs ETDs and ITDs.

Design Alternative 3: Complementary Truck Arrival Management System

The last DA, DA 3, is shown in Figure 6.2c. In this DA, EU trucks arrive via the TAS and are unloaded during TAS slots. In case trucks missed their time slot, they are replanned to another empty slot. If no empty slots are available, trucks wait till the slots for the TAS finish during a day and unload during time reserved for the D&S system. Truck from outside the EU arrive via the D&S system and unload in principle during time reserved for D&S. In case they are ready for unloading during the TAS slots, an empty slot is available and an ITD is available, these trucks can fill an empty slot in the TAS.

The layout of the complementary TAM system can change and depends on the input. The ratio TAS:D&S is based on the ratio EU:non-EU trucks from the Truck Scenario. The number of slots opened for TAS and the number parking lots reserved for TAS trucks depend on the percentage EU trucks in the TS. The remaining values for the D&S system also result from this reasoning.

As can be seen in Table 6.2, 70% of the trucks come from inside the EU in TS 1. Consequently, 70% of the slots are opened in the TAS. Moreover, 70% of the initial value for the number of parking lots is reserved for TAS trucks. These values are calculated in Equation 6.1 and 6.2, respectively. The rounding off of the values is also shown. The values are rounded down to the nearest integer. As can be concluded, 12 slots are opened in the TAS and 17 parking lots are reserved for TAS trucks. The value of 17 parking lots remains constant, independent of a change in the total number of parking lots.

$$\begin{gathered}Percentage\ EU\ Trucks \cdot Regular\ Number\ Slots\ TAS = Resulting\ Number\ Slots\ TAS \\ 70\% \cdot 18 = 12.6 \\ 70\% \cdot 18 \approx 12\end{gathered} \tag{6.1}$$

$$\begin{gathered}Percentage\ EU\ Trucks \cdot Initial\ Number\ Parking\ Lots = Resulting\ Number\ Parking\ Lots\ TAS \\ 70\% \cdot 25 = 17.5 \\ 70\% \cdot 25 \approx 17\end{gathered} \tag{6.2}$$

For TS 2, 50% of the trucks come from inside the EU. Therefore, 50% of the slots in the TAS is opened and 50% of the initial value for the number of parking lots is reserved for TAS trucks. The calculation of these values is shown in Equation 6.3 and 6.4, respectively. If necessary, these equations include the rounding off of the values. For this TS, 9 slots are opened in the TAS and 12 parking lots are reserved for TAS trucks. Again, the value of 12 parking lots stays the same, independent of a change in the total number of parking lots.

$$\begin{gathered}Percentage\ EU\ Trucks \cdot Regular\ Number\ Slots\ TAS = Resulting\ Number\ Slots\ TAS \\ 50\% \cdot 18 = 9\end{gathered} \tag{6.3}$$

$$\begin{gathered}Percentage\ EU\ Trucks \cdot Initial\ Number\ Parking\ Lots = Resulting\ Number\ Parking\ Lots\ TAS \\ 50\% \cdot 25 = 12.5 \\ 50\% \cdot 25 \approx 12\end{gathered} \tag{6.4}$$

The fact that the number of parking lots stays the same for the TAS part in DA 3 independent of the total parking lot capacity, is supported by Figure C.9 in Appendix C. Figure C.9a shows the parking lot occupation in case TS 1 serves as input. Figure C.9b shows the parking lot occupation in case TS 2 serves as input. DA 1 defines the layout of the TAM system. In both cases it is observed that the parking lot occupation does not exceed the value of 25. Therefore, it has been chosen to keep the value for TAS parking lots constant.

6.4. Overview Experiments

Tables 6.8 till 6.16 give an overview of the experiments executed. Every green cell represents a test that has been executed. In total, multiple tests have been done which can be distributed over 9 experiments.

The experiment numbers are presented in the most left column of every table. The results are also presented accordingly the experiment numbers.

In every experiment different factor(s) have been researched that could influence the system performance. The factors that have been researched are the DAs for various TSs and numbers of generated trucks. Furthermore, the influence of the number of parking lots, the number of ITDs, the number of ETDs and the number of Expedition members have been focused on.

Experiment 1

Table 6.8 shows that the influence of the DAs on TS 1 and TS 1a is studied. It has been researched if implementing a complementary TAM with the initial parameters for the number of parking lots, ITDs, ETDs and Expedition members could already give an improvement in the system performance of an LBT. The system performance is researched for DA 1, DA 2 and DA 3.

Table 6.8: Overview Experiment 1 - Comparison of TAM Systems for Truck Scenario 1 and 1a

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
1	1 and 1a	840																

Experiment 2

Table 6.9 shows that the influence of the DAs on TS 2 and TS 2a is researched in experiment 2. Again it has been researched if implementing a complementary TAM with the initial parameters for the number of parking lots, ITDs, ETDs and Expedition members could already give an improvement in the system performance of an LBT. The system performance with a complementary TAM is again compared to a complete TAS and a complete D&S system.

Table 6.9: Overview Experiment 2 - Comparison of TAM Systems for Truck Scenario 2 and 2a

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
2	2 and 2a	1155																

Experiment 3

Experiment 3 focused on DA 3 (the complementary TAM system) for TS 1 and TS 2, as can be seen in Table 6.10. It has been researched if by exclusively increasing the number of parking lots, the system performance increases as well. Therefore, the initial capacity of 25 parking lots has been compared to a capacity of 30 and 35 parking lots. The number has been increased with steps of 5 as the expectation is that increasing the number with a smaller value does not show a noticeable change in the system performance. Furthermore, keeping in mind the implementation in the real world, the number is not increased to a very large value. The reason is that a parking lot at an LBT can in some cases be increased, but not infinitely. Therefore, it has been chosen to see if a small adjustment can make differences in the system performance.

Moreover, the TSs 1 and 2 have been chosen as the NVWA inspection is done at the LBT in these scenarios. Trucks that need NVWA inspection therefore occupy parking lots at the terminal for a larger time compared to TS 1a and TS 2a. Therefore, the aim of this experiment is to research if increasing the capacity of the parking lot increases the system performance.

Table 6.10: Overview Experiment 3 - Influence of Parking Lot Capacity on Complementary TAM System

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
3	1 and 2	840 1155																

Experiment 4

In Table 6.11, the parameters for experiment 4 are shown. Again TS 1 and TS 2 have been chosen with the complementary TAM system as DA. In this experiment, the number of ITDs is variable. The initial value for this parameter is 1. This value has been increased to 3 with steps of 1. The increase in the number of ITDs has been done per 1, as the aim is to keep the number of ITDs low. Hence, the gradual influence of the increase in the number of ITDs on the system performance was of interest.

Table 6.11: Overview Experiment 4 - Influence of Number of ITDs on Complementary TAM System

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
4	1 and 2	840 1155																

Experiment 5

In Table 6.12, the parameters for experiment 5 are shown. For this experiment, several parameters were changed at the same time for a complementary TAM. Exclusively TS 2 was chosen to research the influence of multiple parameters. The number of ITDs ranges from 1 to 5. The number of parking lots was set to 25 and 30. Moreover, the number of ETDs was set to 2 and 3. The number of Expedition members stayed constant with a value of 1.

Table 6.12: Overview Experiment 5 - Influence of Multiple Parameters on Complementary TAM System

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
5	2 and 2a	1155																

Experiment 6

In Table 6.13, the parameters for experiment 6 are shown. In this experiment, the influence of the number of Expedition members on a complementary TAM system was researched. It has been investigated if increasing the number of Expedition members can further increase the system performance. The best performing combination of parameters of experiment 5 was taken. This has been done for both TS 2 and TS 2a. The parameters for TS 2 are shown in Table 6.13a. The parameters for TS 2a are presented in Table 6.13b.

Table 6.13: Overview Experiment 6 - Influence of Number of Expedition Members on Complementary TAM System

(a) Overview Experiment 6 - TS 2

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
6	2	1155																

(b) Overview Experiment 6 - TS 2a

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
6	2a	1155																

Experiment 7

In experiment 7, the influence of two DAs on TS 3 and TS 3a has been researched, as shown in Table 6.14. There are no incoming trucks from within the EU in TS 3 and TS 3a. Therefore, only DA 1 and DA 2 have been compared to each other.

Table 6.14: Overview Experiment 7 - Comparison of TAM Systems for Truck Scenario 3 and 3a

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
7	3 and 3a	420 1155 1575																

Experiment 8

Table 6.15 shows that experiment 8 focused on TS 3 and TS 3a. Only the complete D&S system has been researched as TAM system. It has been studied if the number of parking lots influences the system performance. Again the number of parking lots has been set to 25, 30 and 35.

Table 6.15: Overview Experiment 8 - Influence of Parking Lot Capacity on Complete D&S System

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
8	3 and 3a	1575																

Experiment 9

In Table 6.16, an overview has been given for the parameters in experiment 9. The influence of the combination of various parameters for TSs 3 and 3a in which 1575 trucks were generated was studied. DA 2 served as layout for the TAM system, which aligns with the complete D&S system. The experiment was focused on maximising the system performance. It has been researched if and under which conditions that would happen. The number of parking lots varies between 25 and 30. The number of ITDs ranges from 1 to 5, with steps of 1. The number of ETDs varies between 2 and 3. Lastly, the number of Expedition members stayed constant throught the experiment, with a value of 1.

Table 6.16: Overview Experiment 9 - Influence of Multiple Parameters on Complete D&S System

Exp. Number	**Truck Scenario**	**Number Generated Trucks**	Design Alternative			Number Parking Lots			Number ITDs					Number ETDs		Expedition Members		
			DA1	*DA2*	*DA3*	*25*	*30*	*35*	*1*	*2*	*3*	*4*	*5*	*2*	*3*	*1*	*2*	*3*
9	3 and 3a	1575																

6.5. Conclusion

In this chapter the focus was on sub-research question 7. First, the input has been elaborated. Subsequently, the parameters and Design Alternatives have been listed. Lastly, an overview of the experiments is given.

For the input, seven Truck Scenarios could be constructed. The trucks in the truck scenarios are generated from a predefined list of truck types. The truck scenarios differ in their ratio EU:non-EU trucks, the percentage of NVWA trucks that has to be inspected at Vopak Terminal Vlaardingen and the number of generated trucks.

Moreover, the parameters are set. A distinction was made between simulation parameters and configuration parameters. Furthermore, the configuration parameters were divided into general, time, operational hour and resource parameters. Some parameters stayed the same throughout the experiments, others differed.

Subsequently, three DAs are introduced. The DAs apply to the layout of the TAM system. The DAs that could be constructed were the complete TAS, the complete D&S system and the complementary TAM system. The complete TAS and the complete D&S system were tested for every Truck Scenario. The exact layout of the complementary TAM system is based on the ratio EU:non-EU trucks in a Truck Scenario.

Lastly, an overview of the experiments performed is presented. A total of 9 experiments has been executed. These groups all focus on different parameters that can influence the system performance.

The subjects that vary in the experiments are the TS, the DA, the number of parking lots, the number of ITDs, the number of ETDs and the number of Expedition members.

7 Results

In this chapter the focus is on sub-research question 8. The results of the experiments as described in Section 6.4 are presented. For every experiment the KPIs are evaluated. The two KPIs that are evaluated are explained in Section 2.3 and consist of the number of unloaded trucks and the TTT of unloaded trucks. Additional results can be found in Appendix D, that include the number of arrived trucks, queues at Expedition the occupancy rate per unloading bay, the prepump time.

The Truck Scenarios can be found in Table 6.2, the parameters for the experiments are elaborated in Section 6.2 and the Design Alternatives are elaborated in Section 6.3.

First, the interpretation of the results is discussed. Subsequently, in every section an experiment is treated according to the following structure: the experiment is shortly recapped, the KPIs are presented in a figure and lastly, the results are discussed.

7.1. Interpretation of the Results

To shortly recap: The TSs served as input and the DAs determined the layout of the TAM. Three main TS were determined, namely two TSs which consisted of EU and non-EU trucks. The third TS exclusively consisted of non-EU trucks. Furthermore, every TS has been duplicated. For every first TS, the NVWA inspection is done at the LBT. For every second TS, the NVWA inspection is done prior to arrival at the LBT. Moreover, three DAs were designed for the TAM. DA 1 is a complete TAS, this represents the current situation at VTV. DA 2 is a complete D&S system and DA 3 is a complementary TAM.

The aim is to maximise KPI 1 and minimise KPI 2. The maximal operational capacity is based on the assumption that 18 trucks can unload in the TAS (DA 1). The calculation is explained in Section D.1 in Appendix D. The maximal operational capacity per TAM system is presented in Table 7.1. The table gives a good estimation, but the values are subject to stochasticity due to the technical unavailability and tank swaps.

Table 7.1: Maximal Occupancy per Truck Arrival Management System

Truck Arrival Management	Maximal Operational Capacity per Month
Complete TAS	862.4
Complete D&S	915.7
Complementary TAM System 70/30	827.9
Complementary TAM System 50/50	837.7

KPI 2 cannot be minimised further than the minimal TTT, which is approximately between 45 minutes and 1 hour. This is determined by taking the average preparation time, the pumptime and the post pumptime without any waiting times, as shown in Equation 7.1.

$$\begin{aligned} \mu_{TTT} &= \mu_{Preparation\ Time} + \mu_{Pumptime} + \mu_{Post\ Pumptime} \\ \mu_{TTT} &= 10.5 + 35.68 + 2.5 = 48.68\ minutes \end{aligned} \tag{7.1}$$

Additional to maximising KPI 1 and KPI 2, the aim is to minimise resource utilisation if possible. This has been taken into account while analysing the results.

7.2. Experiment 1: Comparison of TAM Systems for Truck Scenario 1 and 1a

In experiment 1, TS 1 and 1a were evaluated for DAs 1, 2 and 3. The number of parking lots, number of ITDs, ETDs and members of Expedition stayed constant throughout this experiment. The values were respectively 25, 1, 2 and 1.

The results of KPI 1 and KPI 2 can be found in Figure 7.1. The leftmost result represents the KPIs for the validation runs, this is done for comparison. The middle results represent the KPIs for TS 1, in which the NVWA inspection is done at the LBT. The rightmost results represent the KPIs for TS 1a, in which the NVWA is done prior to arrival at the LBT.

Additional results can be found in Figure D.1 in Appendix D. In Figure D.1a, the number of arrived trucks can be found. This number is divided into unloaded trucks and not unloaded trucks. Figure D.1b shows the occupancy rate per unloading bay. In Figure D.1c the prepump time and its distribution per TS and DA is shown.

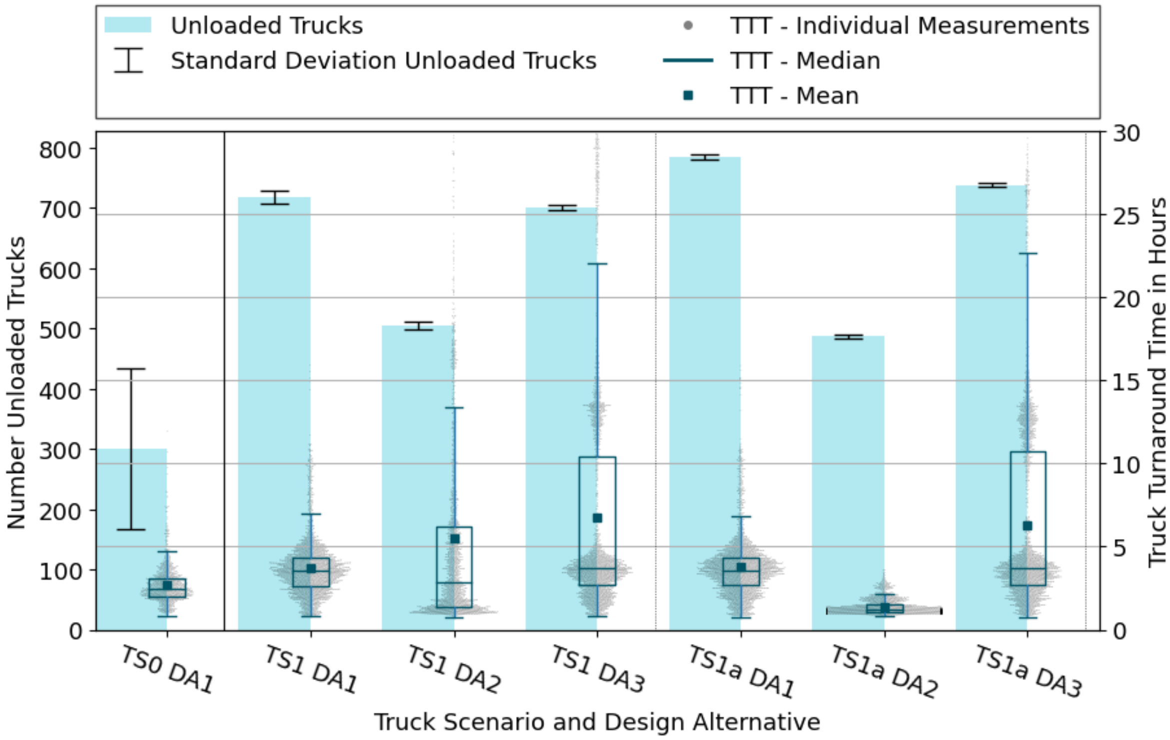


Figure 7.1: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 1

KPI 1: Number Unloaded Trucks

For none of the DAs, it was possible to maximise the number of unloaded trucks as presented in Table 7.1. However, there are differences between the DAs and TSs.

DA 1 can handle the most trucks for TS 1, despite slots that have been missed. DA 2 shows the least good system performance as the least number of unloaded trucks result from this DA. DA 3 shows that the number of unloaded trucks is a little less compared to DA 1, but the difference is small.

For TS 1a, it can be seen that in DA 2 the least number of trucks have been unloaded again. In DA 3, less trucks have been unloaded compared to DA 1. With 840 trucks generated, the system is not overloaded. Therefore, DA 1 is still performing a little bit better than DA 3 regarding KPI 1. There are still empty slots available in the TAS. Therefore, trucks that missed their time slot in the TAS have a chance of being replanned to another time slot. Furthermore, not every missed slot is filled with a

D&S truck by the ITD. This has several reasons. The first is that the ITD can be engaged in another action once an empty slot occurs. It could be in line for Expedition or preparing another truck at another unloading bay for example. Another factor that contributes to this, is that it could be that no D&S truck is ready to unload at the moment an empty slot occurs. The parking lot at the LBT has limited space for D&S trucks. Especially if the NVWA is done at the LBT, many of those parking lots are taken by trucks that are waiting for NVWA approval or waiting to be removed after rejection.

The significant difference in KPI 1 between TS 1 and TS 1a for DA 2 is due to the fact that the NVWA inspection is executed at the LBT instead of prior to arrival at the LBT. Although the NVWA inspection might seem as a thing to overcome, it also ensures that the ITD only has to register these trucks at Expedition. The ITD has to take care of these trucks again once they have been inspected. In the mean time, the focus of the ITD is on other trucks that arrive and are ready for unloading. For TS 1a, the ITD has to serve three unloading bays and trucks that have to be registered all in succession. As explanation: the cycle of preparing three trucks at their unloading bays already takes approximately 45 minutes, after which the first truck is approximately done with unloading. There is almost no time to register trucks in the mean time. If registration is done in the mean time, the ITD is not back in the minimum time that the first truck is done with unloading at the unloading bay. This decreases the efficiency of the system.

For DA 1 and DA 3 the number of unloaded trucks have both significantly increased by comparing TS 1 and TS 1a. The reason is that the NVWA inspection is done prior to arrival at the LBT in TS 1a, by which less TAS trucks miss their planned time slot.

KPI 2: Truck Turnaround Time

In all DAs and TSs, trucks have the minimum TTT of Equation 7.1. However, differences are observed in the median, mean and maximum values.

The large TTT in DA 2 for TS 1 compared to the small TTT for TS 1a can be attributed to the fact that NVWA trucks might wait for a long time at the parking lot of the terminal till they can be inspected and unloaded. First of all, inspection happens in small groups of containers, it might take some time till a new group is ready and can be inspected by the NVWA. Second, as the NVWA only has one veterinarian, inspections are not executed on a high rate.

The value for KPI 2 is high as well in DA 3. This has on one side to do with the previously mentioned reason: trucks have to wait till groups can be formed for the NVWA inspection and the veterinarian has to be available. On top of the this, if TAS trucks missed their slot they have to wait till the time reserved for D&S starts, to be able to still unload on the same day. This contributes to a larger TTT. In DA 1, if TAS trucks miss their time slot, they are replanned to another slot if that is available. If that slot is not the same day, or within the first two slots of the next day, the truck has to leave. The truck returns before the new time slot starts. The time between the moment the truck left from and returns to the terminal, is not added to the TTT. Moreover, trucks in the TAS have their own truck driver. They do not have to wait for an ITD to start the processes at the terminal. This all contributes to the fact that the TTT is smaller in DA 1.

7.3. Experiment 2: Comparison of TAM Systems for Truck Scenario 2 and 2a

In this experiment, TSs 2 and 2a were evaluated for DAs 1, 2 and 3. The number of parking lots, ITDs, ETDs and Expedition members again stayed constant throughout this experiment. The values were respectively 25, 1, 2 and 1.

The results can be found in Figure 7.2. The leftmost result represents the KPIs for the validation runs. The middle results represent the KPIs for TS 2, in which the NVWA inspection is done at the LBT. The rightmost results represent the KPIs for TS 2a, in which the NVWA is done prior to arrival at the LBT.

Additional results are presented in Appendix D, Figure D.2. Figure D.2a shows the number of arrived trucks divided into unloaded trucks and not unloaded trucks. In Figure D.2b, the occupancy rate per unloading bay is shown. Lastly, Figure D.2c shows the prepump time and its distribution per TS and DA.

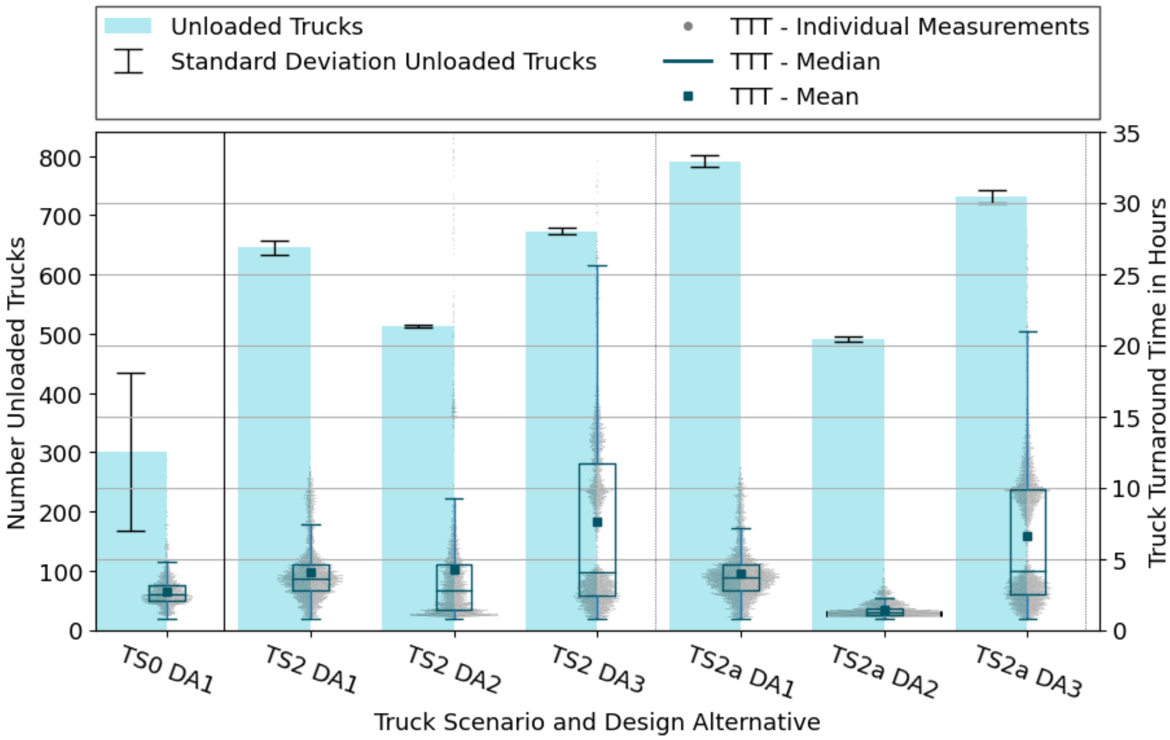


Figure 7.2: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 2

KPI 1: Number Unloaded Trucks

For none of the DAs, the maximum capacity of Table 7.1 was reached. Figure 7.2 almost shows the same tendency as Figure 7.1. DA 2 shows again the least number of unloaded trucks for both TSs compared to DA 1 and DA 3. Moreover, the significant difference in number of unloaded trucks for DA 2 in TS 2 and 2a is the same as well as previously mentioned: due to the NVWA inspection at the LBT, ITDs can focus on less trucks at the same time that have to pass all the physical processes in succession.

For TS 2, DA 3 shows a significant improvement compared to DA 1 and DA 2 for KPI 1. This is due to the fact that the system is overloaded with 1155 trucks. Therefore, if a truck missed its time slot in DA 1 (a complete TAS), there is a small chance that empty slots are left at the moment replanning of the truck is done. In DA 3, the empty slots of trucks that missed their time slot still have a chance of being filled by D&S trucks if the ITD is available at that moment. Furthermore, trucks can wait till the D&S time shift starts and still unload, which contributes to a higher number of unloaded trucks.

The reason that the number of unloaded trucks is not higher in DA 3 compared to DA 1 for TS 2a can be found in the same reasoning: the NVWA inspection is done prior to unloading at the LBT by which less trucks miss their time slot. These slots do not have to be filled with D&S trucks by the ITD.

KPI 2: Truck Turnaround Time

The TTT also shows the same tendency as in experiment 1. For experiment 2, it is also the case that the TTT for the complementary TAM system (DA 3) is large and is caused by the same reason as mentioned in Section 7.2: TS trucks have to wait till the D&S time starts during a day to unload at the same day if they missed their slot.

The large TTT for TS 2 compared to TS 2a in DA 2 can be attributed again to the fact that groups of NVWA trucks have to be formed and that the NVWA inspection is executed by one veterinarian.

7.4. Experiment 3: Influence of Parking Lot Capacity on Complementary TAM System

KPI 1 is not maximised yet by solely implementing a complementary TAM, as resulted from experiment 1 and 2. Therefore, it has been researched if changing parameters can increase the system performance.

In experiment 3, TS 1 and TS 2 were evaluated for DA 3. The number of parking lots changed during the experiment. The TSs were evaluated for a parking lot capacity of 25, 30 and 35 parking lots. The number of ITDs, ETDs and Expedition members stayed constant with values of 1, 2 and 1 respectively.

The influence of the number of parking lots has been researched, as trucks that are inspected by the NVWA at the LBT take up a parking space. This ranges from the moment they arrive from the DST at the parking lot of the LBT until inspection is finished and they can be unloaded. This could sometimes take a long time. The parking space cannot be used by non-NVWA trucks that could be handled by the ITDs more quickly. Therefore, the influence of this parameter has been checked. The expectation is that more space is available for non-NVWA trucks at the parking lot of the LBT, by which the number of handled trucks increase.

The results can be found in Figure 7.3. On the left, the results for TS 1 are shown. On the right, TS 2 is presented. In Appendix D, Figure D.3 additional results are shown. Figure D.3a shows the arrived trucks, divided in unloaded trucks and trucks that are not unloaded. Figure D.3b and Figure D.3c show the occupancy rate per unloading bay and the prepump time respectively.

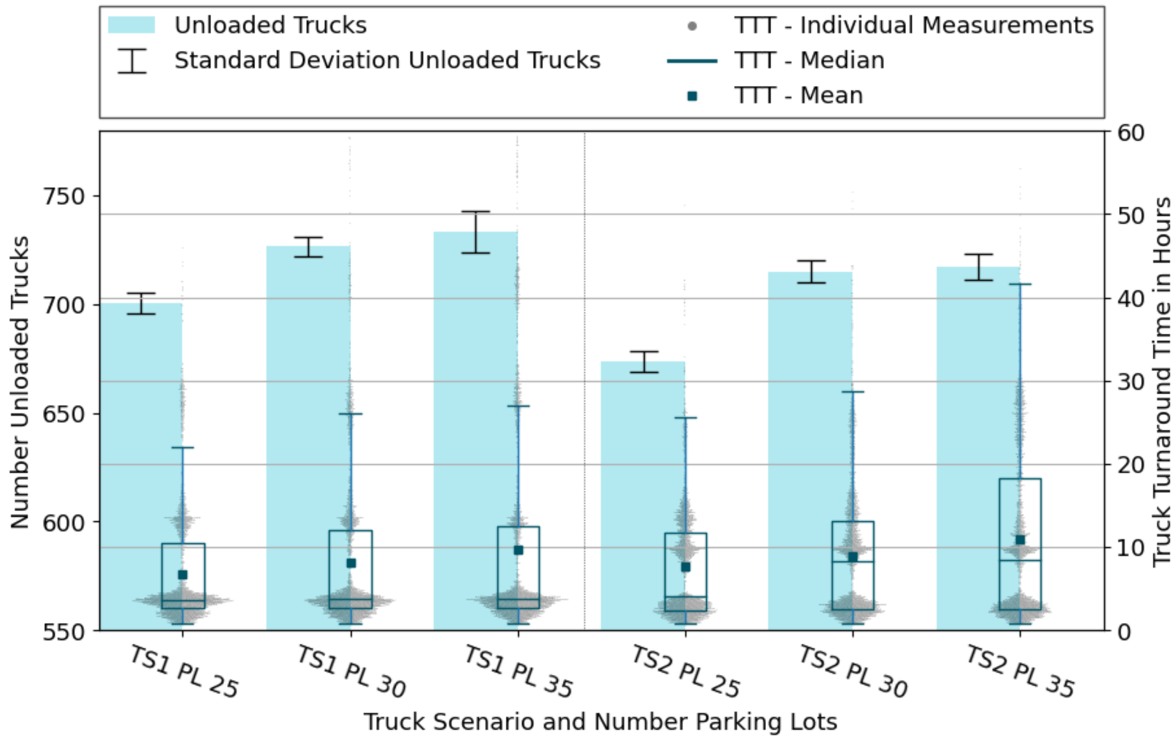


Figure 7.3: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 3

KPI 1: Number Unloaded Trucks

What can be noticed is that the influence of the number of parking lots on KPI 1 is small but significant by changing the capacity from 25 to 30. There is no significant difference between the system where 30 parking lots are compared to 35 parking lots for TS 1 and TS 2. The increase in unloaded trucks by designing a parking with 25 parking spaces or 30 parking spaces is attributed to the fact that more parking spaces are available for D&S trucks. There is a maximum number of NVWA trucks that are transported from the DST to the LBT per day. So the fact that more non-NVWA trucks can be placed at the parking lot of the LBT majorly contributes to the increase in unloaded trucks. The stagnation at

35 parking lots can be explained by the fact that ITDs cannot cope with the arrival rate of trucks.

The same trend can be observed by comparing TS 1 and TS 2. Though, the overall number of unloaded trucks is less for TS 2 compared to TS 1. This is explained by the fact that for TS 1 the system is not overloaded with 840 generated trucks, while in TS 2 the system is overloaded with 1155 generated trucks. Therefore, replanning of TAS trucks is done in better way for TS 1 compared to TS 2. Furthermore, the percentage of non-EU trucks is higher in TS 2. This results in the fact that the number of NVWA trucks is higher as well in TS 2. However, one veterinarian is not able to inspect more NVWA trucks. This limits the efficiency of unloading bays. This is supported by Figure D.3a in Appendix D.

In DA 3 the TAS trucks that missed their time slot have to wait till the D&S time starts at a day to unload at the same day. This results in the fact that less D&S trucks can unload in the time reserved for D&S trucks. Moreover, as previously mentioned, not every empty slot in the TAS is filled with a D&S truck as the ITD might be engaged in another action. Moreover, it could be the case that no trucks ready to unload are available. Therefore, it is hard to reach the maximum number of unloaded trucks from Table 7.1.

KPI 2: Truck Turnaround Time

The TTT does not significantly differ between the six results presented in Figure 7.3. A slight increase in mean values can be noticed, as trucks are able to wait at the parking lot for a longer time due to increased capacity. ETDs can transport more trucks from the DST to the LBT, but they might have to wait for a little longer time till they can unload. The explanation for this is that more trucks can be parked at the parking lot that have to unload before that one particular truck.

7.5. Experiment 4: Influence of Number of ITDs on Complementary TAM System

Changing the parking lot capacity did not maximise KPI 1, as is concluded from experiment 3. In experiment 4, TS 1 and TS 2 were evaluated for DA 3. The number of ITDs changed during the experiment. Both TSs were evaluated for a number of 1, 2 and 3 ITDs. The number of parking lots, ETDs and Expedition members stayed constant, with values of 25, 2 and 1 respectively.

The influence of the number of ITDs has been researched, as it was noticed that not every empty slot in the TAS could be filled with a truck by the D&S system. Therefore, it was checked if increasing the number of ITDs influenced the system performance.

The results of the KPIs can be found in Figure 7.4. On the left, the results for TS 1 are presented. On the right, the KPIs for TS 2 are shown. In Figure D.4 in Appendix D additional results are shown. Figure D.4a shows the arrived trucks, divided in unloaded trucks and trucks that are not unloaded. Figure D.4b and Figure D.4c show the occupancy rate per unloading bay and the prepump time respectively.

KPI 1: Number Unloaded Trucks

No significant increase in KPI 1 can be noticed. The maximum number of trucks from Table 7.1 is reached neither. What stands out is again an overall difference in number of unloaded trucks between TS 1 and TS 2. As previously mentioned, TS 1 does not overload the system, while TS 2 does. TAS trucks that miss their time slot are harder to replan for TS 2 and have to wait till the time reserved for D&S starts till they can unload the same day. Furthermore, there are more NVWA trucks in TS 2. The veterinarian is not able to cope with the increased number of NVWA trucks. This is supported by Figure D.4a in Appendix D.

It can be concluded that solely increasing the number of ITDs does not increase the chance that an ITD is not engaged with another task at the time an empty slot occurs. The ITDs are often still in line for Expedition, once a morning slot becomes available. This has to do with the fact that most TAS trucks arrive in the morning, as visualised in Figure D.5, Appendix D. An example of arrivals of truck drivers at Expedition for one simulation run is shown as a heatmap. The Expedition member is not able to cope with the arrival rate of all truck drivers. This results in long waiting times at Expedition. If ITDs also join the queue, they are not ready in time for the start of an empty slot in the morning.

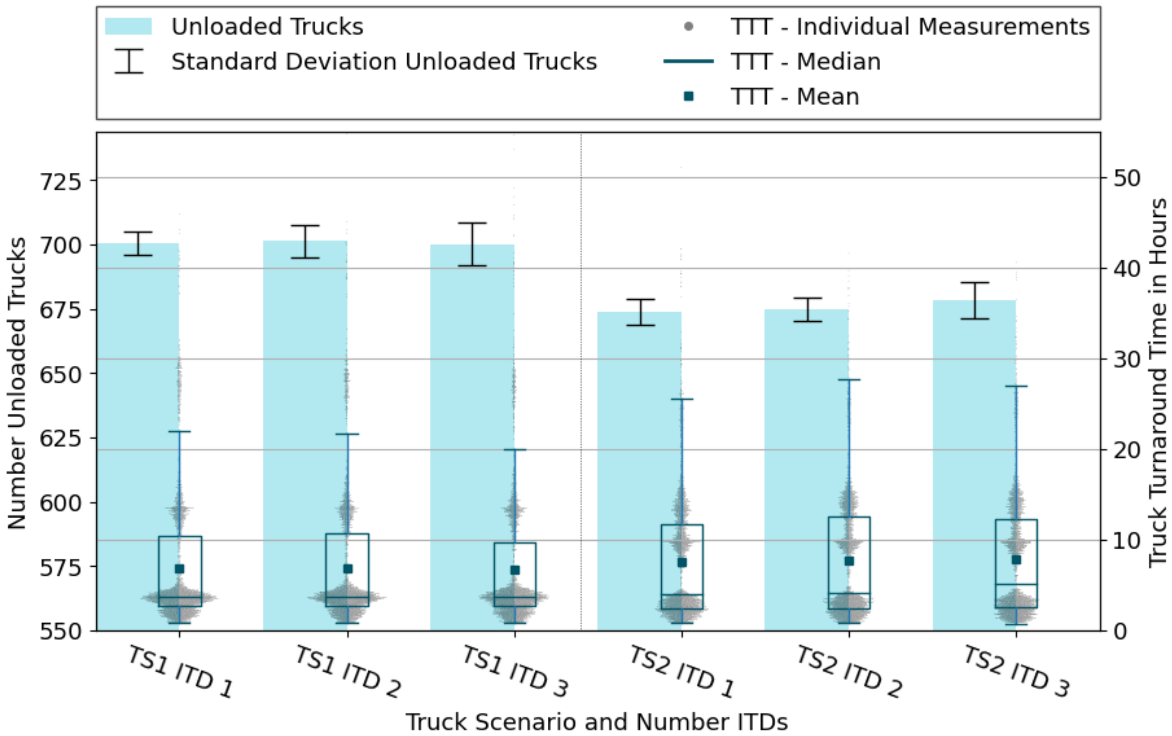


Figure 7.4: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 4

KPI 2: Truck Turnaround Time

As previously mentioned, trucks are not unloaded at a higher rate by solely increasing the number of ITDs. Therefore, the TTT is neither affected. The mean values for the TTT approximately stay the same for different numbers of ITDs.

7.6. Experiment 5: Influence of Multiple Parameters on Complementary TAM System

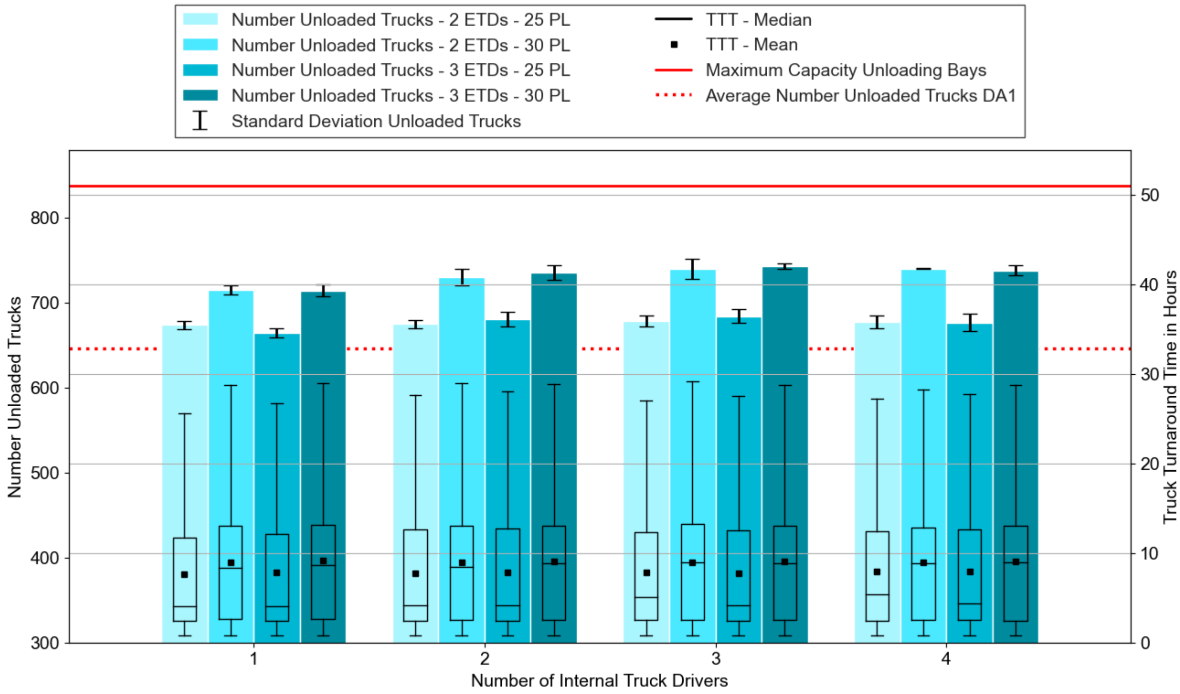
For this experiment, a combination of parameters has been changed. From previous experiments, KPI 1 cannot be maximised by solely changing one parameter. Therefore, multiple parameters were changed in this experiment to see if the KPIs can be improved. The number of ITDs was increased from 1 to 5. The number of ETDs varied between 2 and 3. The number of parking lots was set to 25 and 30. The number of Expedition members stayed constant with a value of 1.

The DA that was studied was the complementary TAM system. This TAM system has only been studied for TS 2 and 2a in this experiment. From previous experiments, the overall tendency of the KPIs was alike between TS 1 and 2. Therefore, only TS 2 and 2a were studied. It is assumed that TS 1 and 1a will approximately react alike, by changing the same parameters. However, for a thorough conclusion, these TSs have to be researched as well in the future.

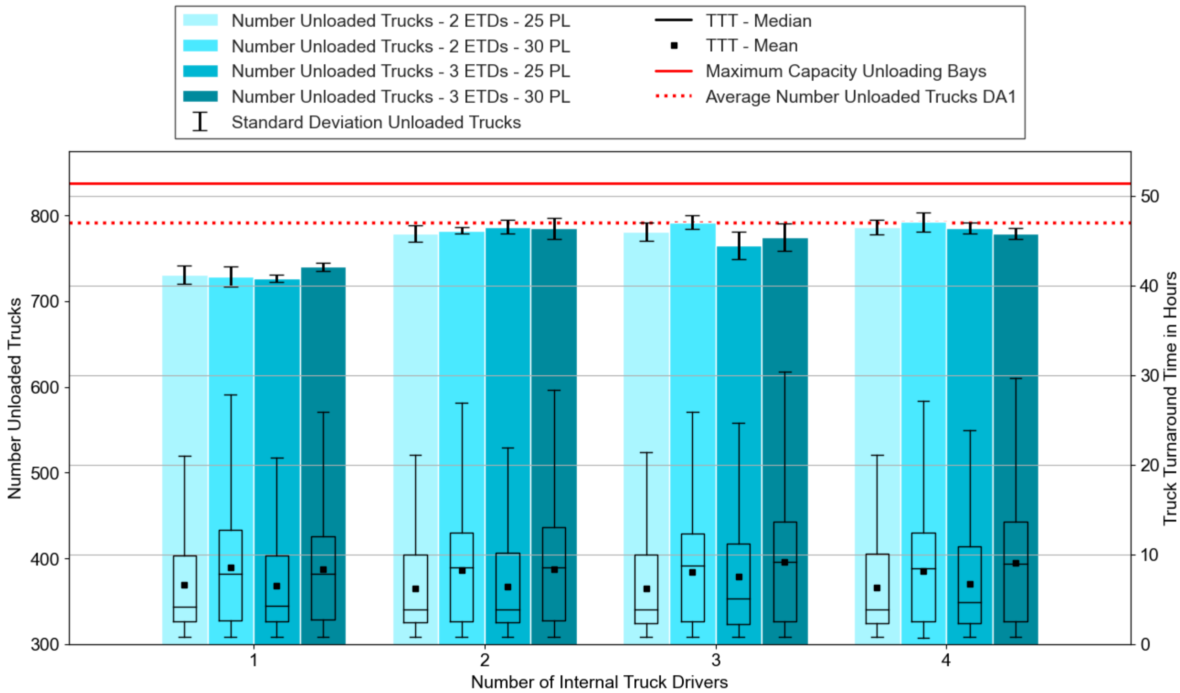
The results of the KPIs can be found in Figure 7.5. In Figure 7.5a the results for TS 2 are presented. Figure 7.5b shows the results for TS 2a. Per number of ITDs on the x-axis, KPI 1 and KPI 2 are presented on both y-axes. The bars have different colours, these each represent a combination of the number of parking lots and ETDs. The spread of the TTT for every parameter combination is shown as a boxplot in each particular bar.

Furthermore, the average number of unloaded trucks for DA 1 is plotted as a red dashed line. This value is taken from experiment 2. The average is plotted to easily compare KPI 1 for DA 1 and DA 3. This comparison is interesting, as it compares situation with a complete TAS and a complementary TAM. The red solid line shows the maximum operational capacity of Table 7.1.

Figure D.6 in Appendix D shows additional results with respect to the occupancy rate of unloading bays.



(a) KPIs for Truck Scenario 2



(b) KPIs for Truck Scenario 2a

Figure 7.5: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 5

KPI 1: Number Unloaded Trucks

For TS 2, the number of unloaded trucks reaches its maximum already for 2 ITDs, 2 ETDs and 30 parking lots. The other bars do not show a significant improvement for KPI 1. As can be seen, the complementary TAM does show an improvement compared to a complete TAS. However, the maximum operational capacity of Table 7.1 is not reached. The NVWA inspection has a major influence on this.

The number of ETDs does not influence KPI 1 much. The number of parking lots does influence the value for KPI 1 significantly. This is attributed to the fact that NVWA trucks take up a parking space as long as they have to wait till they are inspected. The more parking spaces there are at the LBT, the more non-NVWA trucks can be handled.

For TS 2a, the number of ITDs has the largest influence on KPI 1. The number of unloaded trucks reaches its maximum for 2 ITDs, 2 ETDs and 25 parking lots. Not much variation in KPI 1 is noticed once the parameters are increased further. This combination of parameters is close to the average value for KPI 1 in DA 1. The result is that this combination of parameters almost reaches the same result with a complementary TAM as with a complete TAS regarding KPI 1. The maximum value for the unloading bay capacity, as presented in Table 7.1, is not reached. This is due to the fact that ITDs could be engaged with another task, once an empty slot occurs.

As can be noticed between in Figure 7.5, the fact that the NVWA is executed before arrival at the LBT does influence the number of unloaded trucks. More trucks can be unloaded if the NVWA inspection is executed prior to arrival at the LBT. Figure D.6 in Appendix D supports this. The occupancy rate of the unloading bays is presented in Figure D.6a and Figure D.6b for TS 2 and TS 2a respectively. Unloading bay C shows a lower occupancy rate for TS 2 than for TS 2a.

KPI 2: Truck Turnaround Time

The mean value for the TTT does not change much between the different combination of parameters. However, the median does show a difference. For 30 parking lots, the median is higher compared to the situations with 25 parking lots. This can be explained by the fact that for 30 parking lots, more trucks can be transported from the DST to the LBT. The capacity of the parking lot is higher. Hence, more trucks can already be placed at the parking in order to wait for unloading.

7.7. Experiment 6: Influence of Expedition Members on Complementary TAM System

For the previous experiment, it was noticed that the maximum occupancy of table 7.1 is not reached yet. Furthermore, not every slot is filled with a truck yet. Therefore, the influence of the number of Expedition members has been researched for TS 2 and TS 2a. The two combinations of parameters that were chosen were the ones that performed best in experiment 5. The combination of parameters are summarised in Table 7.2.

Table 7.2: Combination Parameters Experiment 5 - Best Performance

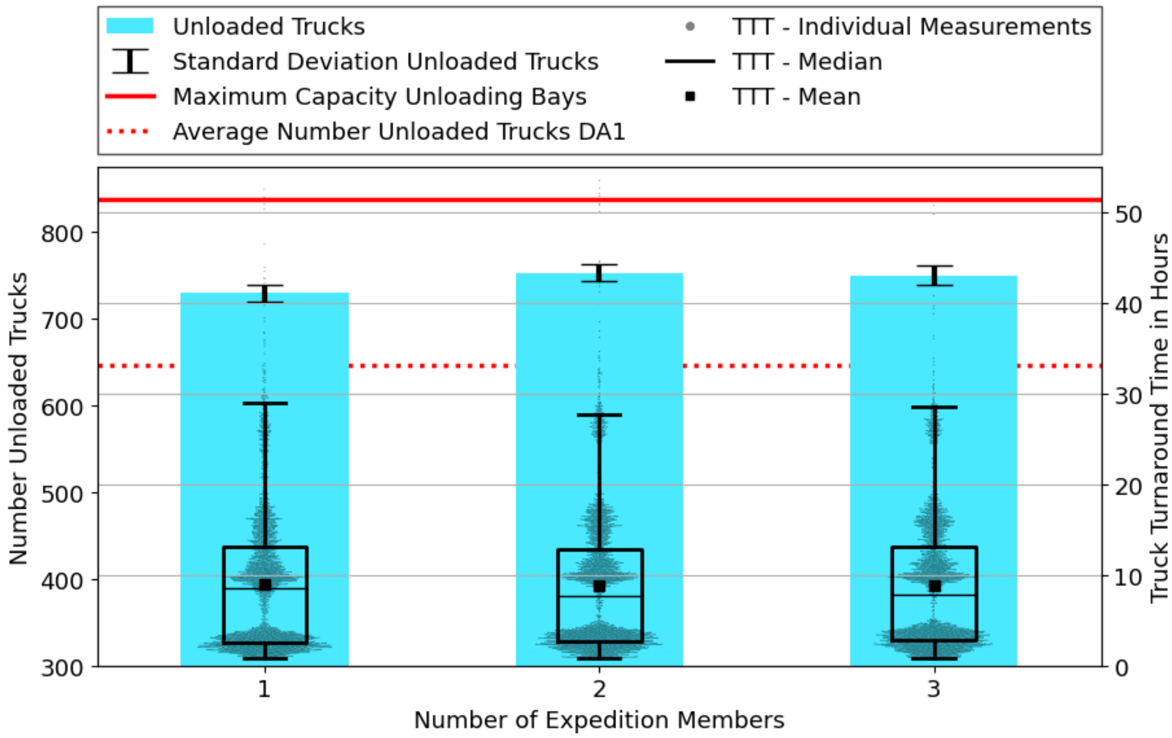
Truck Scenario	Number of Parking Lots	Number of ITDs	Number of ETDs
TS 2	30	2	2
TS 2a	25	2	2

The results can be found in Figure 7.6. Figure 7.6a shows the KPIs for TS 2. Figure 7.6b shows the KPIs for TS 2a. In both figures, the red dotted line shows again the average value for KPI 1 in case the TS would be handled by DA 1. The red solid line shows the maximum operational capacity of Table 7.1. The occupancy rates of the unloading bays for this experiment can be found in Figure D.7 in Appendix D. In Figure D.8, examples of queues at Expedition are presented in heatmaps.

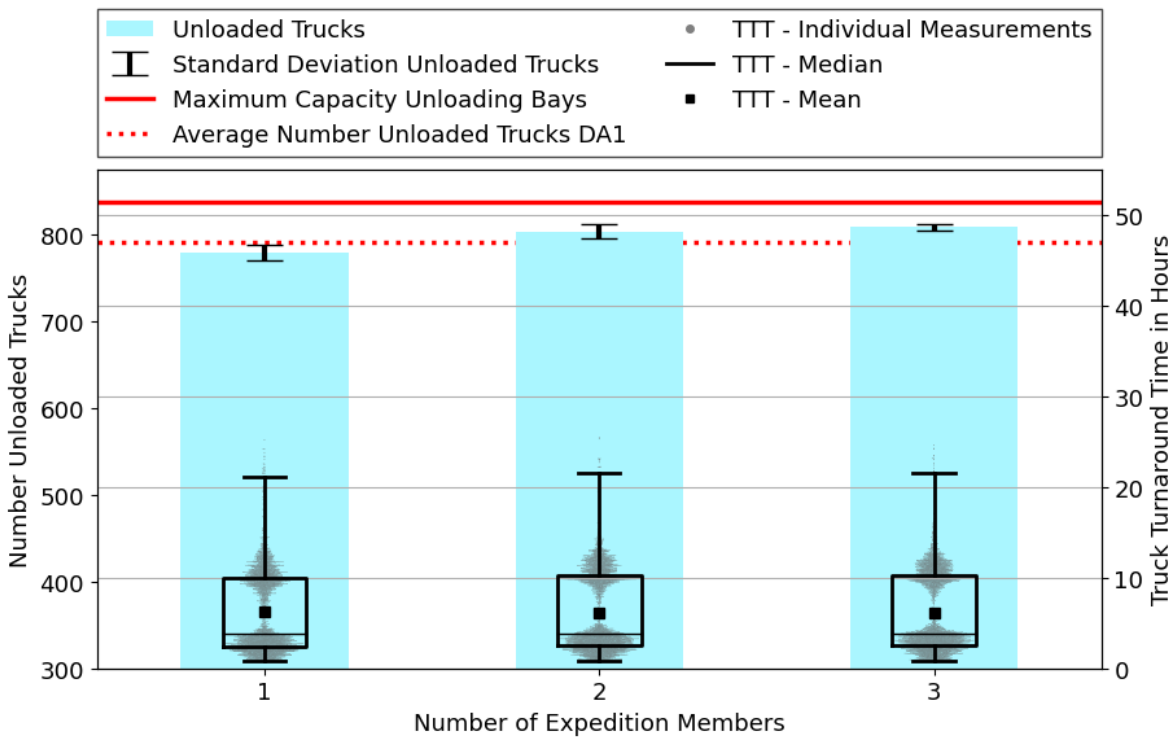
KPI 1: Number Unloaded Trucks

For TS 2, the number of unloaded trucks increased significantly by expanding the number of Expedition members from 1 to 2. No significant difference is noticed by increasing the number of Expedition members from 2 to 3. This can be best explained by Figure D.8a, Figure D.8b and Figure D.8c. The length of queues reduced majorly. The number of unloaded trucks already exceeded the value in case DA 1 was applied with the initial parameters. However, the maximum occupancy rate as presented in Table 7.1 is hard to reach. This is best explained by Figure D.7a. Again, unloading bay C shows the lowest occupancy percentage. This is attributed to the fact that the NVWA inspection rate at the LBT does not match the maximal unloading rate.

TS 2a also shows a significant increase in KPI 1 by changing the number of Expedition members from 1 to 2. The value exceeds the case where DA 1 would be applied. The maximum occupancy of



(a) KPIs for Truck Scenario 2



(b) KPIs for Truck Scenario 2a

Figure 7.6: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 6

Table 7.1 is approached, but still not reached. This can be explained by Figure D.9. Looking at Figure D.9a, Figure D.9b and Figure D.9c in Appendix D, almost all slots are filled. However, there are some slots that are still empty. This is attributed to the fact that sometimes, ITDs are available to serve a truck at a certain time, but the start of the empty time slot already passed. In order to not negatively impact the next scheduled truck, the slot is not always filled. Therefore, it is hard to reach the maximum operational capacity.

KPI 2: Truck Turnaround Time

The TTT does not necessarily change by expanding the number of Expedition members for TS 2. A slight decrease can be noticed. This is explained by the fact that queues for Expedition are smaller, as the capacity increased. Therefore, truck drivers and ITDs spend less time in line. This results in the fact that less slots will be missed. Moreover, ITDs are available again sooner, by which other actions can be performed.

The TTT for TS 2a is overall smaller compared to TS 2. The NVWA inspection is the main contributor to the larger TTT.

7.8. Experiment 7: Comparison of TAM Systems for Truck Scenario 3 and 3a

In experiment 7, TS 3 and 3a were evaluated for DAs 1 and 2. In this experiment the number of parking lots, ITDs, ETDs and Expedition members stayed constant. The values were respectively 25, 1, 2 and 1. For TS 3 and TS 3a, three different numbers of trucks were generated by the system, namely 420, 1155 and 1575.

The results for experiment 7 can be found in Figure 7.7. The leftmost result represents the KPIs for the validation runs. In the subsequent ”blocks” of four, the KPIs for TS 3, TS 3a, DA 1 and DA 2 are plotted. Every block represents a different number of trucks generated.

Figure D.10 in Appendix D contains additional results for experiment 7. Figure D.10a shows the number of arrived trucks, divided into unloaded and not unloaded trucks. In Figure D.10b, the occupancy rate per unloading bay is shown. Lastly, in Figure D.10c the prepump time per DA, TS and number of generated trucks is presented.

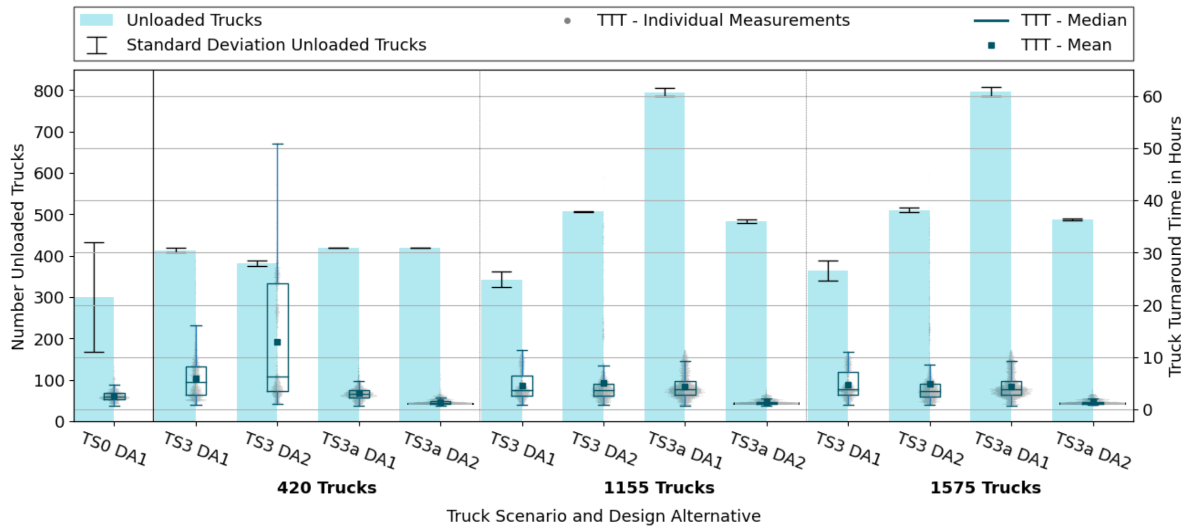


Figure 7.7: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 7

KPI 1: Number Unloaded Trucks

None of the DAs reaches the maximum value for KPI 1 of Table 7.1. In the first case of 420 trucks, it is not even possible to reach the maximum. The number of generated trucks is namely less than the maximum. The value for KPI 1 approximately stays constant for the DAs and TSs, except for TS 3, DA 2. In this case not all NVWA trucks can be transported, inspected and unloaded. What was striking for TS 3a and DA 2, was that the unloading of trucks was finished before the 21^{st} day of simulation. This is visualised in Figure D.11 in Appendix D. The reason for this can be found in the fact that the system was not overloaded and trucks could be unloaded one after another. Trucks do not have to wait till their planned time slot at a certain day, as is the case in the TAS. Figure D.11a shows the parking lot occupancy per day, Figure D.11b and Figure D.11c show the occupancy of the unloading bays at day 17 and day 18. It can be seen that all trucks are unloaded after day 18.

For 1155 generated trucks, DA 2 shows a better performance for TS 3 compared to DA 1. This is due to the fact that all trucks come from outside the EU. Many NVWA inspections have to take place by which many trucks miss their planned time slot in the TAS. Not much replanning can be done, as the system is overloaded and the chance of an empty slot at the moment a truck missed its time slot is small. If the NVWA inspection is done prior to arrival at the LBT (TS 3a), DA 1 shows more unloaded trucks again compared to DA 2 as less trucks miss their time slot. The fact that the number of unloaded trucks in DA 2 is small, is because the ITD is not able to cope with the arrival rate of trucks. The ITD has to register and unload trucks all by itself, while in DA 1 trucks have their own truck driver.

1575 trucks shows the same tendency as 1155 trucks. This is logical, as in both cases the system is overloaded. Therefore, KPI 1 does not show an increase once the number of generated trucks is higher.

KPI 2: Truck Turnaround Time

For 420 trucks, DA 2 shows the highest TTT for TS 3. The spread is large and can be explained by Figure D.12 in Appendix D. At a certain moment, no non-NVWA trucks are available at the DST anymore. From this moment, exclusively NVWA trucks are transported to the LBT. However, the NVWA veterinarian is not able to cope with this arrival rate. It can only inspect a certain number of trucks per day. Therefore, NVWA trucks have to wait for a long time till they can be inspected and unloaded. This contributes to the high TTT.

For 1155 and 1575 trucks, the system is overloaded. Therefore, there are enough non-NVWA trucks to choose from at the DST in TS 3 and DA 2. This results in the fact that the spread of the TTT is smaller compared to the case with 420 trucks.

For all cases with TS 3a and DA 2, the TTT is the lowest. Trucks almost do not have to wait till they can be can be unloaded.

7.9. Experiment 8: Influence of Parking Lot Capacity on Complete D&S System

In experiment 8, TS 3 and TS 3a are studied for several numbers of parking lots in DA 2. In TS 3 and 3a, all trucks come from outside the EU. Therefore, all trucks are handled via the D&S system. Furthermore, the system is overloaded. However, the value for KPI 1 was still low by solely implementing DA 2, as can be concluded from experiment 7. Therefore, it was checked if exclusively increasing the number of parking lots influenced the system performance. The number of parking lots was set to 25, 30 and 35. The number of ITDs, ETDs and Expedition members stayed constant, with values of 1, 2 and 1 respectively.

The results are shown in Figure 7.8. On the left, the results for TS 3 are shown. On the right, the results for TS 3a are shown. Additional results are presented in Appendix D, Figure D.13. Figure D.13a shows the arrived trucks, divided in unloaded trucks and trucks that are not unloaded. Figure D.13b and Figure D.13c shows the occupancy rate per unloading bay and the prepump time respectively.

KPI 1: Number Unloaded Trucks

No significant increase in the number of unloaded trucks is noticed for either TS 3 and TS 3a. This is attributed to the fact that one ITD is not able to keep up with the arrival rate of trucks. Therefore, solely increasing the capacity of the parking lot does not influence the system performance. It only influences the number of trucks transported to the terminal, as visualised in Figure D.13a in Appendix D.

There is a significant difference in number of unloaded trucks between the two TSs. This can best be explained by Figure D.13b in Appendix D. The occupancy rate of unloading bay C04C is very low compared to unloading bays C04A and C04B. As trucks with product Category 1 can exclusively be unloaded at C04C and have to be inspected by the NVWA, this influences the number of unloaded trucks. The NVWA inspection may seem as a factor to overcome. However, it helps to improve the efficiency of the ITD in a complete D&S system . In TS 3a, the ITD has to cope with arriving trucks

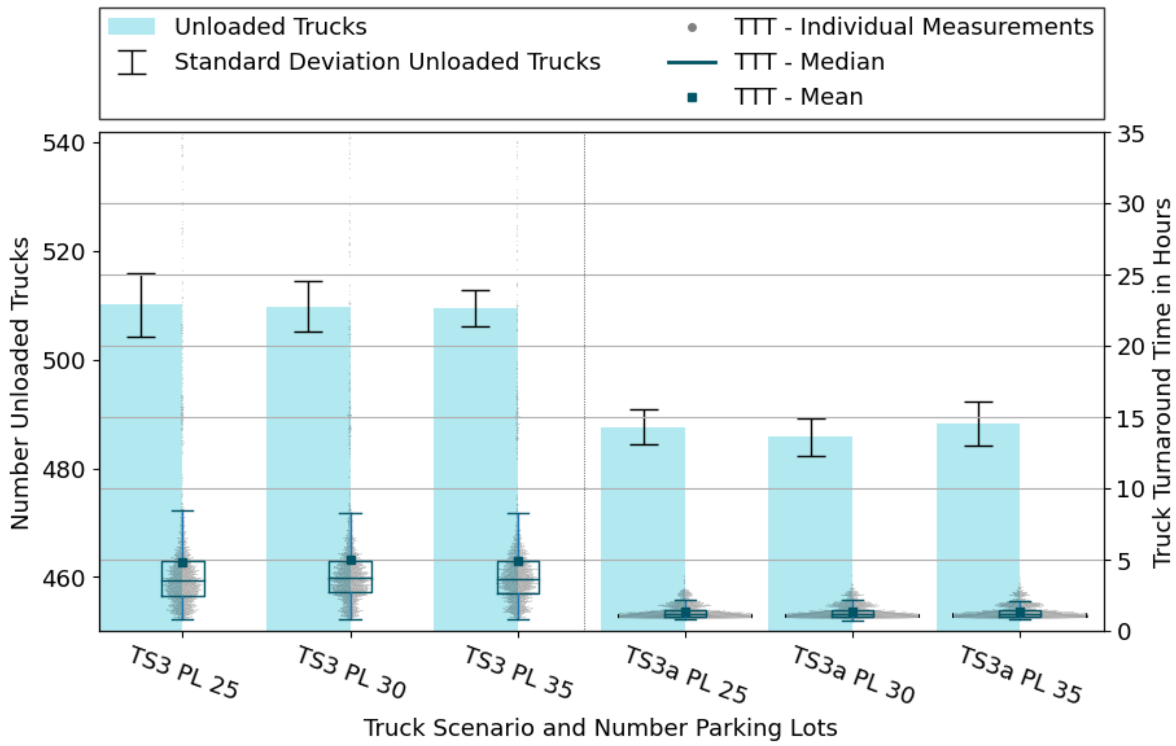


Figure 7.8: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 8

that can immediately unload after registration once its unloading bay is empty. One ITD is not able to keep up with that rate. For TS 3, NVWA trucks are transported to the parking lot of the LBT and have to wait for NVWA inspection after registration. A maximum number of NVWA trucks is allowed to be transported to the LBT, by which the rest of the day is used for the transport of non-NVWA trucks. These non-NVWA trucks are unloaded exclusively at unloading bays C04A and C04B. The ITD is better able to cope with this situation where two unloading bays have the major focus. For example, an ITD is able to prepare two trucks at two unloading bays and can register trucks in the remaining pumptime till the trucks that are unloading are ready to leave the unloading bay.

KPI 2: Truck Turnaround Time

The TTT remains the same as well for both TS 3 and TS 3a. More trucks can be placed at the parking lot, but the TTT is measured from the moment it is registered at Expedition. For most trucks, the ITD executes the physical processes consecutively for one truck at a time. Therefore, the time between the moment of registration and the moment a truck finished unloading does not increase with more parking lots.

The difference in KPI 2 between TS 3 and TS 3a is explained by the fact that the NVWA inspection is done prior to arrival at the LBT. Consequently, trucks do not have to wait for inspection at the time they are registered at the LBT. Hence, the TTT is lower for TS 3a compared to TS 3.

7.10. Experiment 9: Influence of Multiple Parameters on Complete D&S System

In experiment 9, multiple parameters varied. The TSs that served as input were TS 3 and TS 3a in which 1575 trucks were generated. The system is overloaded by the input. DA 2, a complete D&S system, served as TAM system. The influence of the combination of changing the number of parking lots, ITDs and ETDs has been studied, to check if the system performance could be maximised. The number of parking lots is set to 25 and 30, the number of ITDs ranges from 1 to 5 and the number of ETDs is set to 2 and 3. The number of Expedition members stayed constant with a value of 1.

Figure 7.9 presents the results of the KPIs. In Figure 7.9a the results for TS 3 are presented. Figure

7.9b shows the results for TS 3a. The number of ITDs is shown on the x-axis. The left y-axis belongs to KPI 1 and the right y-axis belongs to KPI 2. The bars have different colours, these each represent a combination of the number of parking lots and ETDs. The spread of the TTT for every parameter combination is shown as a boxplot within each particular bar.

Furthermore, the red dashed line represents the average number of unloaded trucks for DA 1. This value is taken from experiment 7. The average is plotted to easily compare KPI 1 for DA 1 and DA 2. This comparison is interesting, as it compares situation with a complete TAS and a complete D&S. The red solid line represents the maximum capacity of unloading bays from Table 7.1.

Figure D.14 in Appendix D shows extra results for this experiment. Figure D.14a shows the occupancy rate of the unloading bays for TS 3 and Figure D.14b shows the occupancy rate of the unloading bays for TS 3a.

KPI 1: Number Unloaded Trucks

For TS 3, KPI 1 is already improved by implementing DA 2 with the initial parameters compared to DA 1. Moreover, the number of unloaded trucks reaches the maximum value for 2 ITDs, 3 ETDs and 25 parking lots. Further increasing the parameters does not significantly increase KPI 1. The number of ITDs has the largest influence on KPI 1. Subsequently, it is noticed that the number of ETDs has a larger influence compared to the number of parking lots.

The maximum value of Table 7.1 is not reached. This can be best explained by Figure D.14a in Appendix D. The occupancy rate of unloading bay C is low compared to unloading bays A and B. The explanation for this is that exclusively Category 1 product can be unloaded at unloading bay C. All Category 1 products from outside the EU have to be inspected by the NVWA, before they can be unloaded. The veterinarian at the LBT can only inspect a certain number of trucks per day. This reduces the efficiency of unloading bay C.

For TS 3a, the maximum value for KPI 1 is reached for 4 ITDs, 3 ETDs and 25 parking lots. No significant increase for KPI 1 can be measured by further increasing the parameters. DA 2 is does exceed the value for KPI 1 of DA 1 already when at least 2 ITDs and 3 ETDs are implemented. Again the number of ITDs has the largest influence. Subsequently, the influence of the number of ETDs is higher than the influence of the number of parking lots.

Moreover, the combination of 4 ITDs, 3 ETDs and 25 parking lots does reach the maximum operational capacity of the unloading bays from Table 7.1. This can be explained with Figure D.15 in Appendix D. Figure D.15a and Figure D.15b show the unloading bays on any given day in the simulation. It is shown that the unloading bays are almost full. Furthermore, the ITDs do not have to wait till the start of a slot to start unloading. Therefore, the maximum operational capacity can be reached.

KPI 2: Truck Turnaround Time

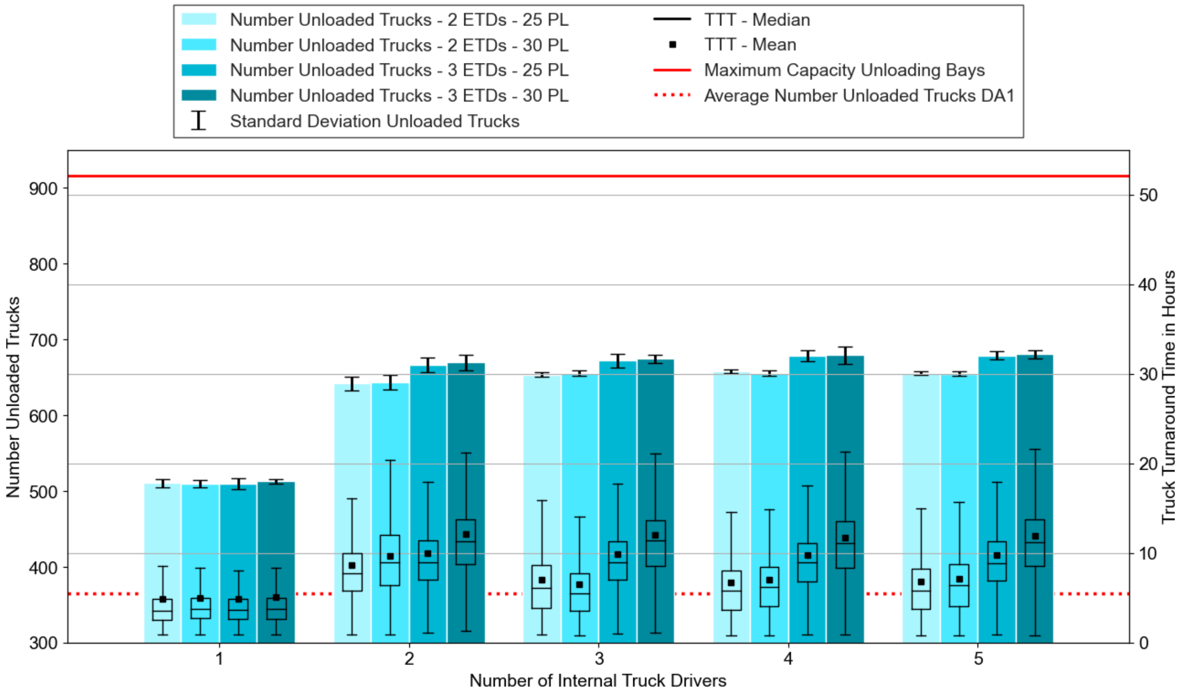
For TS 3, the mean value for the TTT increases by increasing the number of ETDs and parking lot capacity. Per ITD, the tendency of the TTT is approximately the same. An exception for this tendency is the case where there is only 1 ITD. For 1 ITD the TTT remains constant. The same reason as in experiment 8 can be used: the TTT is measured from the moment of registration at Expedition. The ITD is not able to cope with the arrival rate of trucks at the parking lot. As a consequence, the ITD executes the physical processes consecutively for one truck at a time.

Once there are 3 ITDs, all three unloading bays can in practice be served by a single ITD. This is observed in the mean TTT. The value is a little lower compared to 2 ITDs for the cases where there are 2 ETDs.

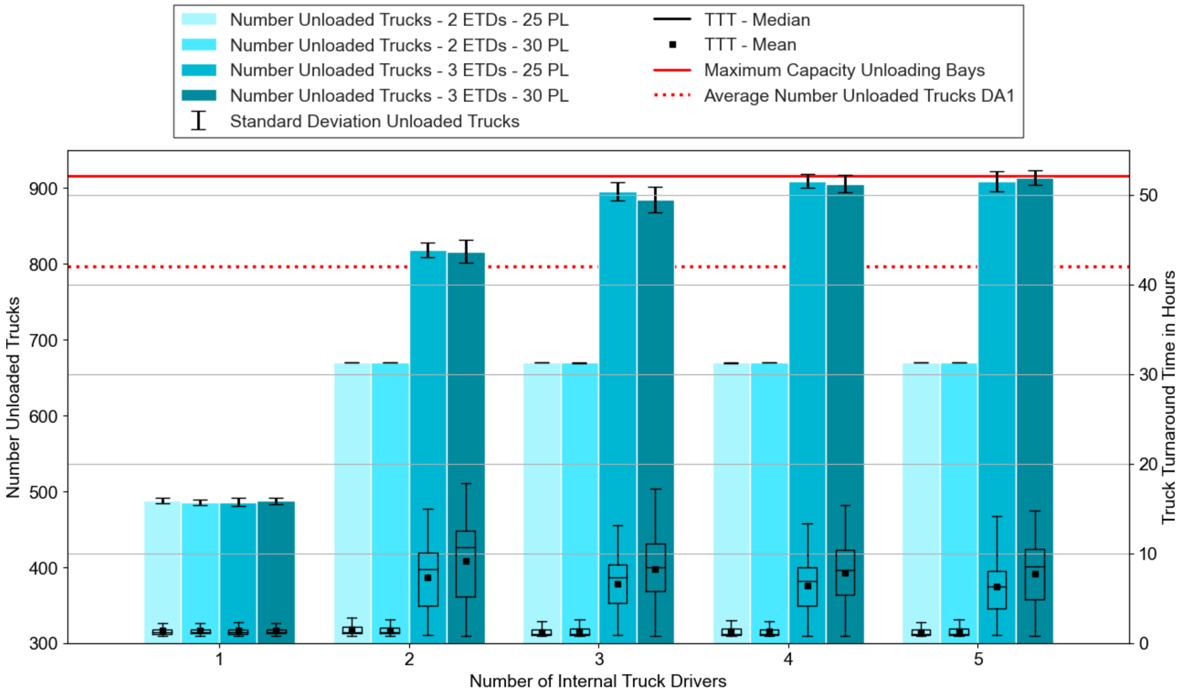
An overall reduction in TTT is observed by comparing TS 3 to TS 3a. By performing the NVWA inspection prior to arrival at the LBT, the TTT is reduced significantly.

For TS 3a, an increase in the TTT is observed for the cases where there are 3 ETDs and at least 2 ITDs. The reason for this is that the arrival rate is higher than the unloading rate. It is possible to already register trucks while other trucks are still unloading. As a consequence, the physical processes are not all executed consecutively per truck. In the cases where there are 2 ETDs and at least 2 ITDs, the arrival rate is lower than the unloading rate. Hence, the limiting factor is the number of ETDs and the accompanying arrival rate of trucks.

Furthermore, it can be seen that again the mean value for the TTT is slightly reduced by comparing 2 and 3 ITDs. This holds for the cases where there are 3 ETDs. This is the same as in experiment 8. For 3 ITDs, all three unloading bays can in practice be served by an individual ITD.



(a) KPIs for Truck Scenario 3



(b) KPIs for Truck Scenario 3a

Figure 7.9: Number of Unloaded Trucks and Truck Turnaround Time for Experiment 9

7.11. Evaluation of KPIs

To be able to comment on the improvement of a complementary TAM compared to a complete TAS, the increase in percentage of the KPIs has been investigated. This formula is also used to evaluate the influence of the NVWA inspection on the system performance of the complementary DA. The increase is calculated with Equation 7.2. According to the LLN, that states that the mean of the sample approaches the mean of the population it is taken from as the size of a sample increases, the mean values of the complementary TAM are compared to the mean values for a complete TAS [65, 66]. By comparing the TAM systems, the improvement becomes clear that can be obtained for the researched supply scenarios with a complementary TAM compared to the current situation at VTV.

$$\begin{aligned} Increase_{KPI_{TAM}} &= \frac{\mu_{Complementary\ TAM\ System} - \mu_{Complete\ TAS}}{\mu_{Complete\ TAS}} \cdot 100\% \\ Increase_{KPI_{NVWA}} &= \frac{\mu_{NVWA\ Prior\ to\ LBT} - \mu_{NVWA\ at\ LBT}}{\mu_{NVWA\ at\ LBT}} \cdot 100\% \end{aligned} \tag{7.2}$$

The mean values that are used for the evaluation of KPI 1 and KPI 2 are the ones for the best performing combinations of parameters regarding KPI 1. These are retrieved from experiment 6 and experiment 9. The values are summarised in Table 7.3.

Table 7.3: Combination Parameters - Best Performance

TAM System	**NVWA *at* or *prior* to LBT?**	**Number Parking Lots**	**Number ITDs**	**Number ETDs**	**Number Expedition Members**
Complementary TAM System	At	30	2	2	2
Complementary TAM System	Prior	25	2	2	2
Complete D&S System	At	25	2	3	1
Complete D&S System	Prior	25	4	3	1

As previously mentioned, the complementary TAM is exclusively researched for TS 2 and TS 2a in detail. Therefore, an exact comparison with respect to the improvement for TS 1 and TS 1a cannot be made. However, it is expected that the combination of parameters for which TS 2 and TS 2a reach their maximum possible system performance, can also be used for TS 1 and TS 1a. This assumption is based on experiment 3 and 4.

The values used to calculate the increase are presented in Table 7.4. The values for KPI1 shows the number of unloaded trucks per operational month. The values for KPI 2 shows the TTT in hours. Table 7.4a shows the increase with respect to the TAM systems and the NVWA. The mean values resulted from experiment 2 and experiment 6. The input that was used was TS 2 and TS 2a. The complementary TAM system consisted of 50% TAS and 50% D&S. Table 7.4b shows the increase in KPIs for a complete D&S system. The mean values resulted from experiment 7 and experiment 9. The input that was used was TS 3 and TS 3a, for which the complementary TAM system automatically resulted in a complete D&S.

Table 7.4: Increase in KPIs

(a) Complementary TAM System

μ_{KPI}	**Complete TAS**	**Complementary TAM**	**Increase KPI$_{TAM}$**	**Complete TAS**	**Complementary TAM**	**Increase KPI$_{TAM}$**	**Increase KPI$_{NVWA}$**
	NVWA at LBT			*NVWA prior to LBT*			
$\mu_{KPI\ 1}$ in trucks	645.6	752.6	16.57%	791.4	803.4	1.52%	6.75%
$\mu_{KPI\ 2}$ in hours	4.09	8.77	114.65%	3.99	6.15	54.11%	-29.87%

(b) Complete D&S System

μ_{KPI}	**Complete TAS**	**Complete D&S**	**Increase KPI$_{TAM}$**	**Complete TAS**	**Complete D&S**	**Increase KPI$_{TAM}$**	**Increase KPI$_{NVWA}$**
	NVWA at LBT			*NVWA prior to LBT*			
$\mu_{KPI\ 1}$ in trucks	364.6	666.2	82.72%	796.2	909.0	14.17%	36.45%
$\mu_{KPI\ 2}$ in hours	4.79	9.92	107.17%	4.45	6.36	42.91%	-35.89%

The results for the improvement in KPIs if the NVWA inspection is done prior to arrival at the LBT, is shown in Figure 7.10. As can be seen, the NVWA inspection has a major influence on the system performance. The value for KPI 1 increases for both TAM systems. At the same time, the value for KPI 2 decreases.

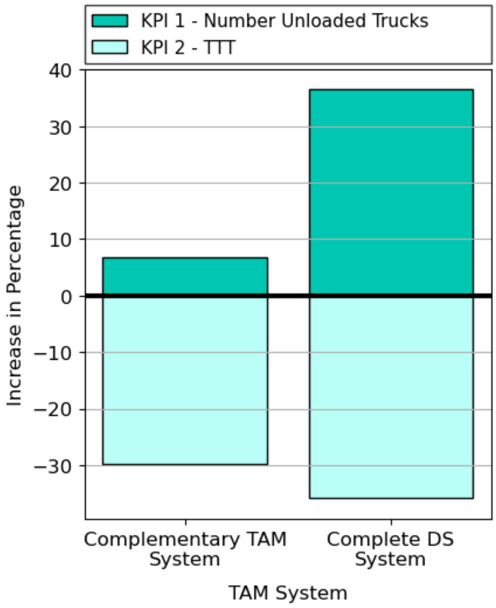


Figure 7.10: Increase KPIs per TAM System if NVWA Inspection is executed before arrival at an LBT. Comparison Relative to if NVWA Inspection is executed at LBT with same TAM System

The results for the increase in case the complementary TAM systems are compared to the complete TAS, are plotted in Figure 7.11. The bars represent the increase in KPIs compared to the complete TAS with initial values for parameters. It can be concluded that a complementary TAM system improves KPI 1 for the scenarios researched. Furthermore, the improvement is larger with a complete D&S system compared to a complementary TAM system. This is mainly attributed to the ratio EU:non-EU trucks and the accompanying NVWA inspection. However, if the number of unloaded trucks increases, KPI 2 increases as well. The aim was to maximise KPI 1 and minimise KPI 2. As can be observed, there will be a trade-off between these two KPIs. The NVWA inspection has a large influence on either the number of unloaded trucks and the TTT.

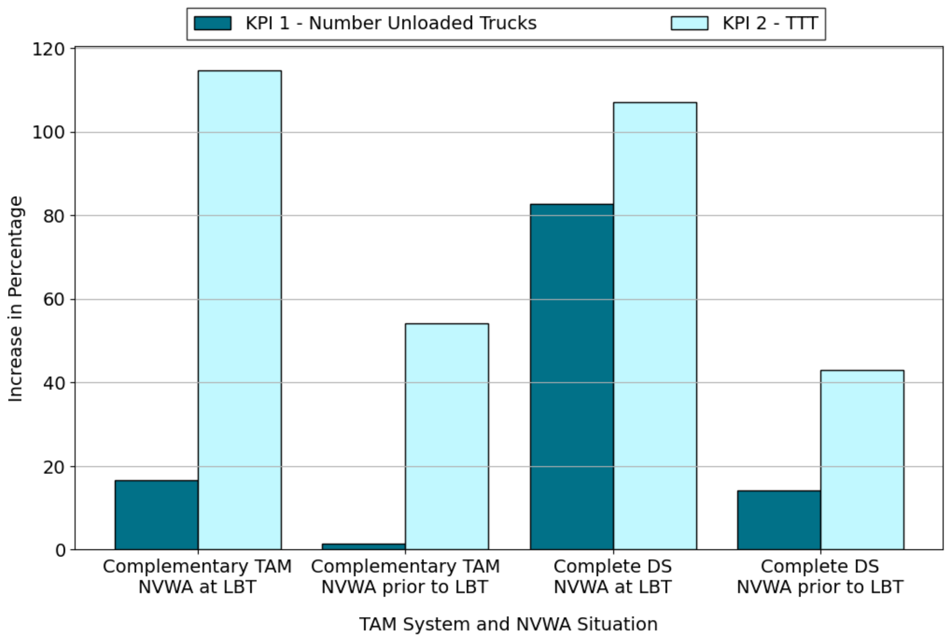


Figure 7.11: Increase KPIs per Truck Arrival Management System and NVWA Situation. Comparison Relative to the same Truck Scenario with a Complete Truck Appointment System

7.12. Conlusion

This chapter focused on sub-research question 8. The influence of the supply scenarios, parameters and Design Alternatives on the system performance has been investigated.

First, the results of the experiments are presented and discussed. 9 experiments are performed and the system performances are evaluated. The system performance is measured by two KPIs, namely the number of unloaded trucks and the Truck Turnaround Time of unloaded trucks. The aim is to maximise the number of unloaded trucks and minimise the TTT at the same time. The influence of DAs has been studied for different Truck Scenarios. The TS defines the input and the DA defines the layout of the TAM system. Furthermore, the influence of the parking lot capacity at the Liquid Bulk Terminal, the number of Internal Truck Drivers, External Truck Drivers and Expedition members has been researched.

All resource parameters influenced the KPIs. For a complementary TAM system, 2 ITDs, 2 ETDs and 2 Expedition members maximise KPI 1. In case the NVWA inspection is done at the LBT 30 parking lots are sufficient. If the NVWA inspection is done prior to arrival the the LBT, 25 parking lots are sufficient. In case the complementary TAM system results in a complete D&S system due to the input, a parking lot capacity of 25, 3 ETDs and 1 Expedition member are sufficient. If the NVWA inspection is done at the LBT, 2 ITDs are suitable. If the NVWA inspection is done prior to arrival at the LBT, 4 ITDs maximise KPI 1. At a certain moment the number of unloading bays is the limiting factor. Once that point is reached, KPI 1 cannot be enhanced any further.

Moreover, the NVWA inspection majorly influences the system performance. Furthermore, it influences the combination of resource parameters that reach the maximum possible system performance. In case the NVWA inspection is done prior to arrival at the LBT, the number of unloaded trucks is higher. Furthermore, the TTT reduces for the same DA.

By comparing the KPI values of the complementary TAM system relatively to a complete TAS, it can be observed that the complementary TAM increases KPI 1. The maximum value for KPI 1 is not always reached. Especially in the cooperation between TAS and D&S, not every empty slot is filled yet with a truck. This has to do with the strict schedule that is present in the TAS. On the other side, the value for KPI 2 increases as well. Hence, there will always be a trade-off between these two KPIs.

8
Conclusion

In this thesis it is researched to what extent a complementary Truck Arrival Management can improve the system performance of a Liquid Bulk Terminal in the context of a global intermodal supply chain. A case study has been performed at Vopak Terminal Vlaardingen, where the truck supply significantly increases.

LBTs often suffer from congestion caused by trucks upon arrival and entering. Most LBTs use a TAM system to control truck arrivals and maximise resource utilisation. However, TAM systems have advantages and disadvantages. This research focused on developing a TAM system in which two TAM systems work complementary to each other. It has been investigated if the disadvantages of TAM systems could be overcome.

Liquid Bulk Terminal as a System and the KPIs

An LBT can be treated as a system in which several processes happen. The system has multiple functions. The main function of an LBT is to store and transport liquids. A terminal utilises equipment to execute its functions.

The main truck logistic processes that take place at an LBT can be divided into an information/communication stream and a physical stream. The information/communication stream is represented by the TAM system and can be seen as the planning part. Planning happens before a truck physically arrives at a terminal in order to coordinate truck arrivals and achieve efficient usage of resources. Various TAM systems exist.

The four physical processes consist of arriving, entering, unloading and departing. Arriving usually shows two arrival peaks per day. Entering represents the registration of truck drivers at the gate. During unloading, a truck is discharged by a pump. Lastly, during departing, the paperwork is finished and the the truck leaves the terminal. Arriving and entering have the largest risk of congestion.

The two KPIs that represent the system performance are the number of unloaded trucks and the Truck Turnaround Time for unloaded trucks. The aim is to maximise the first one and minimise the latter one.

Truck Arrival Management Systems and Simulation Model

The TAM systems examined for the complementary TAM system are the TAS and D&S. TAS is the most used and researched TAM system at terminals. Transport operators have to book an appointment in the TAS to be served by the terminal. The TAS is based on a strict schedule. The advantage is that the schedule is known in advance, the disadvantage is that ad hoc changes are harder to make. Furthermore, the TAS has to smooth out peaks in truck arrivals. However, truck drivers are not incentivised enough to change their arrival time.

D&S is a promising TAM system that could mitigate peaks in truck arrivals and therefore reduce congestion terminals. A D&S system separates internal and external truck activities through a Drop and Swap Terminal. External trucks drop off their container and pick up another container of the same transport operator at a DST. External Truck Drivers and Internal Truck Drivers take care of the (un)loading of containers at the LBT. Both TAM systems have advantages and disadvantages. The aim of designing a complementary TAM system was to overcome the disadvantages of both systems to see if the system performance of an LBT could be improved.

The operational level of a terminal and its characteristics are of interest. A DES shows the system status at discrete time steps and can enable stochastic, dynamic and complex characteristics by which reality is simulated well.

A case study has been performed at Vopak Terminal Vlaardingen to model and research the complementary TAM system. Both the current situation at VTV, with a TAS as TAM system, and the situation with a complementary TAM system have been analysed. Furthermore, the truck logistics at VTV are investigated. An important feature in the entering process for VTV is the handling of NVWA trucks, which have to have an extra inspection before they can unload at the terminal. Moreover, factors that influence the supply are the product type, the truck type, the origin and supply scenarios.

The main takeaway for the complementary TAM system is that the arrival of trucks is separated based on the origin of the trucks. During a day, the morning is reserved for TAS trucks and the afternoon is reserved for D&S trucks. In the morning, D&S trucks can be transported to the terminal such that they can already be registered and inspected if necessary. Trucks that miss their slot in the TAS can unload during the reserved D&S time. D&S trucks that are ready to unload in the morning can fill empty slots.

The Design Alternatives and Influence on the System Performance

Three relevant Truck Scenarios were established. Two of which the supply consists of a combination of EU and non-EU trucks. The third TS contains trucks that all come from outside the EU.

Three DAs were established for this research: a complete TAS, a complete D&S system and a complementary TAM system. The origin ratio of trucks in the TS determines the exact layout of the complementary TAM system. The parking lot capacity was set to 25, 30 and 35. The number of ITDs ranged from 1 to 5 and the number of ETDs was set to 2 and 3. The number of registration servers at the gate ranged from 1 to 3.

A complementary TAM system with TAS and D&S is mainly influenced by the NVWA inspection, the parking lot capacity, the number of ITDs, ETDs and the number of servers upon registration. A TAM system that completely consists of D&S is mainly influenced by the NVWA inspection, the number of ITDs and ETDs. At a certain moment, the value for KPI 1 is limited by the number of unloading bays. Once that point is reached, KPI 1 cannot be enhanced further unless the number of unloading bays is expanded.

The number of ETDs determines the arrival rate of trucks. The parking lot serves as buffer for (NVWA) trucks. The number of servers at registration influence the queue and the waiting times. The number of ITDs determines the rate at which the unloading bays are served. In case the NVWA inspection is done prior to arrival at the LBT, an overall increase in KPI 1 and decrease in KPI 2 is noticed for the same TS and DA. For a complementary TAM system, KPI 1 can be increased with 7% and KPI 2 can be decreased with almost 30%. For a complete D&S system, an increase of 36% is achieved for KPI 1. KPI 2 decreases with almost 36%.

In this research, the aim was to assess to what extent a complementary TAM system could improve the system performance of an LBT. In case an LBT has to handle trucks that come from both inside and outside the EU, a complementary TAM system with TAS and D&S increases KPI 1. If the NVWA inspection is done at the terminal, the number of unloaded trucks improves with 17% to 753 trucks. At the same time the average TTT also increases with 115%. If NVWA inspection is done before arrival at the LBT, an increase of 2% to 803 trucks is measured for KPI 1. The mean value for KPI 2 increased as well with 54%.

If an LBT has to handle trucks that all come from outside the EU, the complementary TAM system results in a complete D&S system. In case the NVWA inspection is done at the LBT, the number of unloaded trucks increased with 83% to 666 trucks. The average TTT increased as well with 107%. In case the NVWA inspection is done before arrival at the LBT, the value for KPI 1 increased with 14% to 909 trucks. The mean value for KPI 2 increased with 43% at the same time. The relative increases result from the comparison in case the TS is handled by a complete TAS with initial values for parameters. The results can be applied to LBTs with an equivalent layout and design as in the case study at VTV.

In general, it can be concluded that an increase in the number of unloaded trucks can be achieved. However, this also results in an increase in the TTT by comparing TAM systems. The extent to which depends on the input and system design. Hence, there will be a trade-off between KPI 1 and KPI 2.

9 Future Research

In this chapter, recommendations for future research are discussed. New areas of research are proposed. On top of that, an advice given to Vopak Terminal Vlaardingen.

9.1. Scientific Research

In this thesis the aim was improve the system performance of a Liquid Bulk Terminal by designing a complementary Truck Arrival Management system. For this Truck Arrival Management system the Truck Appointment System and Drop and Swap were used as TAMs that had to work in a complementary way. These systems are applicable to the Liquid Bulk Terminal Vopak Terminal Vlaardingen. Though, not for every LBT these systems might be applicable. To expand the suitability of a complementary TAM system at Liquid Bulk Terminals, other TAMs could be researched to see if they could work in a complementary way. Examples of other Truck Arrival Management systems are First Come First Serve, Time-Varying Fee and Vessel Dependent Time Windows. For some TAM systems, it is beneficial to incorporate (information of) other transport modalities, e.g. VDTW.

By incorporating multiple modalities into the system, another research comes into play which is a three year project led by the Alliance for Logistics Innovation through Collaboration in Europe (ALICE) that started in 2021: the BOOSTLOG project. This project is focused on achieving a seamless integration and harmonisation of transport modes in order to build an integrated freight transport and logistics system, as visualised in Figure 9.1.

The project is not focused on a single case study, but the aim is to rather systematically summarise key results and outcomes in a logic way from over 160 EU funded research and innovation projects and to make them available and accessible to a large audience. With this, facilitating knowledge exchange at several levels comes along. Furthermore, strategies to overcome barriers and accelerating innovation uptake are developed and implemented. In addition, the identification and prioritisation of research and innovation gaps in logistics research for today's and tomorrow's needs are executed. To research these gaps, there is being reached out and engaged with researchers and companies to participate in future projects [95].

As visualised in Figure 9.1, less means of transport are necessary for the same amount of freight. This contributes to reducing the GHG emissions, which is one of the targets set by the European Commission. It can be meaningful to incorporate the outcomes of this project into a complementary Truck Arrival Management system with multiple transport modalities. It can either be investigated if the overall system performance of an LBT can be improved by adding several modes of transport and it can be studied what influence adding modes of transport has on a complementary TAM system.

To achieve an integrated logistics system as formerly mentioned, boundaries have to be conquered. Another research that can be explored and has a link to the previously mentioned research is the one focusing on Dynamic Truck Appointment System. This is an extension of the TAS used for this research but seems to be promising. Though, an extensive amount of coordination, cooperation and business boundaries have to be overcome in order to implement a DTAS that works well. Projects are already setup to test DTASs. One of those projects is FTMaaS, which is a project that is currently running [56, 96]. Because it is currently running, no publications could be found yest about the results of

Figure 9.1: Challenge of BOOSTLOG Project, led by Alliance for Logistics Innovation through Collaboration in Europe [95]

the project. Once the results are available, they could be used for further research. The aim is to make a connection between real-life logistics and traffic management systems. This connection is made by developing, implementing and testing applications that aim for a significant impact on either logistic performance and traffic networks. The purpose is that value chains are build from data to information which either work from traffic to logistics and vice versa. Data analysis has to be done in order to produce information, which can also be done with the help of Artificial Intelligence (AI) driven modelling approaches [57]. Within FTMaaS, projects are tested in living labs, which benefit from the interface between research and practice. Three main research projects and six sub-research projects are investigated [96]. One of the main projects is the ”ETA driven dynamic slot re-planning at a chemical plant” which suits this thesis [57, 58]. The aim of this case is to better utilise the storage capacity of a terminal and reduce waiting times at terminals. This is accomplished by optimising the assignment, re-planning and adjustment of slots to trucks by taking into account reliable predictions of data related to external factors, e.g. traffic jam. An accurate planning, a fast and more continuous flow of traffic and more efficient deployment of employees for executing (un)loading operations are opportunities within this case. A comprehensive data analysis is necessary to convert raw data into usable data [58]. Outcomes of this case that contribute to the reduction of truck congestion can be implemented as well at other terminals.

Furthermore, other forms of modelling methods can be applied to this study. This research focused on the operational level of the terminal. However, an optimisation study might be interesting as well. Furthermore, as mentioned in Section 3.2, ABS could also be of interest. There are multiple agents in this system that have to cooperate seamlessly to maximise the system performance. It might be interesting to investigate the influence of agents on each other.

9.2. Advice to Company

The advice for Vopak Terminal Vlaardingen is that more research can be done on the system performance of a complementary Truck Arrival Management system. The complementary TAM system shows increased performance for some truck scenarios compared to the complete Truck Appointment System. However, the system is not yet so deeply figured out such that it works optimally in every situation. Moreover, during the research, some issues were encountered that are listed below.

First of all, in order to determine the values for KPI 1 and KPI 2 even more precisely, extensive research is necessary. Right now, 5 runs are taken as simulation parameter. To approach the resulting mean value even more, more runs are necessary per experiment. Moreover, TS 1 and TS 1a can be researched in more detail. For now, it is assumed that these TSs reach their maximum possible system performance for the same parameters as TS 2 and TS 2a do. However, extended research is necessary to verify this.

Furthermore, it can be researched if making the distribution of parking lots in the complementary TAM system dynamic, improves the system performance. Right now, the distribution is static: the parking lot capacity determined in advance. TAS trucks cannot use D&S parking lots and vice versa in the DES. By making it dynamic, empty parking lots of the TAS can be used by D&S trucks, once all TAS trucks left the terminal for a particular day for example.

In the Drop and Swap system, the Internal Truck Drivers register one truck at a time. This could be changed to letting ITDs register more trucks at the same time at Expedition. At the moment this is implemented, ITDs are either able to register trucks with paperwork that has been brought already by the External Truck Driver of trucks that are still at the Drop and Swap Terminal. Moreover, ITDs are able to register multiple D&S trucks that arrive at the same time at the parking lot of Vopak Terminal Vlaardingen. The advantage is that ITDs can register trucks at moments there are zero to a few truck drivers in line for Expedition and ITDs are not engaged with another task. Once registered trucks arrive at the parking lot of VTV or an empty slot is available, trucks are immediately able to unload and ITDs do not have to wait in line at Expedition at that particular moment.

Another field of research might be to automate the registration of trucks at the gate. The process requires time and manpower. This results in waiting times at Expedition that resulted in congestion. As a consequence, the system performance was negatively influenced. In case the entering process runs more smoothly, the negative influence might be smaller.

Furthermore, it can be researched if the allocation of the ITDs at particular times can further improve the system performance. The aim is that less empty slots in the complementary Truck Arrival Management system might be missed by optimising the tasks of the ITD.

Another point of attention is the arrival of NVWA trucks in a complete Drop and Swap (D&S) system. right now, a maximum number of NVWA trucks may arrive per day at the parking lot of Vopak Terminal Vlaardingen. The ETDs act on this by making sure this limit is not exceeded. It might be interesting to check if transporting the minimum number of NVWA trucks to the parking lot of VTV influences the system performance, such that NVWA trucks do not have to wait for a long time till they are inspected and such that more parking lots are available for unloading non-NVWA trucks.

In the current design of the simulation, the three unloading bays C04A, C04B and C04C are "coupled". This means that all three unloading bays act in the same way for how the complementary Truck Arrival Management system is designed. Though, unloading bay C04C differs from unloading bays C04A and C04B, in a way that Category 1 product can exclusively be unloaded at unloading bay C04C. Because the design of the Truck Arrival Management system is based on the origin of trucks, it could be useful to decide that not all three unloading bays stick to the same TAM if for example all Category 1 trucks come from within the EU and the rest of the trucks come from both inside and outside the EU. In this case a full Truck Appointment System at unloading bay C04C and a complementary system at unloading bays C04A en C04B could be researched. This feature can be implemented in the simulation by reprogramming the Truck Arrival Management system.

For some countries, the NVWA inspection can be done in batches as mentioned in Section 4.1.1. These NVWA batches have not been implemented in the simulation currently, partly due to the uncertainty of the Purchase Book. In addition, it has neither been done because not every non-EU country has such an agreement and if countries have these agreements, the size of the batch can differ per country. In the future, if the Purchase Book is known in more detail, implementing batches could be an useful feature as it represents reality better. It could either save space at the parking lot of Vopak Terminal Vlaardingen in some cases, as not every container has to be inspected individually. Though, if the first container of a batch is rejected, all containers have to come to Vopak Terminal Vlaardingen.

At this moment, the technical unavailability and tank swaps are set prior to scheduling in the TAS, instead of them happening unpredictably during the simulation and after the first trucks are scheduled respectively. This is done for some reasons. The first one is that rescheduling all trucks during the simulation takes up more computational time in case of an unpredictable technical unavailability happening. Moreover, especially for the tank swaps, the distribution of the exact tanks in which the liquids are discharged is not yet known. If this is implemented, it also influences the arrival pattern of trucks, which should be redefined if tank swaps are planned after the first trucks are scheduled. Moreover, the technical unavailability of unloading bays in the D&S system is decided at the moment a truck enters the unloading bay. In real life, technical unavailability could also happen when no truck enters an unloading bay. Therefore, an improvement of the design can be made by uncoupling technical unavailability and the unloading of trucks, such that technical unavailability of unloading bays in the D&S system can also happen, either unpredictably or planned, without a truck entering the unloading bay.

As previously mentioned, the exact distribution of tanks in which liquids will be discharged can be added to the simulation. This represents reality better, but is not yet possible because the Purchase Book and exact distribution of products amongst tanks is not yet known. For this feature the quality of products mentioned in Table 6.1 is necessary. Furthermore, the tank swaps can be based on this distribution and the replanning of trucks to minimise tank swaps can be taken into account.

Another feature that could be added to the simulation is the realtime (re)planning of trucks. Currently, all trucks are planned prior to the start of the simulation, no extra trucks are scheduled during the simulation in the TAS. Furthermore, the replanning of trucks could happen more frequently. The possibility of rescheduling of trucks is right now checked at fixed moments, e.g. at the moment the truck is registered, at the moment a TAS truck could not be unloaded during the D&S time. However, other trucks could miss their time slot after the fixed moments the empty slots have been checked. If the rescheduling could be done more realtime, the expectation is that more slots that are still empty could be filled with trucks that are ready to unload. This feature takes more computational time, but could represent reality in a better way.

Another point of attention is to optimise the system towards sustainable solutions. Currently, only trucks are taken into account for this research. Though, to meet sustainability goals, the optimisation of rail and IWT can be looked into, e.g. to incorporate the discharge of train compartments at unloading bays into tanks.

If previously mentioned modifications have been implemented, the experiments could be redone or even expanded to see if the system performance can be improved further. At a certain moment it should be the case that the number of unloading bays is the limiting factor in every situation.

Moreover, it is recommended to build a user-friendly interface that allows to only change the input and parameters. This facilitates easy use of the simulation model. The output can also be presented in a user-friendly way for easy interpretation of the results. The output might be for example the best performing DA for a given TS and combination of parameters. This might also result in expanding the use of the simulation to multiple logistic processes at the terminal.

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Appendices

A

Scientific Paper

A Complementary Truck Arrival Management System at a Liquid Bulk Terminal in a Global Intermodal Supply Chain that is Subject to Change

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This paper contributes to the research of a complementary Truck Arrival Management system in order to increase the efficiency of the Liquid Bulk Terminal as a system in a global intermodal supply chain. Nowadays, terminals often suffer from congestion, despite the use of a Truck Arrival Management system. A Truck Arrival Management system controls truck arrivals at terminals. Currently, the Truck Appointment System is the most used and researched Truck Arrival Management system at terminals. The Truck Appointment System has advantages and disadvantages. Therefore, Drop and Swap has been researched as second Truck Arrival Management system. A complementary Truck Arrival Management system is developed and researched in which Truck Appointment System and Drop and Swap cooperate with the objective to overcome disadvantages and enhance benefits. The system should be capable to serve all kind of trucks within the global intermodal supply chain.

Truck Arrival Management•Truck Appointment System•Drop and Swap•Liquid Bulk Terminal•Supply Chain

1. Introduction

In the continuously growing and changing economy, freight transport plays an important role. Growing volumes of goods that need to be transported require adaptations to the worldwide set-up of supply chains and logistics [1, 2, 3, 4]. Moreover, logistics can be seen as the foundation of the economy. Especially during uncertain times, like the COVID-19 pandemic, the economy depends on reliable logistics [5].

Several modes of transport can be used, like road, rail, water, air and pipeline transport. Nowadays, a little more than half of the modal split is taken up by road transport as can be seen in Figure A.1. To meet sustainability goals and reduce Green House Gas (GHG) emissions, a target has been set by the European Commission to shift the modal split to more sustainable ways of transport. Rail- and Inland Waterway Transport (IWT) are seen as more sustainable ways of transport than road transport. Though, road transport continues to play an important role in supply chains in the future [6, 7].

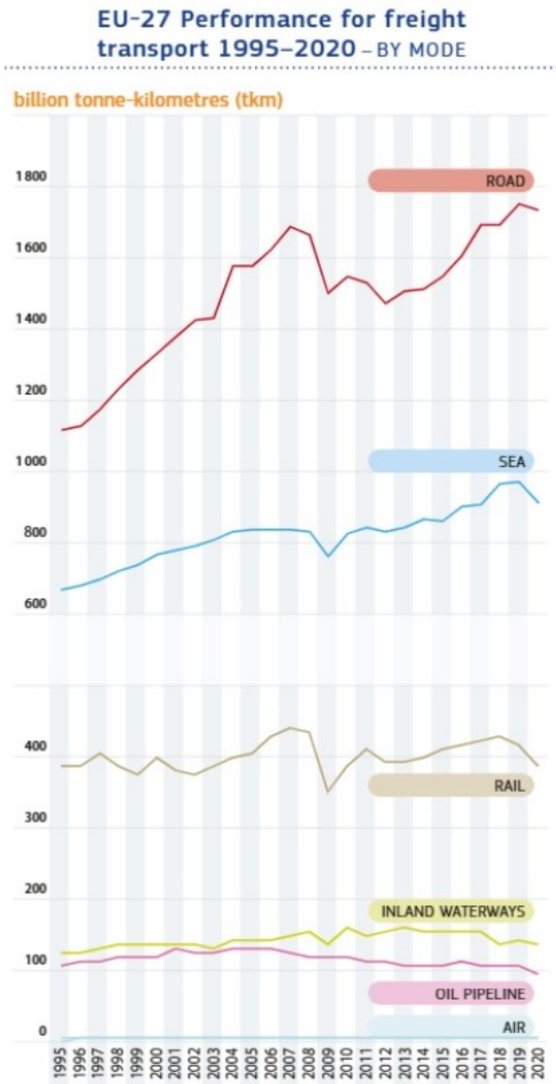


Figure A.1: European Freight Transport by Mode [8]

Road transport also plays an important role in the transport to and from Liquid Bulk Terminals. A Liquid Bulk Terminal (LBT) is a terminal that temporarily stores all kinds of liquids in storage tanks. The objectives are to provide good quality and service to customers and minimise costs. Besides tanks, other kinds of equipment are present at the terminal to transship and transport liquids, e.g. pipelines and pumps [9].

Road transport of liquids to an LBT happens via trucks and containers. The aim of a Truck Arrival Management (TAM) system is to control the arrival of trucks and containers at a terminal [1]. Based on literature research, multiple TAM systems exist beside Truck Appointment System (TAS), like Drop and Swap (D&S), First Come First Serve (FCFS), Time-Varying Fee (TVF) and Vessel Dependent Time Windows (VDTW) [10, 11, 12, 13, 14, 15, 16]. All systems have their advantages and disadvantages and work in a different way regarding the mitigation of congestion and prevention of queuing.

Therefore, the research question that has been investigated is: **”To what extent can truck logistics at a Liquid Bulk Terminal be improved by developing a complementary Truck Arrival Management system within a global intermodal supply chain?”**. The objective is to research if the beneficial aspects of TAM systems can be strengthened and bottlenecks can be overcome by combining them.

This paper is structured such that first the method to answer the research question is discussed. Subsequently, the results are presented. Lastly, the results are discussed.

2. Method

To answer the research question, a Discrete Event Simulation (DES) has been made that was designed based on the LBT Vopak Terminal Vlaardingen (VTV). The research was incentivised by VTV due to a significant increase in the supply of trucks. VTV can be classified as an import/export terminal [17]. Liquids are transported to and from the terminal via several modalities, like road, water and rail transport [18]. The liquids are stored in tanks [19, 20]. For this research, the focus is exclusively on supply to the terminal via trucks.

Liquid Bulk Terminal

At an LBT several processes take place. These are split into an information process and physical processes. The information process is equal to the TAM system and contains information about the arrival of trucks [1, 21, 22]. Usually, two arrival peaks per day are noticed for arriving trucks. The peaks often cause congestion and queuing and negatively influence the performance of terminals [**NeagoeHvolbyTurner_whyarewestillqueuing?_2021**, 3, 15, 16]. The physical processes consist of arriving, entering, unloading and departing [4, 15, 16, 23, 24, 25]. During arriving, trucks arrive at the LBT and park their truck. The purpose of entering is the registration of trucks at the gate, such that it is safe to enter the terminal and that the correct truck enters the terminal. This process is handled by Expedition in the case study at VTV. During the entering process, an NVWA inspection might be necessary. This inspection is done on Category 1, Category 2 and Category 3 products that are imported from outside the EU, as these products might contain animal byproducts [26]. Furthermore, the NVWA inspection has to be done at a Border Control Post (BCP), for which VTV has a license [27]. During unloading, the liquid is pumped from the truck to the tank. In the case study, three unloading bays are considered. Category 1 product is only allowed to be discharged on one of them. If Category 1 products concatenate with other product categories or non-categorised products, they all have to be degraded to Category 1 product. Lastly, the paperwork for the truck is finished and the truck leaves the terminal during departing.

Supply Chain

VTV has a new customer that starts to discharge liquids via newly built unloading bays in newly built tanks at the terminal in May 2023. The Purchase Book of the customer contains the composition of which liquids, how much of a liquid and where the liquids are bought in the world. The Purchase Book of the new customer is not yet known and can differ in time, e.g. because of a shortage or surplus of certain liquids at a certain place in the world. The uncertainty in the purchase of liquids makes that the supply chain can differ as well in time. The number of extra trucks coming to the terminal ranges from 5000 to 19000 on a yearly basis.

The supply chain that has been setup is shown in Figure A.2. As can be seen, EU trucks are completely transported via road transport, whereas non-EU containers are first transported overseas and later on via road transported to the LBT. The last-mile transportation of all trucks and containers happens via road transportation.

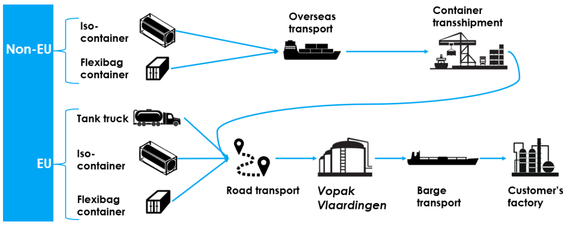


Figure A.2: Supply Chain

Truck Arrival Management Systems

Currently, VTV uses TAS as a TAM system, with a maximum of 18 slots per day with a length of 45 minutes. The combination of this TAM system and the increased number of trucks coming to the terminal might cause congestion at the entrance of the terminal. Furthermore, the chance that trucks miss their time slot increases by which the efficiency of the terminal decreases.

Hence, research is done to a complementary TAM system in which D&S and TAS can work complementary to each other. Both systems are explained below and are visualised in Figure A.3.

Truck Appointment System

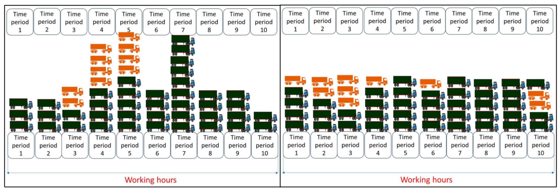
The TAS is shown in Figure A.3a and works as follows: The TAS is usually an electronic system in which transport operators have to book a time slot for a specific unloading bay in which they want to unload their liquids. There are a maximum number of bookable appointments, as such preventing and overflow of trucks that plan to (un)load at the terminal. Furthermore, it is tried to evenly spread truck arrivals and minimise waiting times for drivers with this system [2, 11, 21, 22, 28, 29].

However, in practice the system shows inefficiencies which are not favourable for either the terminal and transport operators. This is mainly because TAS is highly dependable on a strict schedule, while truck arrivals and equipment availability have a stochastic nature. Truck arrivals still often show arrival peaks. Therefore, time losses are still generated [1, 14, 29].

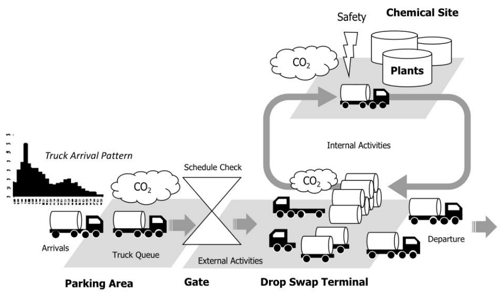
Drop and Swap

D&S is presented in Figure A.3b. The working mechanism of a D&S system is as follows: A D&S system includes a Drop and Swap Terminal (DST) with a large storage capacity for containers. Incoming external trucks drop off their container at this area and pick up another container of the same transport operator after which they leave the DST again. The DST acts as an extra buffer which is not present at (the parking lot of) the actual terminal. This D&S operation takes less time than the actual unloading operation. Therefore, external trucks run through the system faster [15, 16].

External Truck Drivers and Internal Truck Drivers take care of the transportation between the actual terminal and the DST and the unloading operation. These drivers are better acquainted with safety and operational rules of the terminal, because of routine. This results in more efficient unloading operations. The terminal is completely in control of truck arrivals with a D&S system. A disadvantage is that not all truck drivers visit the terminal regularly. Therefore, swapping containers is not always possible, as truck drivers cannot take containers that are not their possession. Though, it is stated that D&S is a robust TAM system system that can handle peaks in truck arrivals [15, 16].



(a) Truck Arrivals without and with Truck Appointment System [1]



(b) Drop and Swap System [16]

Figure A.3: Truck Arrival Management Systems

The choice for the TAS is either because this is the most used and researched TAM system at terminals and it is used at VTV nowadays. The choice for D&S has been made because of the supply chain that has been setup by the customer. A separation is made in the way EU and non-EU trucks arrive at the LBT. EU trucks are handled via the TAS and non-EU trucks are handled via the D&S system. Non-EU trucks arrive at a container terminal in the port of Rotterdam. This container terminal can directly be used as DST for the D&S system. Therefore, these two systems are chosen as for this research it is important that the TAM can handle both trucks arriving via road transport and sea transport in an efficient way.

Modelling Method

To research if the system performance of an LBT can be increased under a complementary TAM system and if possible congestion can be prevented, the TAM systems TAS and D&S and the physical processes arriving, entering, unloading and departing are modelled in a DES. The DES is programmed in Python version 3.7.9 with a SimPy package version 4.0.1 for DES features. Furthermore, the simulation needs an input, parameters and the Design Alternative, as shown in Figure A.4. A distinction is made between simulation parameters and configuration parameters.

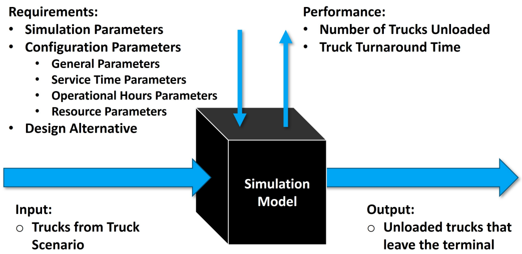


Figure A.4: Simulation Model

The Truck Scenarios are based on scenarios that were setup by the new customer that is going to store its liquids at VTV. A Truck Scenario (TS) differs in the ratio of EU:non-EU trucks, how many trucks have to be inspected by the NVWA and the number of trucks generated per operational month. An overview of TSs is given in Table A.1. In the TSs where 0% of the trucks has to be inspected by the NVWA, all NVWA-trucks are inspected by the NVWA prior to arrival at the LBT. These scenarios measure the influence the NVWA inspection has on the system performance.

The parameters that serve as input for the simulation are explained in Table A.2 till Table A.6. Two simulation parameters are defined, which are presented in Table A.3. Table A.2 presents the general parameters. Table A.4 shows the parameters for the service times of several processes in the simulation. Table A.5 presents information about operational hours of resources within the simulation. Lastly, Table A.6 gives information about the number of several resources.

Table A.3: Simulation Parameters

Parameter	Value	Unit	Same for Every Experiment?
Number of Replications	5	Runs	Yes
Length of Simulation	21	Days	Yes

Furthermore, four Design Alternatives are designed for the TAM system. A Design Alternative (DA) differs in the layout of the TAM system. DA 1 is a complete TAS. DA is a complete D&S system. DA 3 is complementary TAM system. The exact layout of the TAM system is based on the TS. For TS 1 and TS 1a, 70% of the TAS slots are opened per day, which is rounded to 13 slots. For TS 2 and TS 2a, 50% of the slots are opened per day, which comes down to 9 slots. The rest of the day, either 30% and 50% respectively, is reserved for handling D&S trucks at the LBT. Though, D&S trucks can already be transported by the External Truck Driver (ETD) to the parking lot of the LBT in the morning to be registered by the Internal Truck Driver (ITD) and if necessary to be inspected by the NVWA. The initial value for the number of parking lots is set to 25. The number of parking lots reserved for TAS trucks is also associated with the percentage of the day that is reserved for TAS. In for TS 1 and TS 1a, 17 parking lots are reserved for TAS trucks. TS 2 and TS 2a, 12 parking lots are reserved for TAS trucks. This number does not change in the experiments where the total number of parking lots is increased.

Two KPIs are defined to measure the system performance. KPI 1 is the number of unloaded trucks per operational month. KPI 2 is the Truck Turnaround Time (TTT). The aim is to maximise the number of unloaded trucks, whereas the TTT has to be minimised.

Experiments

The experiments that are executed are done to check the influence of several parameters on the system performance. In total 9 experiments are performed. In the experiments, the TSs and DAs differ. Furthermore, input values for the number of

Table A.1: Truck Scenarios

Truck Scenario	EU Trucks	non-EU Trucks	NVWA Inspections at Vopak Terminal Vlaardingen	Number Trucks per Operational Month
1	70%	30%	21%	840
1a	70%	30%	0%	840
2	50%	50%	35%	1155
2a	50%	50%	0%	1155
3	0%	100%	70%	[420, 1155, 1575]
3a	0%	100%	0%	[420, 1155, 1575]

Table A.2: General Parameters

Parameter	Value	Unit	Same for Every Experiment?
Number Slots for TAS	[0,18]	Slots	No
Technical Unavailability	20%	-	Yes
Number of Tank Swaps per Day (Besides Predefined Switch from TAS to D&S)	1	Swaps	Yes
NVWA Pass Rate	90%	-	Yes
PIT Pass Rate	60%	-	Yes

Table A.4: Service Times Parameters

Parameter	Value	Unit	Same for Every Experiment?
Arrival Times TAS	$\mathcal{T}ri$(6.17,7.15,14) $\mathcal{T}ri$(11,13.25,22.5)	Hours	Yes
Slot Preference TAS	$\mathcal{T}ri$(0,1,7) $\mathcal{T}ri$(6,7,17)	Slotnumbers	Yes
Fill in Guidance Form	$\mathcal{N}$(4,1)	Minutes	Yes
Expedition	$\mathcal{L}ogn$(1.9768,0.64858)	Minutes	Yes
PIT	$\mathcal{U}$(20,36)	Minutes	Yes
NVWA Inspection	$\mathcal{N}$(30,2.5)	Minutes	Yes
Drivetime from DST to VTV	30	Minutes	Yes
Preparation Time Bay before Start Pumping	$\mathcal{N}$(10.5,1.75)	Minutes	Yes
Pumptime at Unloading Bay	$\mathcal{L}ogi$(35.68,1.2565)	Minutes	Yes
Post Pumptime at Unloading Bay	$\mathcal{W}ei$(2.49169,5.92423)	Minutes	Yes

parking lots, the ITD and ETD change.

In the first experiment, TS 1 and TS 1a serve as input for DA 1, 2 and 3. The number of parking lots is 25, the number of ITDs is 1, the number of ETDs is 2 and the number of members at registration is 1.

In the second experiment, TS 2 and TS 2a are tested for DA 1, 2 and 3. The number of parking lots, ITDs, ETDs and members at registration again stay constant with values of 25, 1, 2 and 1 respectively.

The third experiment focuses on the influence of the number of parking lots on a complementary TAM system. TS 1 and TS 2 served as input. The number of parking lots is set to 25, 30 and 35. The number of ITDs, ETDs and members at registration stayed constant with values of 1, 2 and 1 respectively.

In the fourth experiment, the focus is on the influence of the number of ITDs on a complementary TAM system. TS 1 and TS 2 served as input. The number of ITDs ranges from 1 to 3. The number of parking lots, ETDs and members at registration are constant with values of 25, 2 and 1 respectively.

In the fifth experiment, the focus is on the influence of multiple parameters on the complementary TAM system. TS 2 and TS 2a served as input. The number of ITDs ranges from 1 to 3. The number of parking lots is set to 25 and 30. The number ETDs differed between 2 and 3. The number of members at registration is constant with a value of 1.

In the sixth experiment, the focus is on the influence of the number of members at registration on the complementary TAM system. TS 2 and TS 2a served as input. The combination of best performing parameters of experiment 5 is taken. The number of members at registration ranged from 1 to 3.

In the seventh experiment, TS 3 and TS 3a are tested for DA 1 and 2. In TS 3 and 3a, several numbers of trucks are generated. These differ between 420, 1155 and 1575. The number of parking lots, ITDs, ETDs and members during registration again stay constant with values of 25, 1, 2 and 1 respectively.

In the eighth experiment, the influence of the number of parking lots on a complete D&S system was investigated. TS 3 and TS 3a, in which 1575 trucks were generated, served as input. The number of ITDs ranges from 1 to 3. The number of parking lots is set to 25 and 30. The number ETDs differed between 2 and 3. The number of members at registration is constant with a value of 1.

In the last experiment the influence of changing several parameters at the same time on a complete D&S system is researched. The number of parking lots is set to 25 and 30, the number of ITDs

Table A.5: Operational Hours Parameters

Parameter	Start	End	Same for Every Experiment?	Comment
External Truck Driver	7 am	10.30 pm	Yes	Last request accepted at 10.30 pm
Internal Truck Driver	7.15 am	10.15 pm	Yes	Last start of truck at unloading bay at 10.15 pm, trucks will still be removed from unloading bay when finished
Expedition	7 am	10 pm	Yes	Last request accepted at 10 pm
NVWA	8 am	3 pm	Yes	Last request accepted at 3 pm

Table A.6: Resource Parameters

Parameter	Value	Same for Every Experiment?
External Truck Drivers	[2,3]	No
Internal Truck Drivers	[1,5]	No
Servers at Entering (Expedition)	[1,2,3]	Yes
PIT Computers	1	Yes
NVWA Veterinarians	1	Yes
Total Number Parking Lots	[25,35]	No
Number Parking Lots Reserved for TAS	[0,Total Number Parking Lots]	No

ranges from 1 to 5 and the number of ETDs is set to 2 and 3. The number of members at registration stayed constant.

3. Results

The experiments are evaluated on the two KPIs mentioned, which are the number of unloaded trucks and the TTT. From the experiments it was concluded that DA 3 shows the same tendency irrespective of the input. Therefore, only the results of experiment 6 and 9 are presented. It is assumed that the maximisation of the system performance with TS 1 or 1a as input, is reached for the same combination of parameters where the system performance with TS 2 or 2a as input is maximised.

Both the KPIs are presented in one figure. The left y-axis shows the number of unloaded trucks. The right y-axis shows the TTT. The number of unloaded trucks are visualised by bars. The TTT is presented with a boxplot. The red solid line shows the maximum possible operational capacity regarding KPI 1 for the experiment. The red dashed line shows the number of unloaded trucks for the same TS with a complete TAS and initial values for parameters.

For experiment 6, the results are shown in Figure A.5 and Figure A.6. The x-axis shows the number of members at Expedition, which represents the number of registration servers. The bars represent KPI 1, the boxplots show the spread of the TTT. Figure A.5 shows the result for TS 2. The NVWA inspection is performed at the LBT. The capacity of the parking lot is 30, the number of ITDs is 2 and the number of ETDs is 2. The number of members at registration for which KPI 1 is maximised is 2.

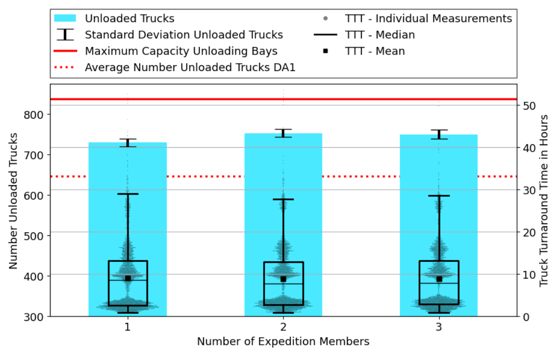


Figure A.5: Number Unloaded Trucks and TTT Experiment 6 - TS 2

Figure A.6 shows the result for TS 2a. The NVWA inspection is performed prior to arrival at the LBT. The capacity of the parking lot is 25, the number of ITDs is 2 and the number of ETDs is 2. The number of members at registration for which KPI 1 is maximised is 2.

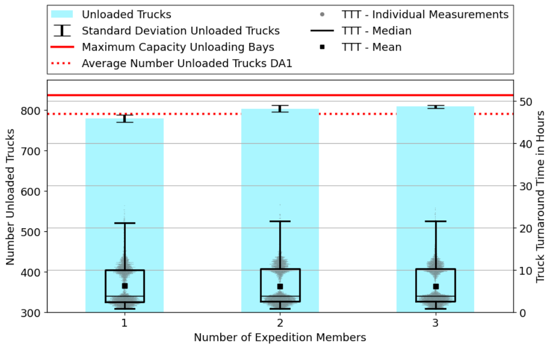


Figure A.6: Number Unloaded Trucks and TTT
Experiment 6 - TS 2a

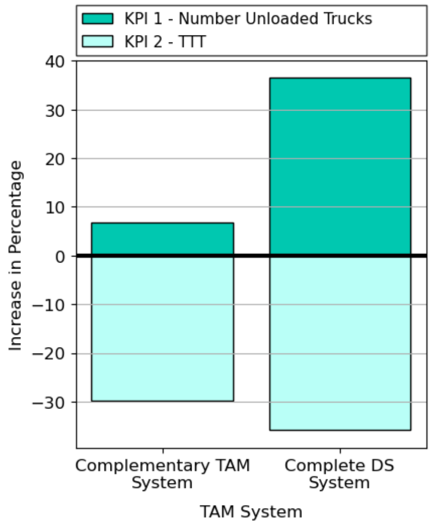


Figure A.9: Relative Increase KPIs
NVWA at or prior to LBT

The results of experiment 9 are shown in Figure A.7 and Figure A.8. The x-axis shows the number of ITDs. The bars represent KPI 1 per number of ETDs and parking lot capacity, the boxplots show the spread of the TTT. Figure A.7 shows the result for TS 3, for which the NVWA inspection is performed at the LBT. The combination of parameters for which KPI 1 is maximised is: 25 parking lots, 2 ITDs and 3 ETDs. The number of members at registration is 1.

Figure A.8 shows the result for TS 3a. In this TS is the NVWA inspection performed prior to arrival at the LBT. The combination of parameters for which KPI 1 is maximised is: 25 parking lots, 4 ITDs and 3 ETDs. The number of members at registration is 1.

The combinations of parameters that maximised the number of unloaded trucks were used to calculate relative improvements for mean values of KPIs. This has been done for the influence of the NVWA inspection on complementary TAM systems. The relative increase in KPIs is also calculated for comparing the complete TAS with a complementary TAM.

Figure A.9 shows the relative improvement of KPIs for a complementary TAM system and a complete D&S system regarding the NVWA inspection. The relative improvement is calculated by comparing the situation where the NVWA is done prior to arrival at the LBT instead of performing the NVWA at the LBT for the same TAM system.

The result of the relative increase by comparing TAM systems to a complete TAS is shown in Table A.7 and Table A.8. In Figure A.10, the relative increase is visualised.

Table A.7: Relative Increase KPIs Complementary TAM

μ_{KPI}	**Increase KPI** *NVWA at LBT*	**Increase KPI** *NVWA prior to LBT*
$\mu_{KPI\ 1}$	16.57%	1.52%
$\mu_{KPI\ 2}$	114.65%	54.11%

Table A.8: Relative Increase KPIs Complete D&S

μ_{KPI}	**Increase KPI** *NVWA prior to LBT*	**Increase KPI** *NVWA prior to LBT*
$\mu_{KPI\ 1}$	82.72%	14.17%
$\mu_{KPI\ 2}$	107.17%	42.91%

4. Discussion

The values of the parameters influenced the system performance. The capacity of the parking lot, the number of ITDs, ETDs and members at registration were of interest.

Furthermore, the NVWA inspections reduced the efficiency of a complementary TAM system. At a certain moment, the NVWA inspection rate does not match the unloading rate, by which the number of unloaded trucks cannot be maximised to the maximum operational capacity. Furthermore, the NVWA enlarges the TTT. In case the complementary TAM system is applied to the LBT, KPI 1 can be increased with 6.7% and the TTT can be reduced with almost 30% if the NVWA inspection is done prior to arrival at the LBT.

In case the complementary TAM system results in a complete D&S, KPI 1 can be increased with 36.4% and the TTT can be reduced with almost 36% if the NVWA inspection is done prior to arrival at the LBT.

As can be observed in Figure A.10, the influence of a complete D&S system is larger com-

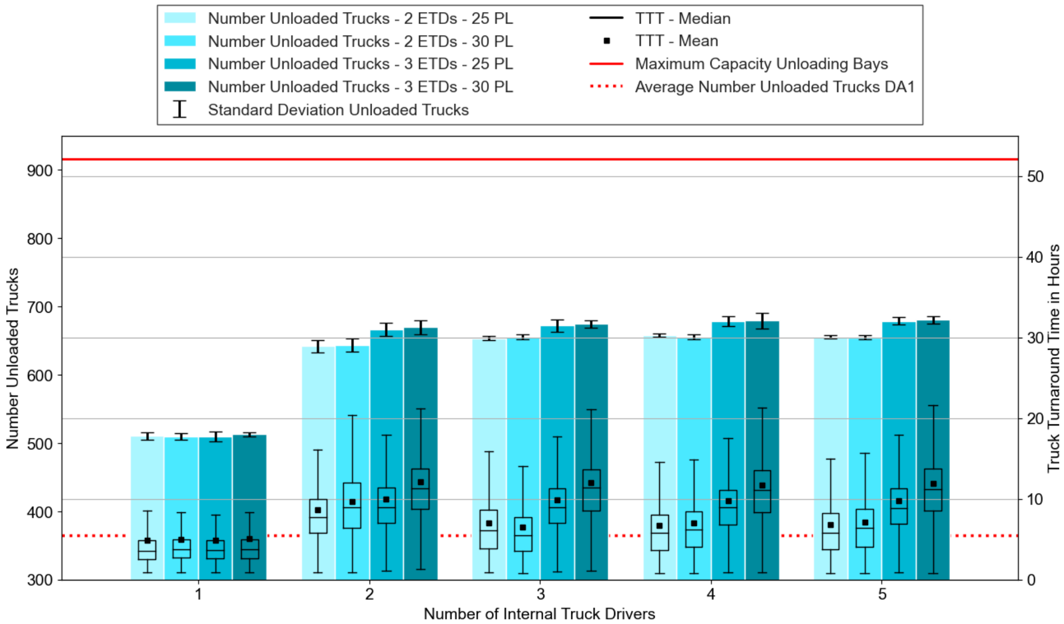


Figure A.7: KPI 1 for Experiment 7

pared to a complementary TAM system. This is mainly attributed to the ratio EU:non-EU trucks and the accompanying NVWA inspection.

A complementary TAM system is not able to reach the maximum possible operational capacity. This is due to the TAS system that is present. Not every empty slot can be filled as it could negatively influence the next scheduled truck. In a complete D&S system, the value for KPI 1 is limited by the number of unloading bays at a certain point. Once that point is reached, KPI 1 cannot be enhanced further unless the number of unloading bays is expanded.

The complementary TAM system influenced the system performance in the way that both the number of unloaded trucks and the TTT increased, comparing the system to a complete TAS.

In case a complementary TAM system is applied to the LBT and the NVWA inspection is done at the terminal, the number of unloaded trucks improves with 17% to 753 trucks. At the same time the average TTT also increases with 115%. If NVWA inspection is done before arrival at the LBT, an increase of 2% to 803 trucks is measured for KPI 1. The value for KPI 2 is increased as well with 54%.

If an LBT has to handle trucks that all come from outside the EU, the complementary TAM system results in a complete D&S system. In case the NVWA inspection is done at the LBT, the number of unloaded trucks increased with 83% to 666 trucks. The average TTT increased as well with 107%. In case the NVWA inspection is done before arrival at the LBT, the value for KPI 1 increased with 14% to 909 trucks. The mean value for KPI 2 increased with 43% at the same time.

The purpose of the current study was to determine to what extent a complementary TAM could increase the system performance at an LBT. The increased values for the KPIs are previously mentioned. It can be concluded that there is a trade-off between KPI 1 and KPI 2 by implementing a complementary TAM system compared to a complete TAS. With an increased number of unloaded trucks, the TTT increases as well. To what extent these values increase, depend on the input and system design. The results can be applied to Liquid Bulk Terminals with a similar layout and design as the case study at Vopak Terminal Vlaardingen.

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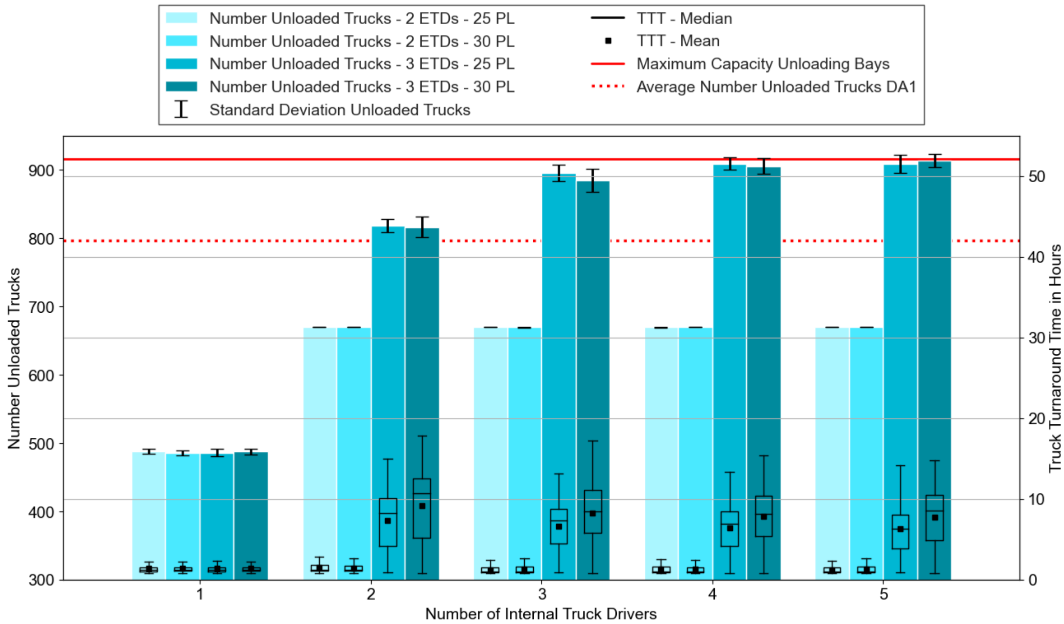

Figure A.8: KPI 1 for Experiment 7

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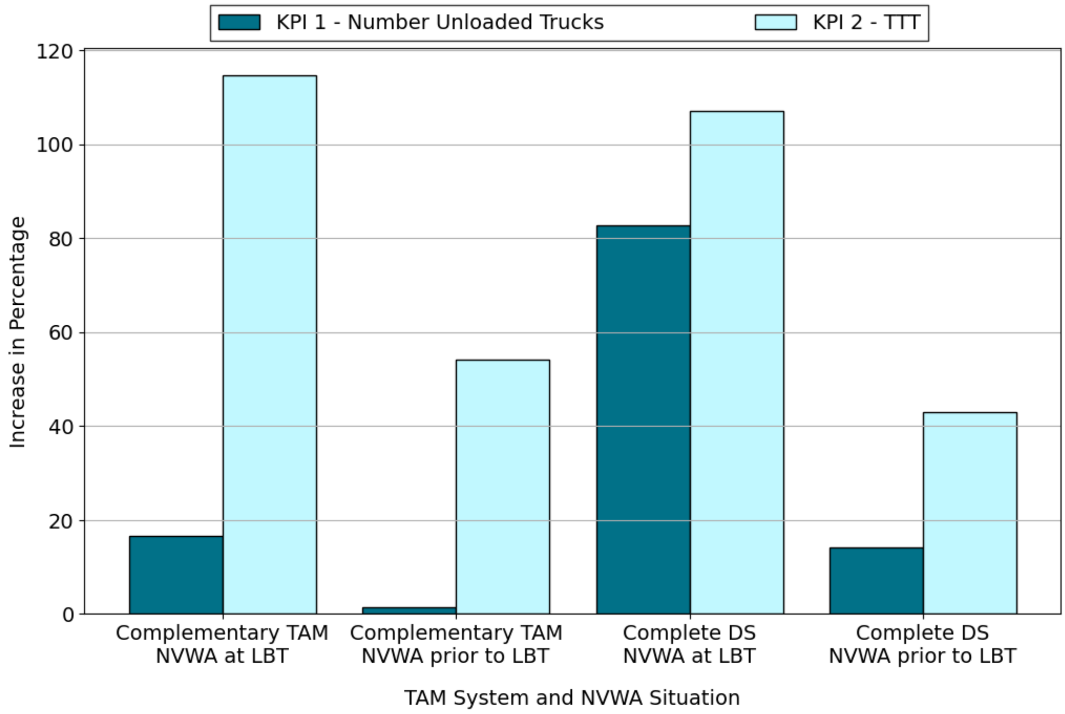

Figure A.10: KPI 1 for Experiment 7

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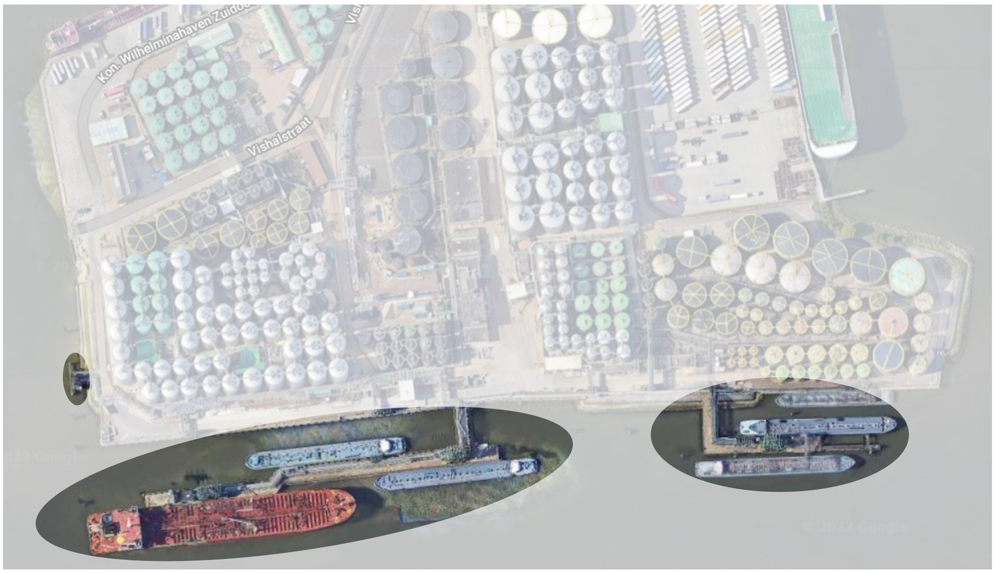
B

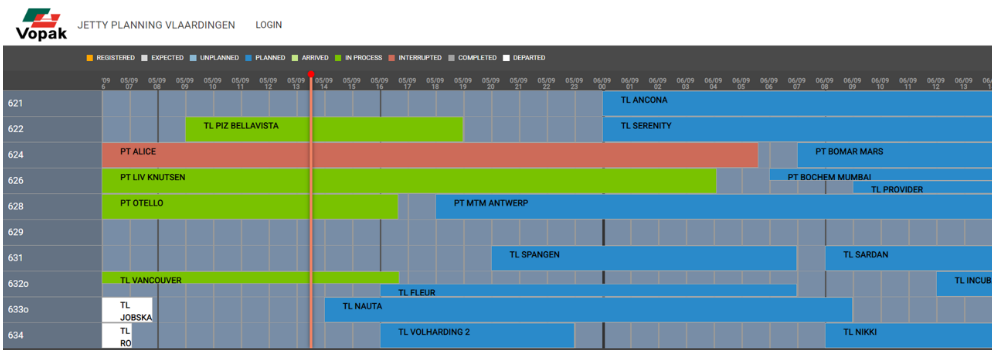
Information about Vopak Terminal Vlaardingen

This appendix shows information that is specific for Vopak Terminal Vlaardingen.

B.1. Jetties at Vopak Terminal Vlaardingen



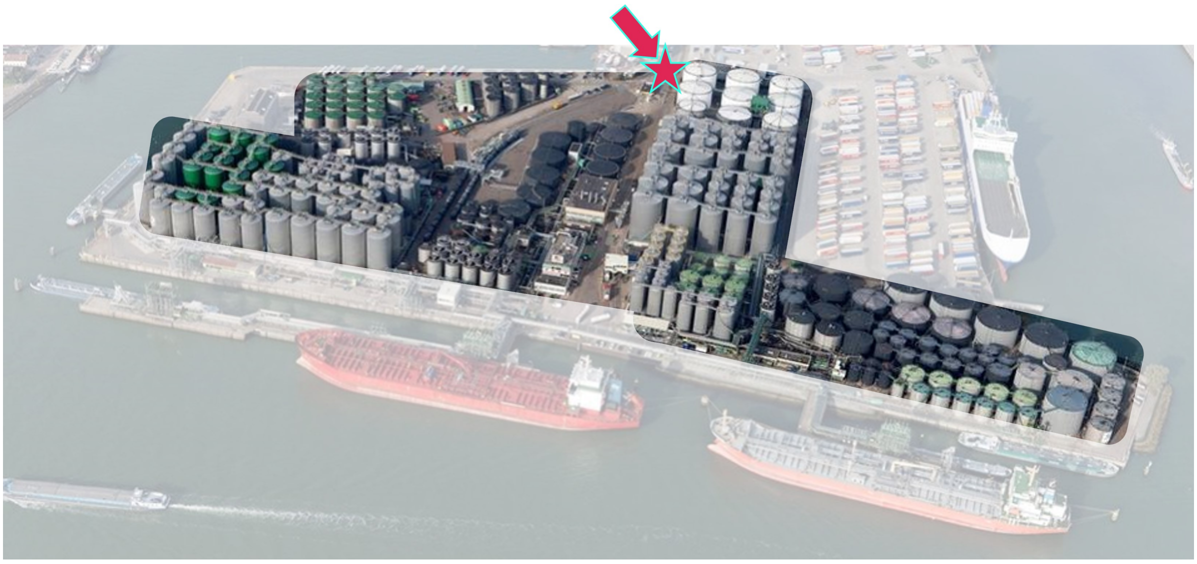
(a) Jetty Locations at Vopak Terminal Vlaardingen [97]



(b) Example of Jetty Planning at Vopak Terminal Vlaardingen [98]

Figure B.1: Jetty Information Vopak Terminal Vlaardingen

B.2. Tanks at Vopak Terminal Vlaardingen



(a) All Tanks at Vopak Terminal Vlaardingen [21]

(b) Close up of Tanks at Vopak Terminal Vlaardingen [99]. Photo taken at location of star in Figure B.2a.

Figure B.2: Tanks at Vopak Terminal Vlaardingen

B.3. Daily Pattern

Figure B.3 shows the daily pattern of slot usage at Vopak Terminal Vlaardingen. The first slot that is usually used starts at 07:30 am.

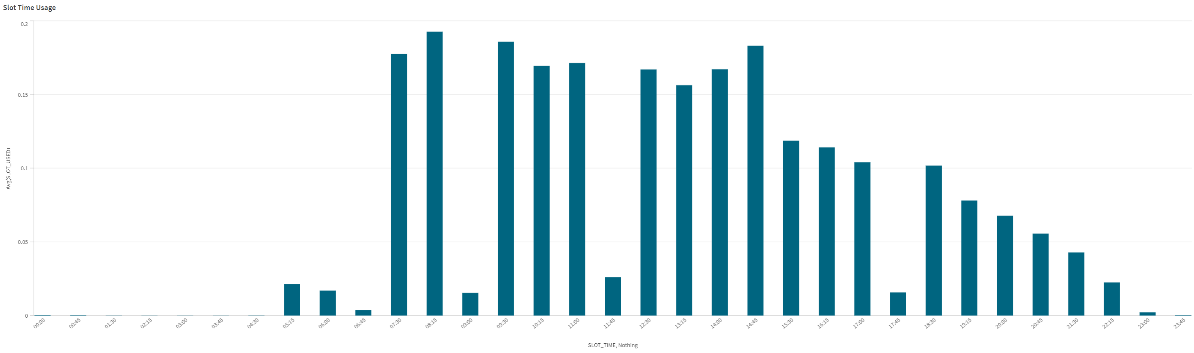


Figure B.3: Daily Pattern at Vopak Terminal Vlaardingen since April 2019 [100]

B.4. Bay Usage

Figure B.4 shows twelve (un)loading bays which are present at Vopak Terminal Vlaardingen. The utilisation rate of bays is highest during weekdays compared to weekends.

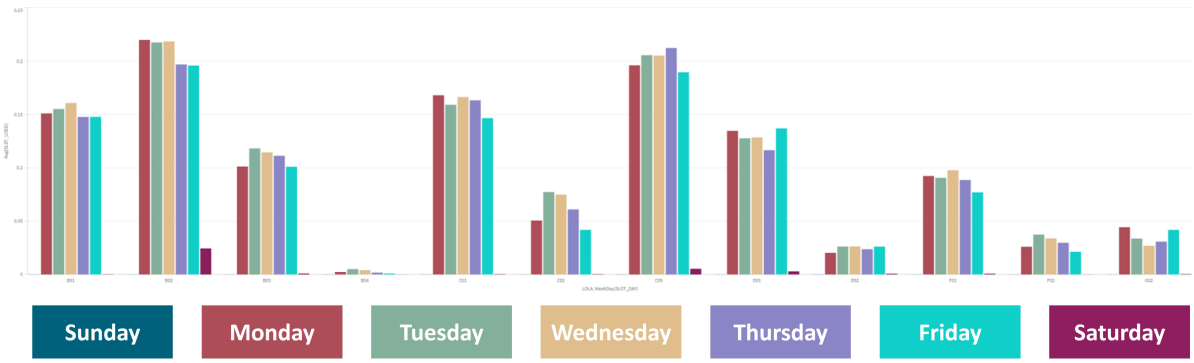


Figure B.4: Bay Usage at Vopak Terminal Vlaardingen During the Week [100]

B.5. Tank Switches

Figure B.5 shows the number of tank switches per month since January 2017.

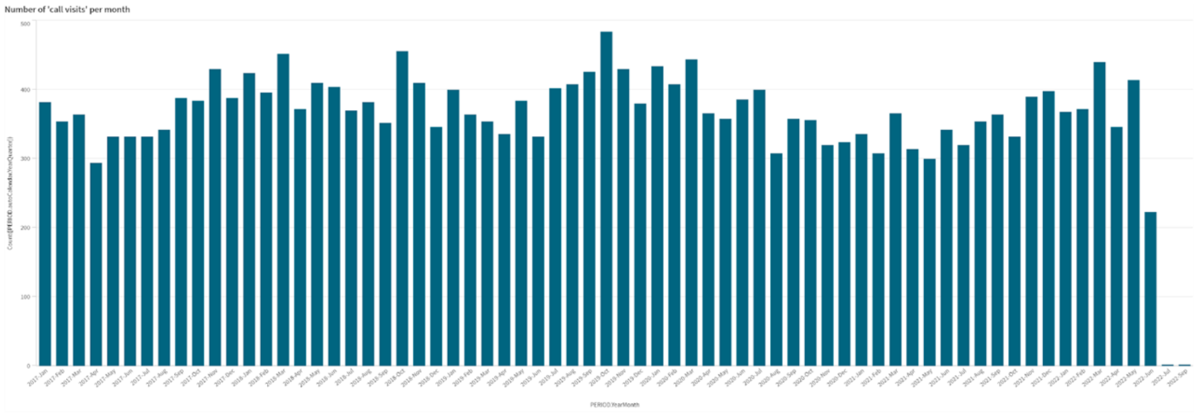


Figure B.5: Total Number of Tank Swaps since January 2017 [101]

Figure B.6 shows which percentage of the days between January 2017 and May 2022 had a certain number of tank switches. For example, 11.7% of the days had 2 tank switches. The system counts the lining up of equipment at the beginning of the day as the first tank switch, therefore the minimum is one tank switch. Days without any bookings were not included in the data.

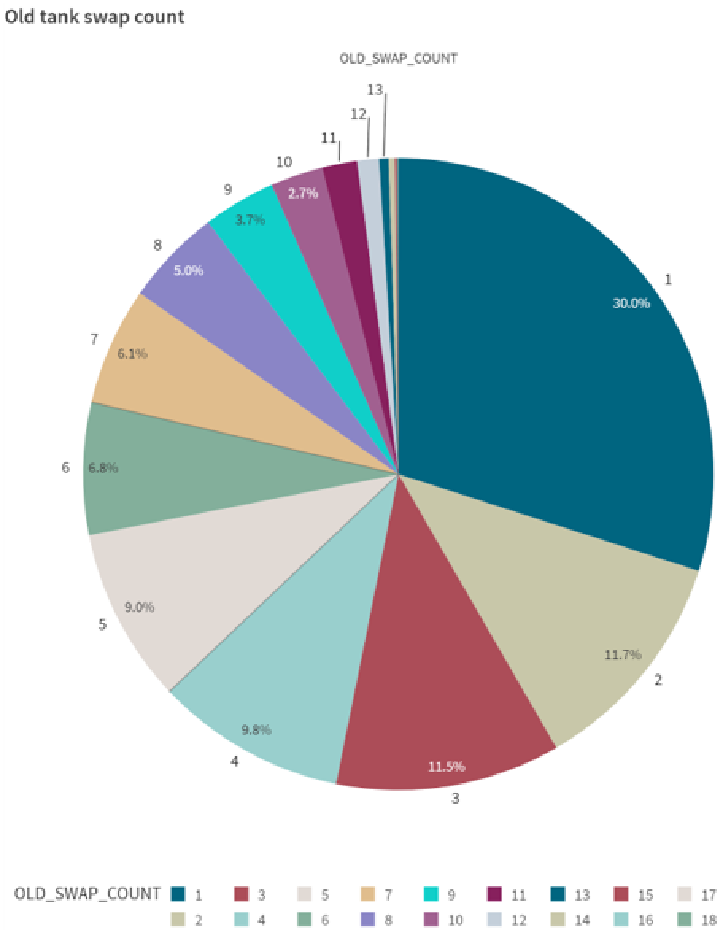


Figure B.6: Number of Tank Switches shown in Percentage of Days between January 2017 and May 2022 [101]

An algorithm tried to optimise the above data by rescheduling trucks such that the minimum number of tank switches is made per day. The outcome is presented below.

Figure B.7 shows the number of modifications in the schedule in order to minimise tank switches. Two optimisations were done. One with the restriction that trucks could be placed at most one time slot earlier or later (purple) and one optimisation with the restriction that trucks could at most be placed two time slots earlier or later (blue). Most of the days are unchanged, as the chart bars are the highest at the 0 location of the x-axis (modifications). Hence, no optimisation was possible for those days and configurations.

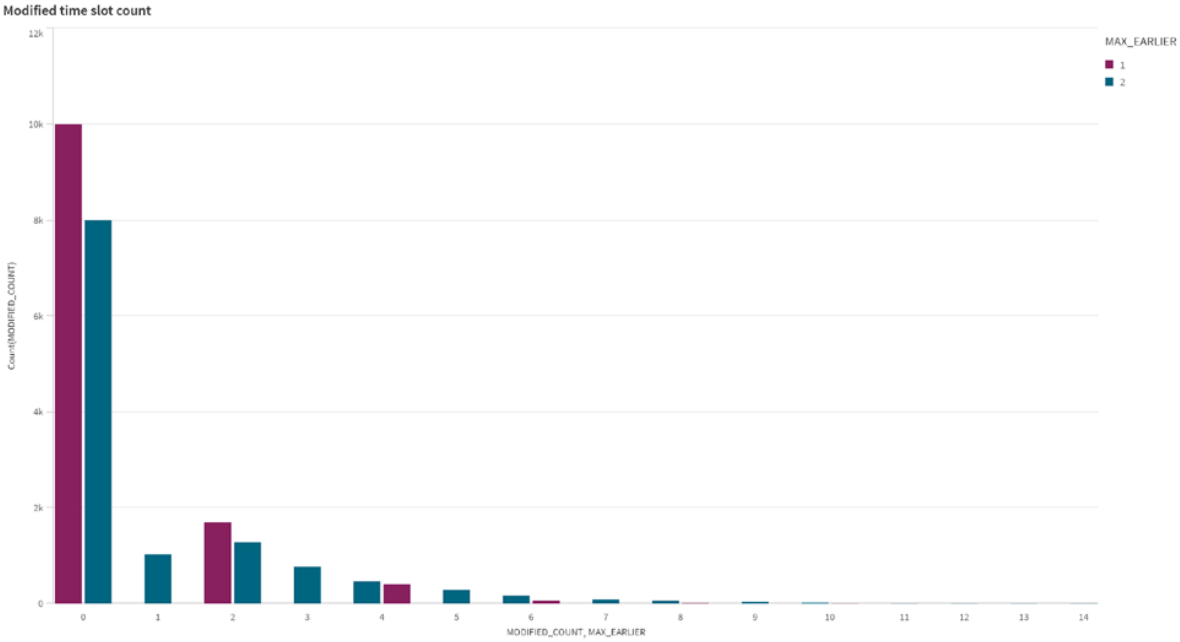
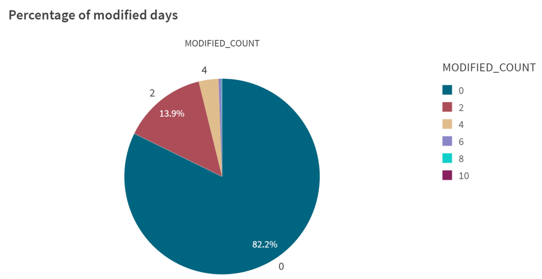


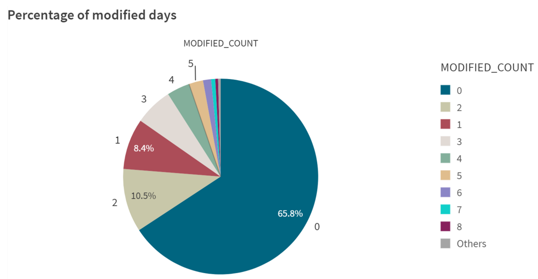
Figure B.7: Count of Modified Time Slots with Optimisation [101]

The results of the optimising the schedule based on Figure B.7 is shown in Figure B.8. With one time slot step allowed, 17.8% of the days could be optimised, as shown in Figure B.8a. With two time slot steps allowed, 34.2% of the days could be optimised, as shown in Figure B.8b.

If the 30% of the days that had no switch to begin with, which is shown in Figure B.6, are removed, the optimised numbers become 25.4% and 48.9% for respectively one time slot step allowed and two time slot steps allowed.



(a) Optimisation with One Time Slot Step Allowed



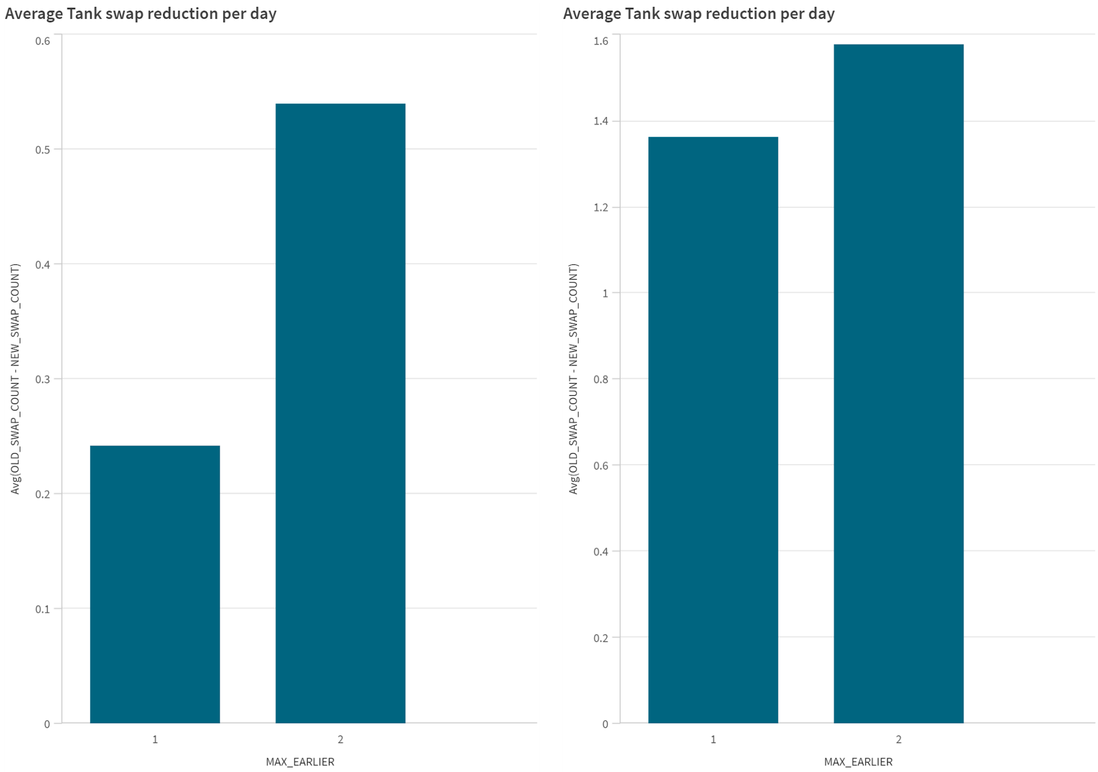
(b) Optimisation with Two Time Slot Steps Allowed

Figure B.8: Optimisation of Schedule with Maximum Time Slot Steps Allowed [101]

The resulting mean tank switch reduction per day can be concluded from the following data which is based on previously mentioned data.

Figure B.9 shows bar charts with the number of average tank switch reductions per day. Figure B.9a shows that the mean tank switch reduction per day is 0.24 if at most one time slot shift is allowed. The tank switch reduction is 0.54 if at most two time slot shifts are allowed. Figure B.9b shows that if data is removed where no optimisation was possible (the two leftmost bars of Figure B.7), the tank switch reduction becomes 1.36 per day for shifting at most one time slot and 1.58 per day for shifting at most two time slots.

The relative difference between shifting one or two shifts seems to become less. However, the algorithm for optimising if shifting two time slots was allowed could optimise about twice as many days.



(a) Average Tank Switch Reduction per Day, Zero Modified Counts Included

(b) Average Tank Switch Reduction per Day, Zero Modified Counts Excluded

Figure B.9: Average Tank Switch Reduction per Day [101]

Therefore, the conclusion is that most days can not even be optimised and that at most two tank switches can be eliminated per day if much flexibility is required from truck drivers. Truck drivers have to be present at least two time slots before their scheduled time slot and they can also be placed two time slots later than their scheduled time slot.

C
Model

This appendix gives information about the Discrete Event Simulation model.

C.1. Flowcharts Enlarged

In this section, the enlarged flowcharts of the logistics can be found. Figure C.1 shows the flowchart of the Truck Appointment System physical flow, which is equal to the current logistics at Vopak Terminal Vlaardingen. Figure C.2 shows the enlarged flowchart of the logistics for Drop and Swap. Figure C.3 shows the enlarged flowchart of the complementary Truck Arrival Management logistics.

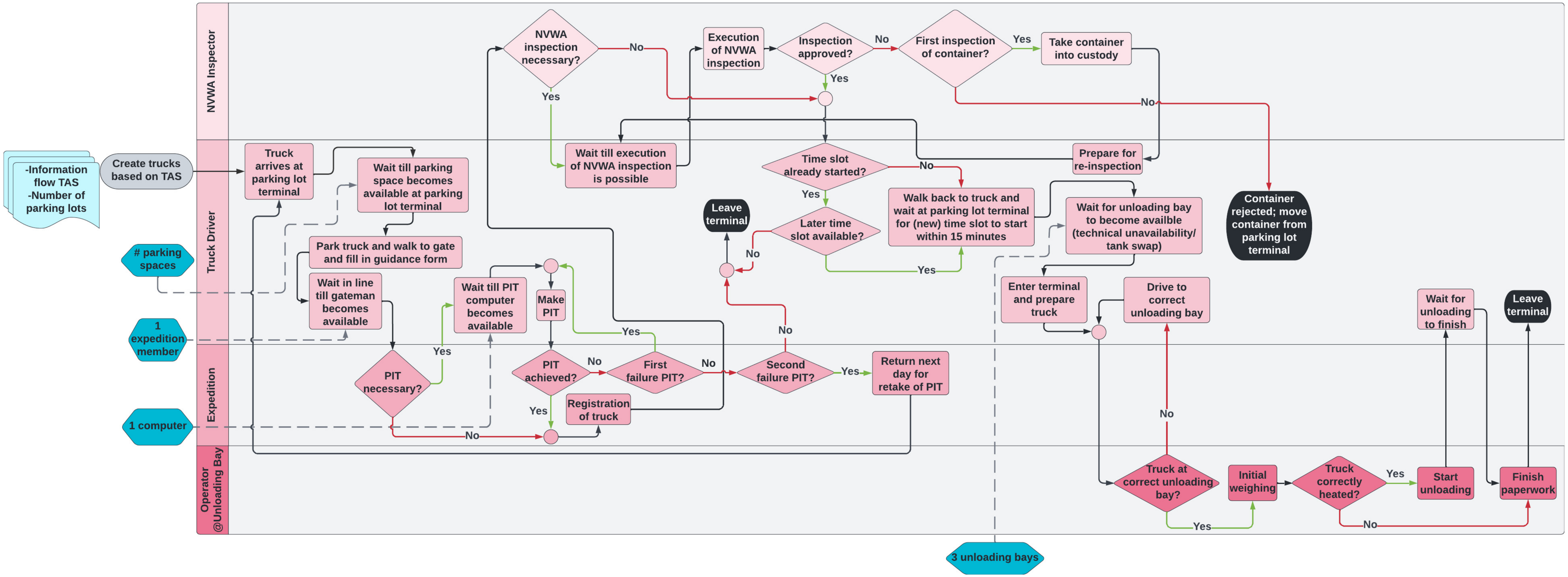


Figure C.1: Enlarged Flowchart of Physical Processes Truck Appointment System

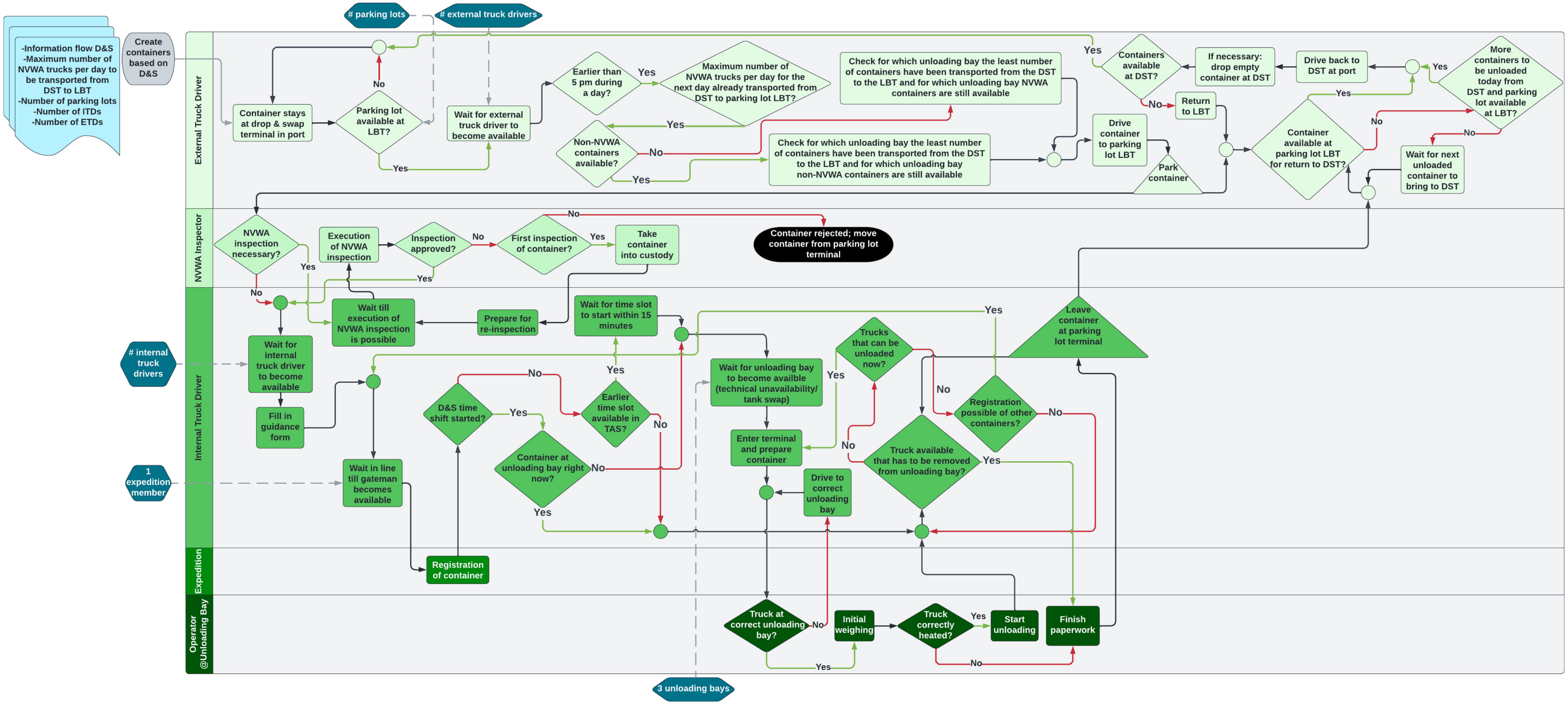


Figure C.2: Enlarged Flowchart of Physical Processes Drop and Swap System

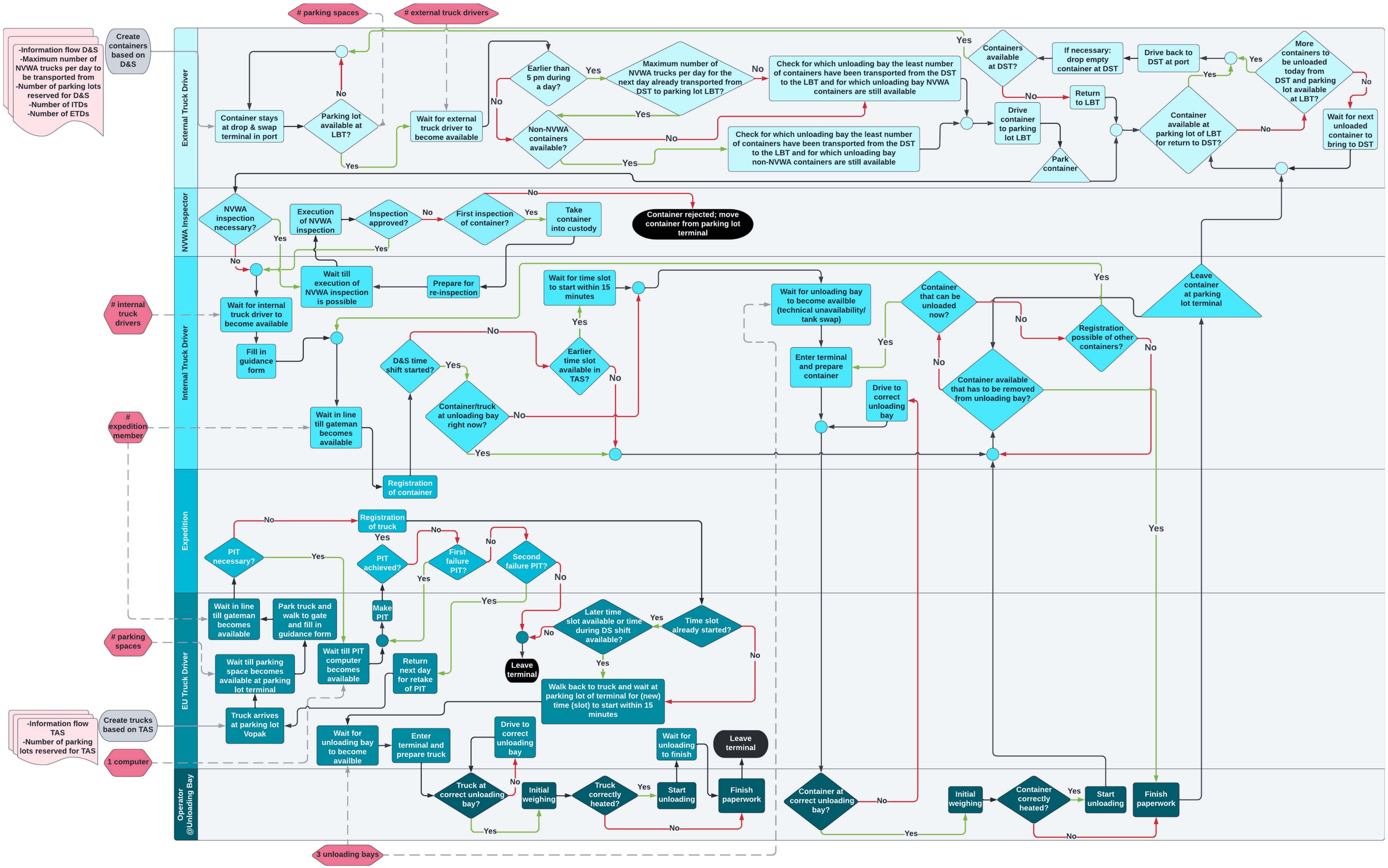
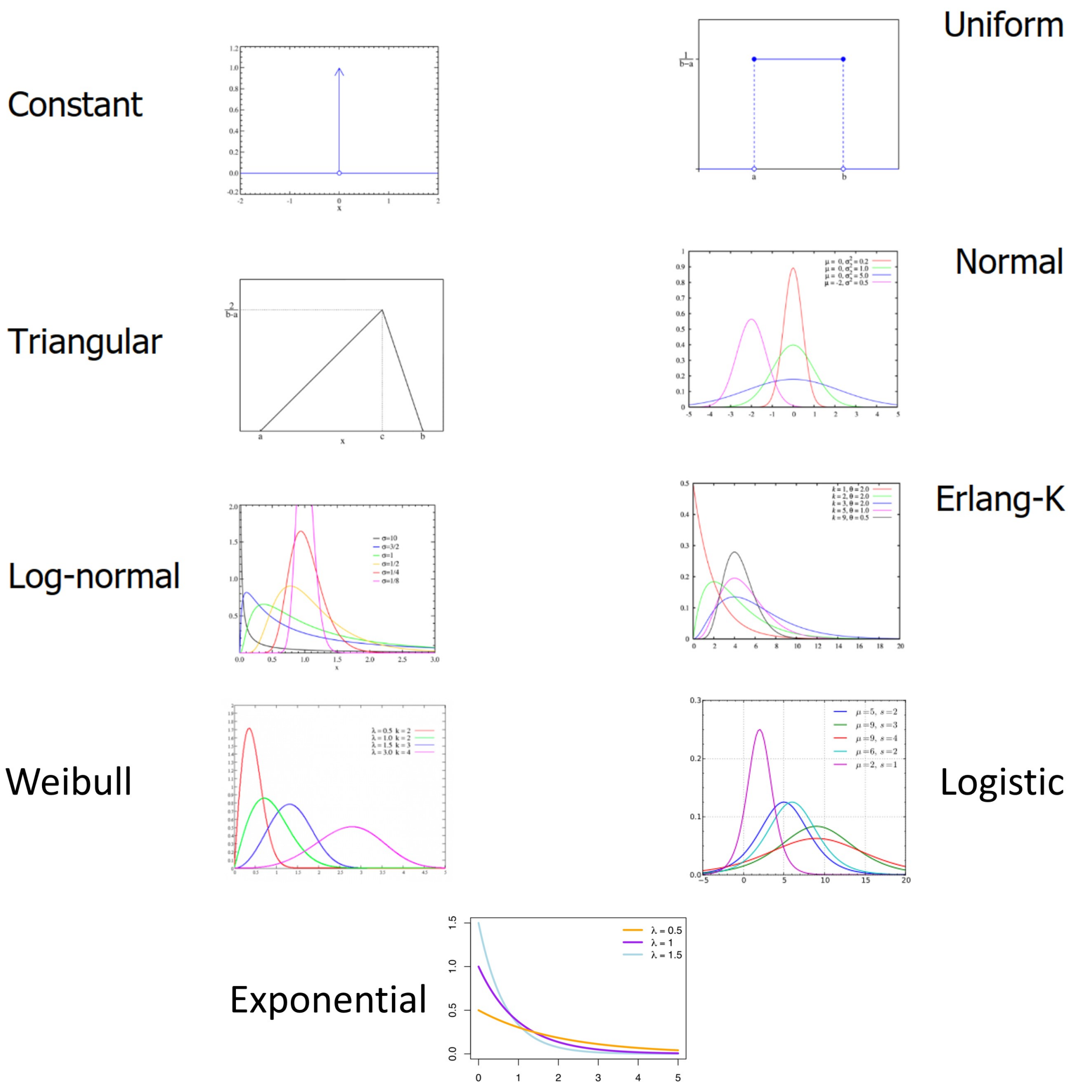
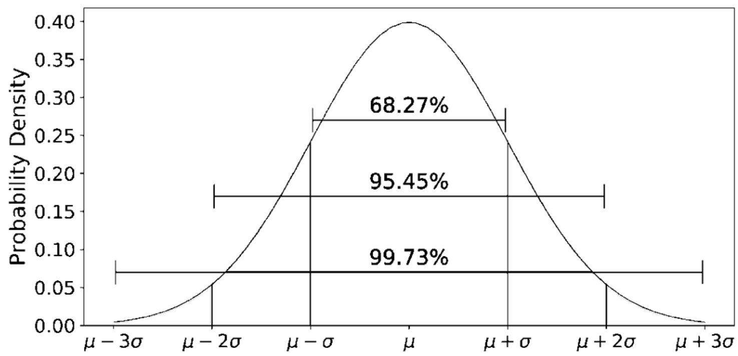


Figure C.3: Enlarged Flowchart of Physical Processes Complementary Truck Arrival Management System

C.2. Distributions



(a) Probability Density Functions of Various Distributions [102, 103, 104, 105]



(b) Detailed Probability Density Function of Normal Distribution [106]

Figure C.4: Distributions

C.3. EasyFit Results

This section contains results of the EasyFit software used to parameterise service times.

Expedition

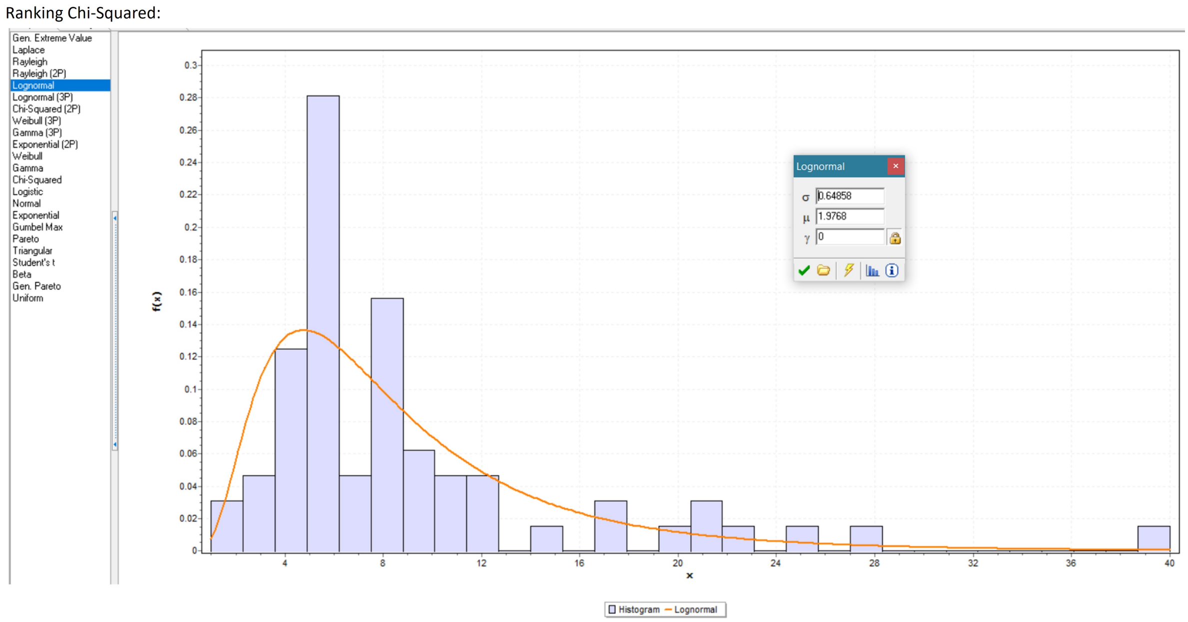


Figure C.5: EasyFit Lognormal Probability Density Function Expedition Service Time

Pumptime

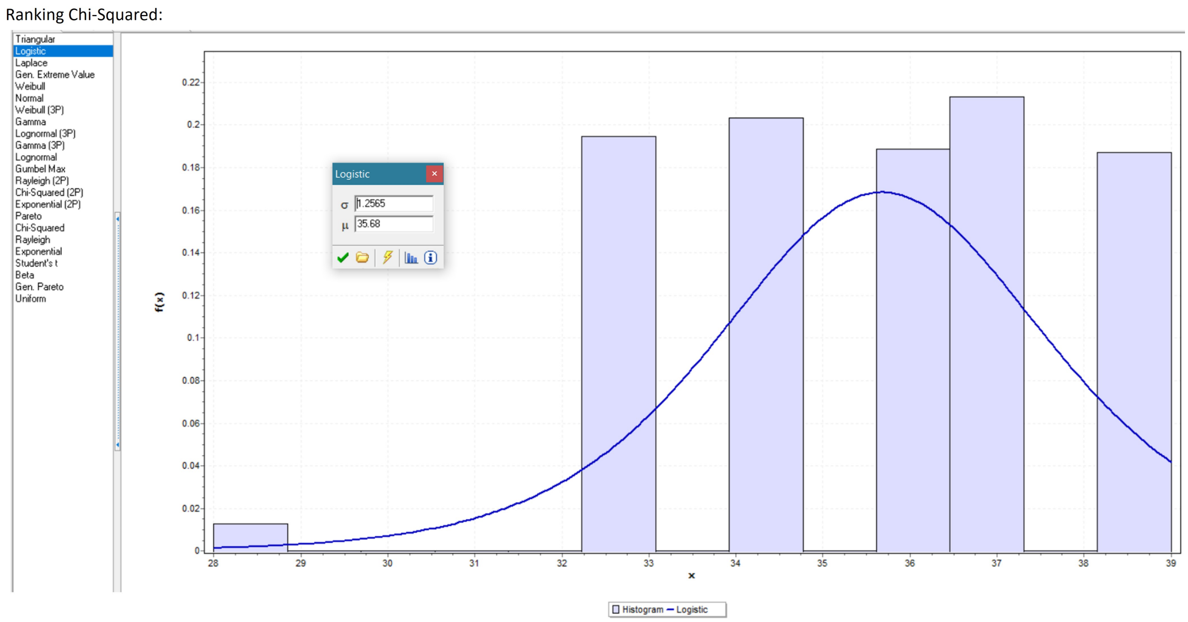


Figure C.6: EasyFit Logistic Probability Density Function Pumptime

Post Pumptime

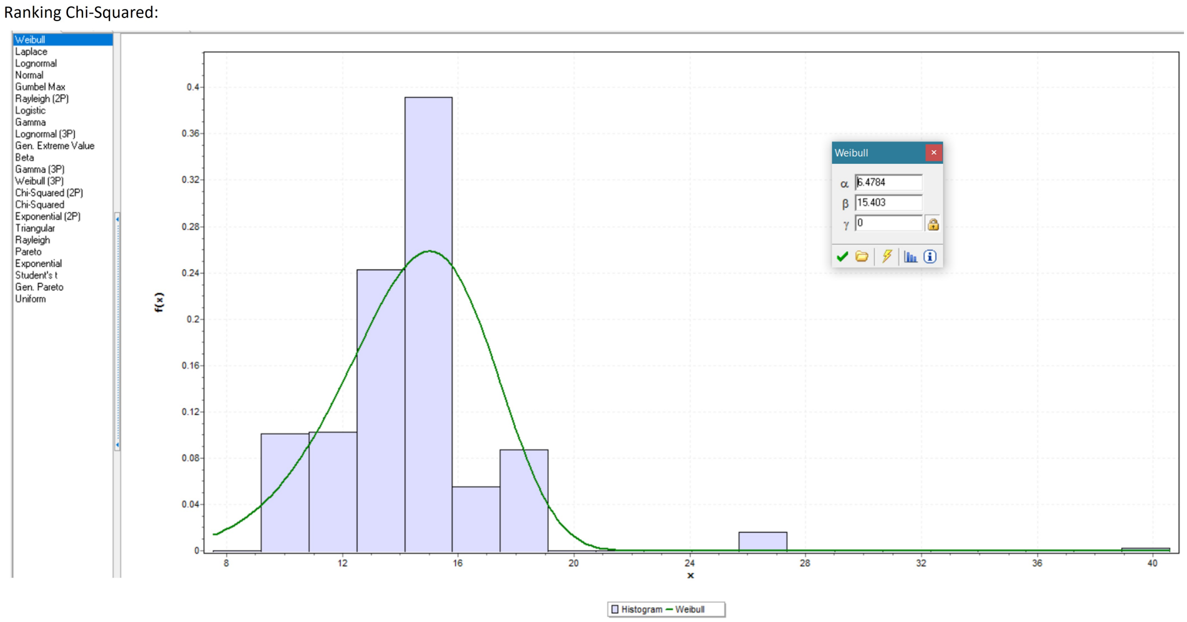


Figure C.7: EasyFit Weibull Probability Density Function Post Pumptime

Number of Trucks

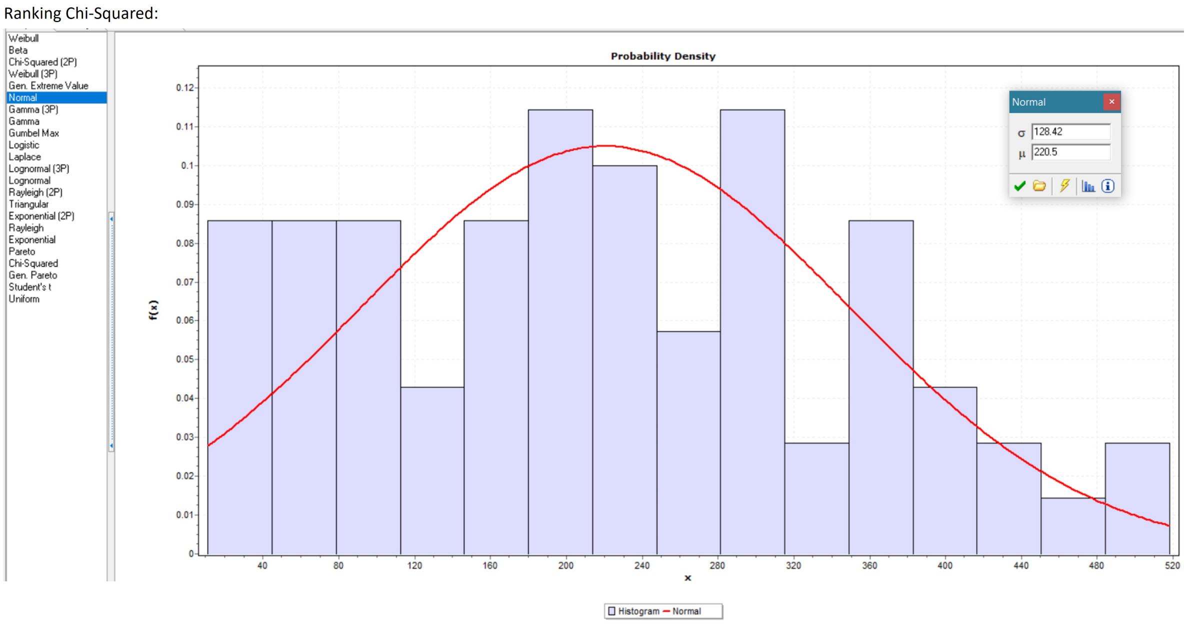
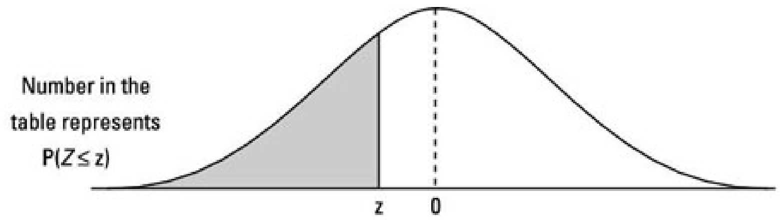


Figure C.8: EasyFit Normal Probability Density Function Number of Trucks

C.4. Z-Score Tables

Table C.1: Z-Score Tables [107]

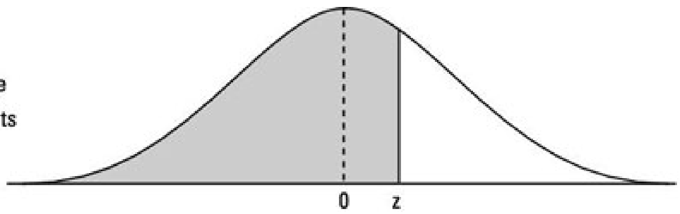
(a) Negative Z-Score Table



z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
−3.6	.0002	.0002	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
−3.5	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002
−3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
−3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
−3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
−3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
−3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
−2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
−2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
−2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
−2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
−2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
−2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
−2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
−2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
−2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
−2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
−1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
−1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
−1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
−1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
−1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
−1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
−1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
−1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
−1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
−1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
−0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
−0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
−0.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
−0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
−0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
−0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
−0.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
−0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
−0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
−0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

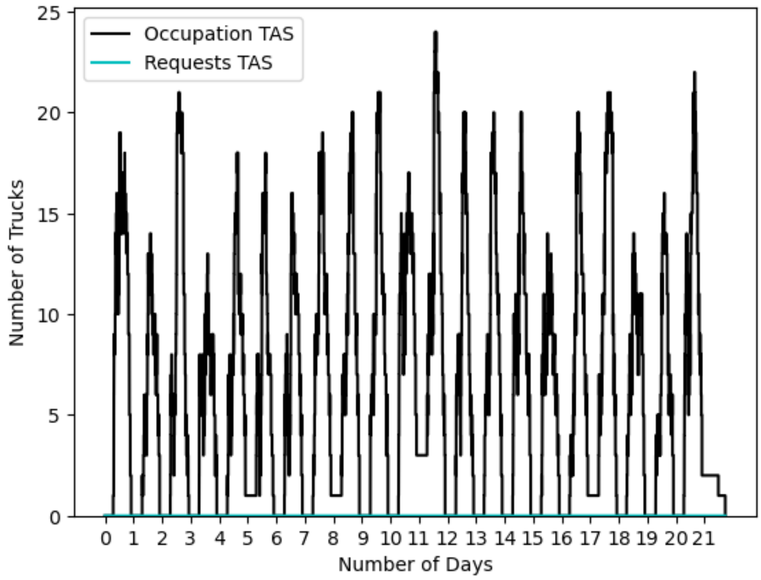
(b) Positive Z-Score Table

Number in the table represents $P(Z \leq z)$

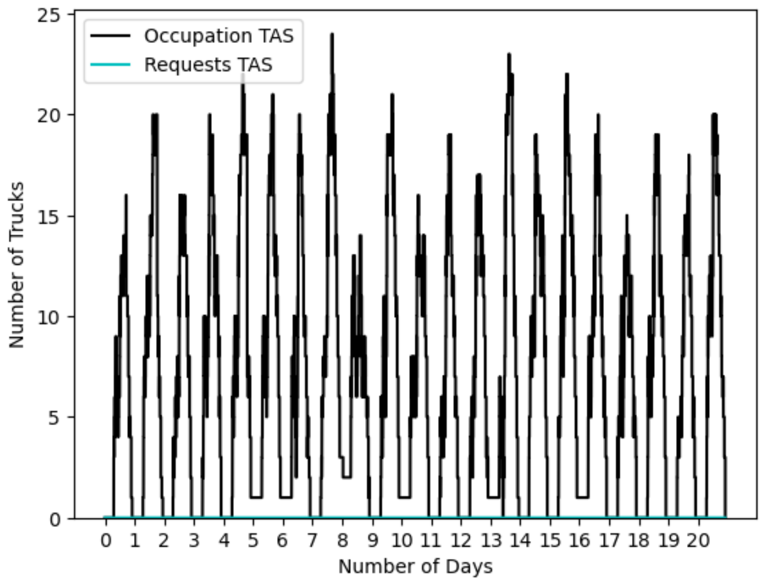


z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998
3.5	.9998	.9998	.9998	.9998	.9998	.9998	.9998	.9998	.9998	.9998
3.6	.9998	.9998	.9999	.9999	.9999	.9999	.9999	.9999	.9999	.9999

C.5. Occupation of Parking Lot for Complementary System



(a) Parking Lot Occupation and Pending Requests - Complete Truck Appointment System Truck Scenario 1



(b) Parking Lot Occupation and Pending Requests - Complete Truck Appointment System Truck Scenario 2

Figure C.9: Parking Lot Occupation Set-up Design Alternative 3

D Comprehensive Results

This chapter includes the explanation of the maximum operational capacity and additional results of the experiments.

D.1. Maximum Operational Capacity per Truck Arrival Management System

The maximum operational capacity per TAM system differs in the DES. This has to do with the stochasticity that has been incorporated in the DES model. The calculation for the maximum operational capacity is based on the TAS in which 18 trucks can unload per day. Per fictional truck, the chance that it can unload has been calculated. The formulas that have been used for calculating the chances of occurrence are shown in Equation D.1 [108].

$$
\begin{aligned}
&P(Technically\ Available\ TAS) = 0.8\\
&P(Technically\ Unavailable\ D\&S) = P(1\ Slot) + P(2\ Slots) – P(1\ and\ 2) = 0.1 + 0.05 - 0.1 \cdot 0.05 = 0.145\\
&P(Technically\ Available\ D\&S) = 1 - P(Technically\ Unavailable\ D\&S) = 1 - 0.145 = 0.855\\
&P(No\ Tank\ Swap,\ Excluding\ First\ and\ Last\ TAS) = 1 - P(Tank\ Swap) = 1 - \frac{1}{18} \approx 0.944\\
&P(No\ Tank\ Swap,\ First\ and\ Last\ TAS) = 1\\
&P(No\ Tank\ Swap,\ Switch\ Complementary\ TAM\ System) = 0
\end{aligned}
\tag{D.1}
$$

The results give a good estimation and are shown in Table D.1. It is an estimation, as the DES is subject to stochasticity. Table D.1a gives the results for the complete TAS and Table D.1b gives the results for the complete D&S. Table D.1c and Table D.1d give the results for the complementary TAM system. Both the cases 70:30 and 50:50 with ratios for TAS:D&S are presented.

The maximal operational capacity in the simulation is calculated by multiplying the daily capacity by the number of days and the number of unloading bays. This is shown in Equation D.2. The results are presented in Table D.2.

$$\#Trucks = Daily\ Capacity \cdot \#Unloading\ Bays \cdot \#Operational\ Days \tag{D.2}$$

Table D.1: Maximum Capacity per Truck Arrival Management System per Day

(a) Complete Truck Appointment System

Fictional Truck	Technical Availability	No Tank Swap	Availability
1	0.8	1	0.8
2	0.8	0.944	0.756
3	0.8	0.944	0.756
4	0.8	0.944	0.756
5	0.8	0.944	0.756
6	0.8	0.944	0.756
7	0.8	0.944	0.756
8	0.8	0.944	0.756
9	0.8	0.944	0.756
10	0.8	0.944	0.756
11	0.8	0.944	0.756
12	0.8	0.944	0.756
13	0.8	0.944	0.756
14	0.8	0.944	0.756
15	0.8	0.944	0.756
16	0.8	0.944	0.756
17	0.8	0.944	0.756
18	0.8	1	0.8
Daily Capacity			13.69

(b) Complete Drop and Swap

Fictional Truck	Technical Availability	No Tank Swap	Availability
1	0.855	0.944	0.8075
2	0.855	0.944	0.8075
3	0.855	0.944	0.8075
4	0.855	0.944	0.8075
5	0.855	0.944	0.8075
6	0.855	0.944	0.8075
7	0.855	0.944	0.8075
8	0.855	0.944	0.8075
9	0.855	0.944	0.8075
10	0.855	0.944	0.8075
11	0.855	0.944	0.8075
12	0.855	0.944	0.8075
13	0.855	0.944	0.8075
14	0.855	0.944	0.8075
15	0.855	0.944	0.8075
16	0.855	0.944	0.8075
17	0.855	0.944	0.8075
18	0.855	0.944	0.8075
Daily Capacity			14.54

(c) Complementary Truck Arrival Management System 70 TAS:30 D&S

Fictional Truck	Technical Availability	No Tank Swap	Availability
1	0.8	1	0.8
2	0.8	0.944	0.756
3	0.8	0.944	0.756
4	0.8	0.944	0.756
5	0.8	0.944	0.756
6	0.8	0.944	0.756
7	0.8	0.944	0.756
8	0.8	0.944	0.756
9	0.8	0.944	0.756
10	0.8	0.944	0.756
11	0.8	0.944	0.756
12	0.8	0.944	0.756
13	0.8	1	0.8
14	0.855	0	0
15	0.855	0.944	0.8075
16	0.855	0.944	0.8075
17	0.855	0.944	0.8075
18	0.855	0.944	0.8075
Daily Capacity			13.14

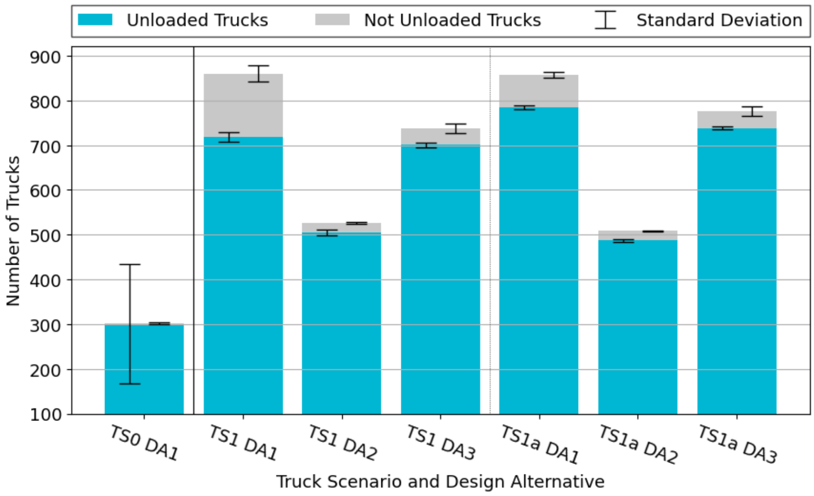
(d) Complementary Truck Arrival Management System 50 TAS:50 D&S

Fictional Truck	Technical Availability	No Tank Swap	Availability
1	0.8	1	0.8
2	0.8	0.944	0.756
3	0.8	0.944	0.756
4	0.8	0.944	0.756
5	0.8	0.944	0.756
6	0.8	0.944	0.756
7	0.8	0.944	0.756
8	0.8	0.944	0.756
9	0.8	0.944	0.756
10	0.8	1	0.8
11	0.855	0	0
12	0.855	0.944	0.8075
13	0.855	0.944	0.8075
14	0.855	0.944	0.8075
15	0.855	0.944	0.8075
16	0.855	0.944	0.8075
17	0.855	0.944	0.8075
18	0.855	0.944	0.8075
Daily Capacity			13.30

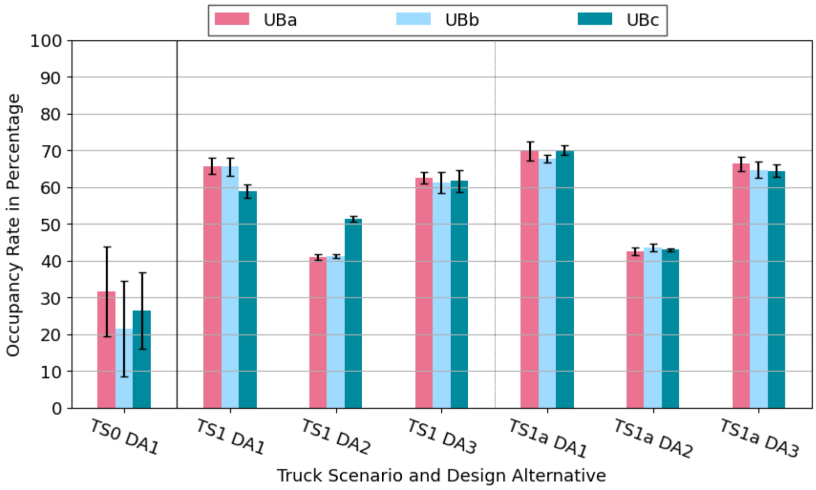
Table D.2: Maximal Operational Capacity per Truck Arrival Management System per Month

Truck Arrival Management System	Maximal Operational Capacity per Month
Complete TAS	862.4
Complete D&S System	915.7
Complementary TAM System 70/30	827.9
Complementary TAM System 50/50	837.7

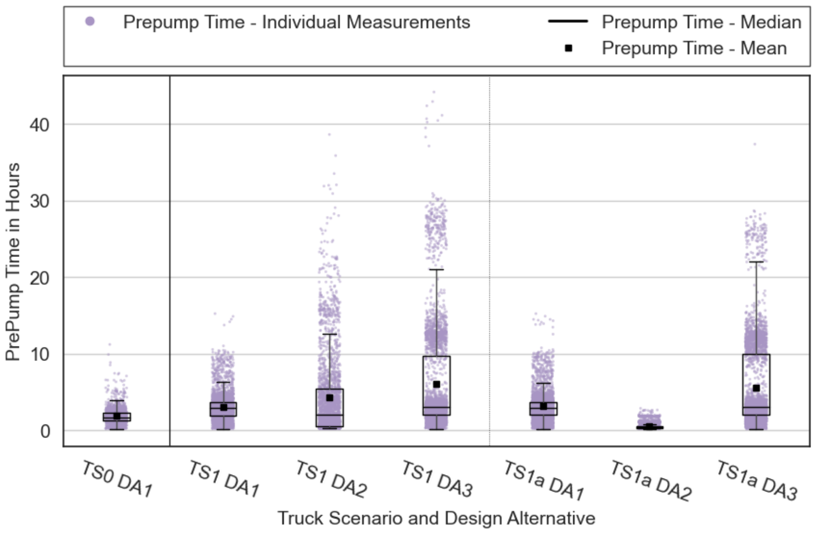
D.2. Additional Results Experiment 1



(a) Arrived Trucks, Divided into Unloaded and Not Unloaded Trucks



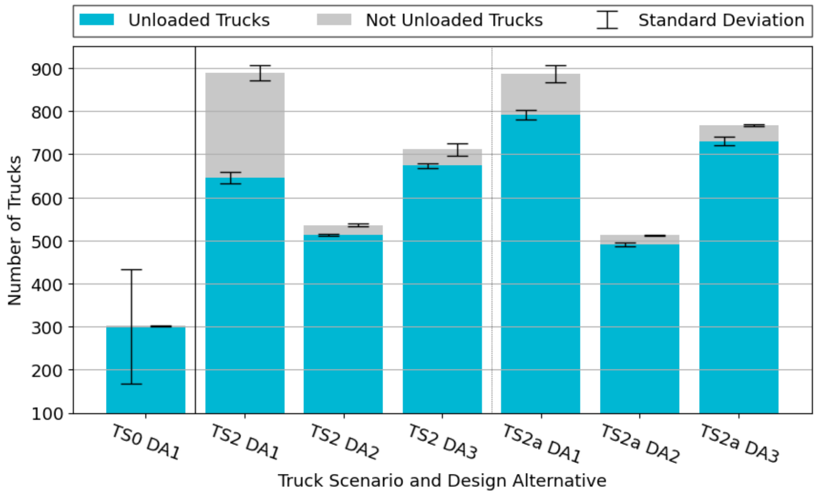
(b) Occupancy Rate Unloading Bays



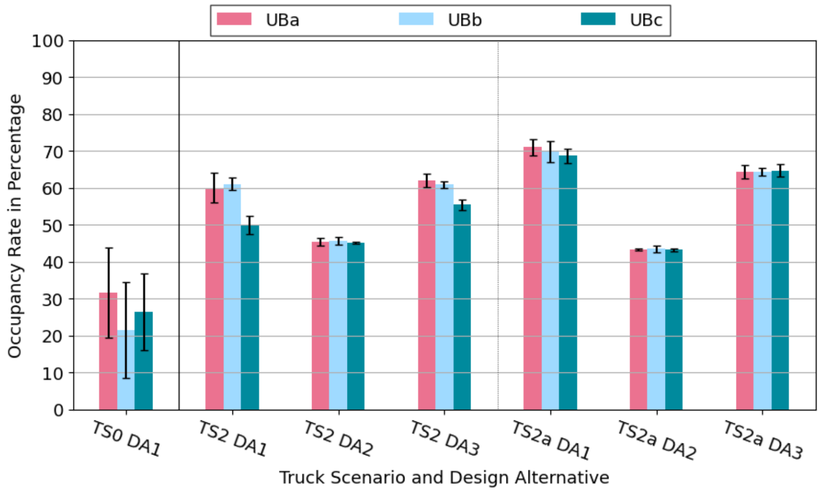
(c) Prepump Time

Figure D.1: Additional Results for Experiment 1

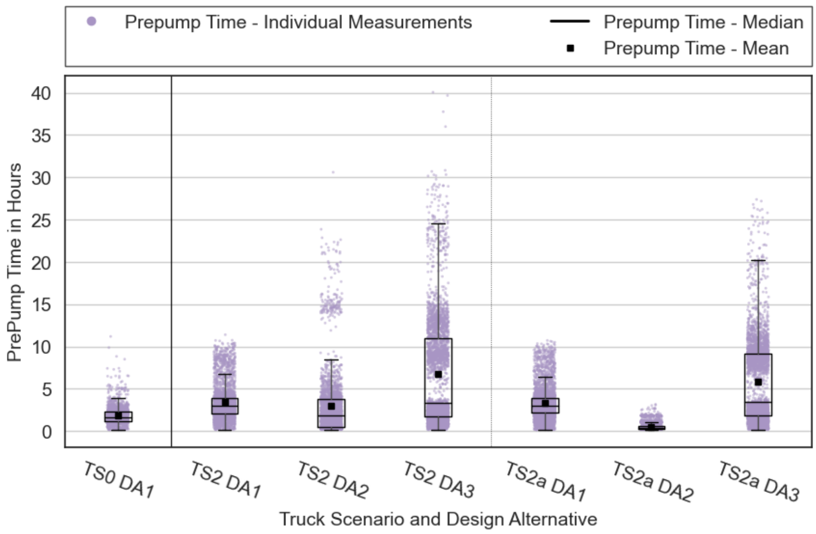
D.3. Additional Results Experiment 2



(a) Arrived Trucks, Divided into Unloaded and Not Unloaded Trucks



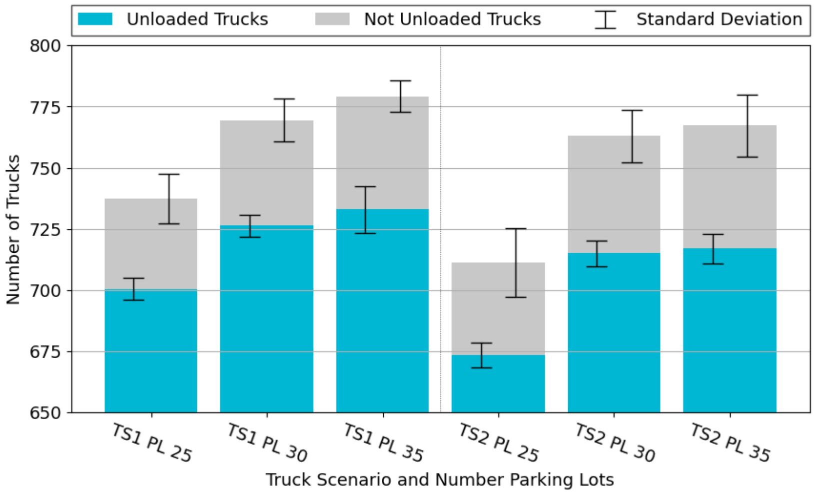
(b) Occupancy Rate Unloading Bays



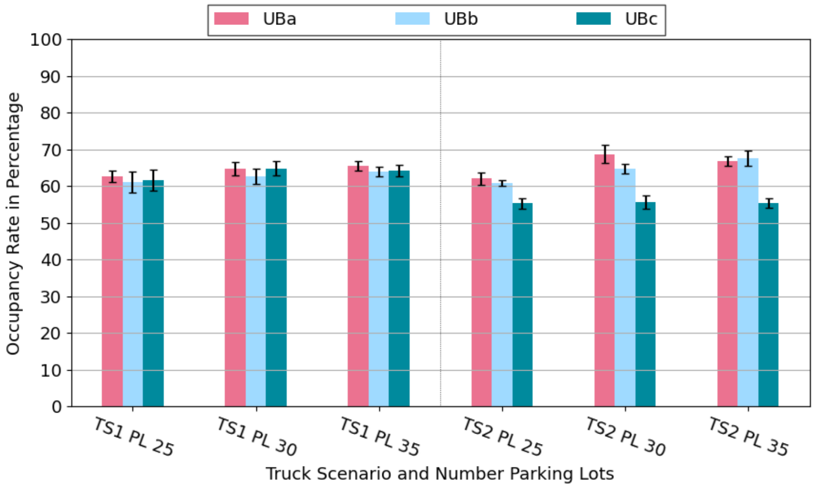
(c) Prepump Time

Figure D.2: Additional Results for Experiment 2

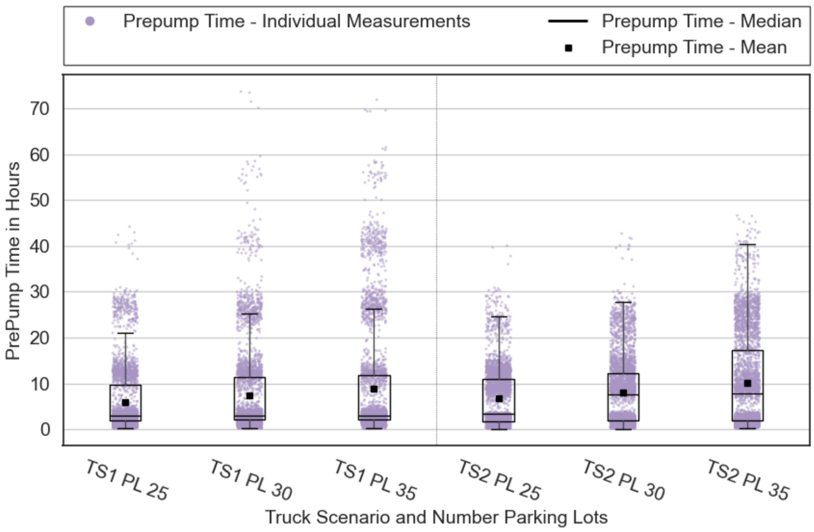
D.4. Additional Results Experiment 3



(a) Arrived Trucks, Divided into Unloaded and Not Unloaded Trucks



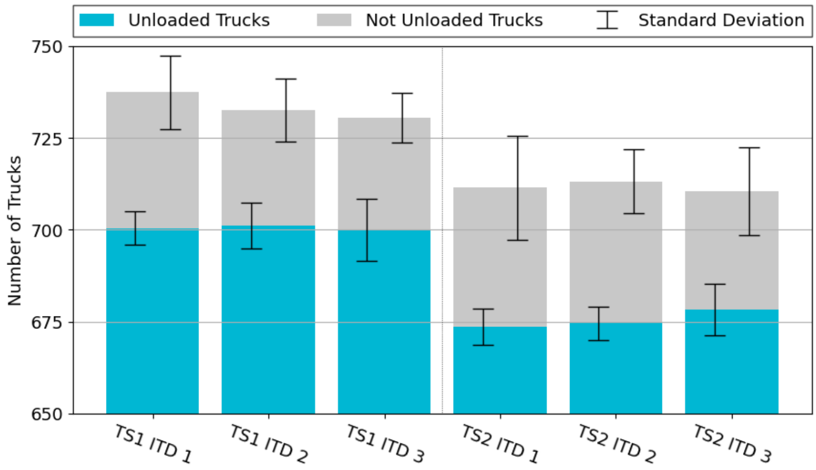
(b) Occupancy Rate Unloading Bays



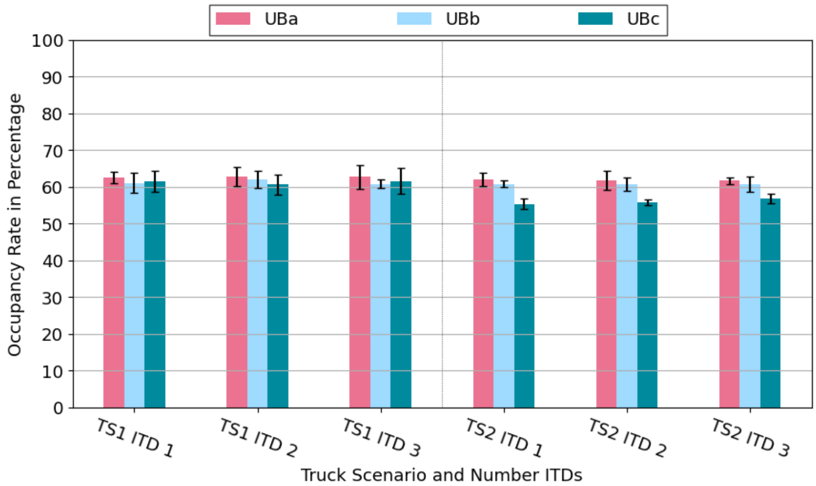
(c) Prepump Time

Figure D.3: Additional Results for Experiment 3

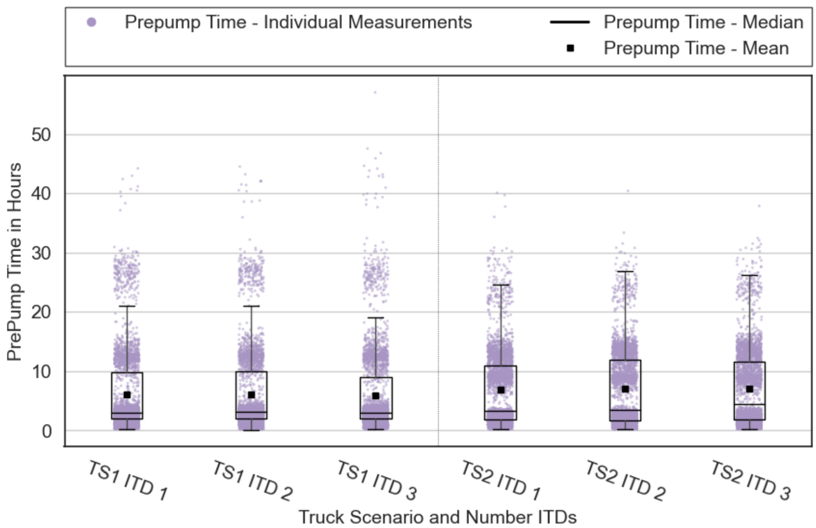
D.5. Additional Results Experiment 4



(a) Arrived Trucks, Divided into Unloaded and Not Unloaded Trucks



(b) Occupancy Rate Unloading Bays



(c) Prepump Time

Figure D.4: Additional Results for Experiment 4

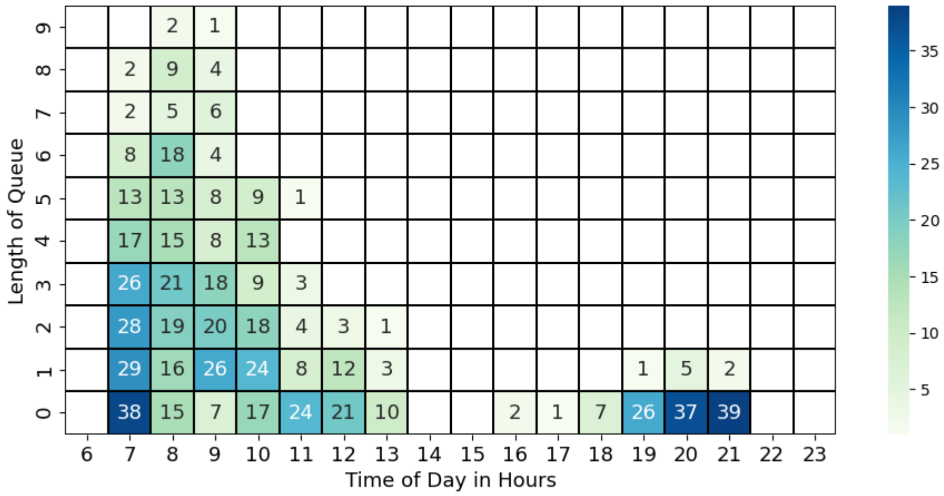
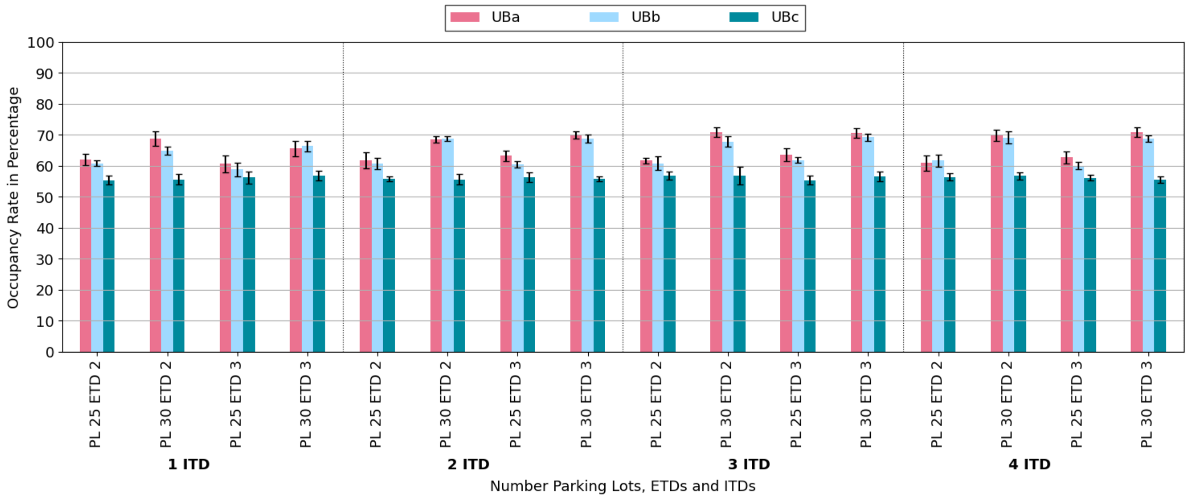
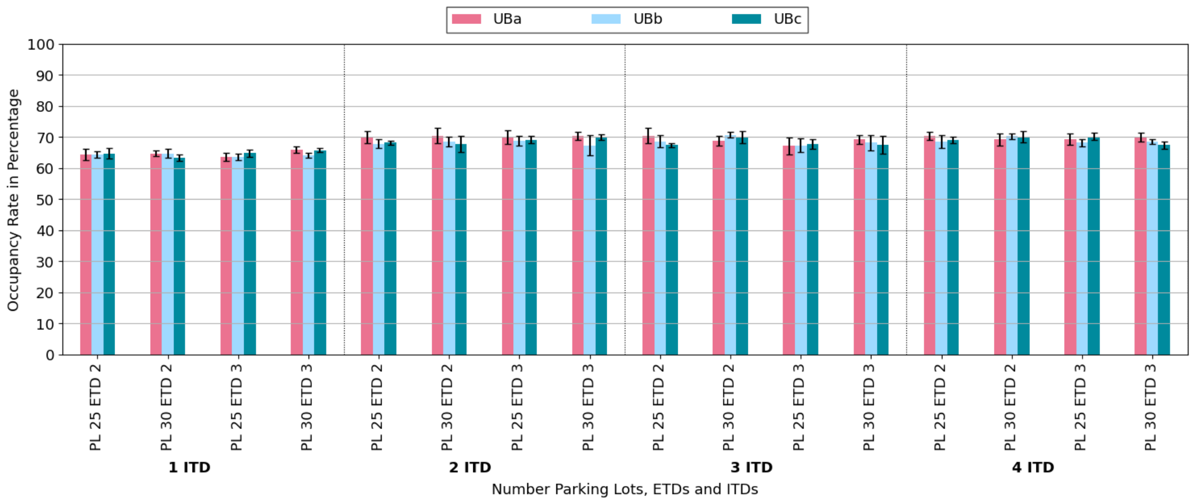


Figure D.5: Heatmap of Queue at Expedition - Truck Scenario 2, Design Alternative 3, 3 Internal Truck Drivers

D.6. Additional Results Experiment 5



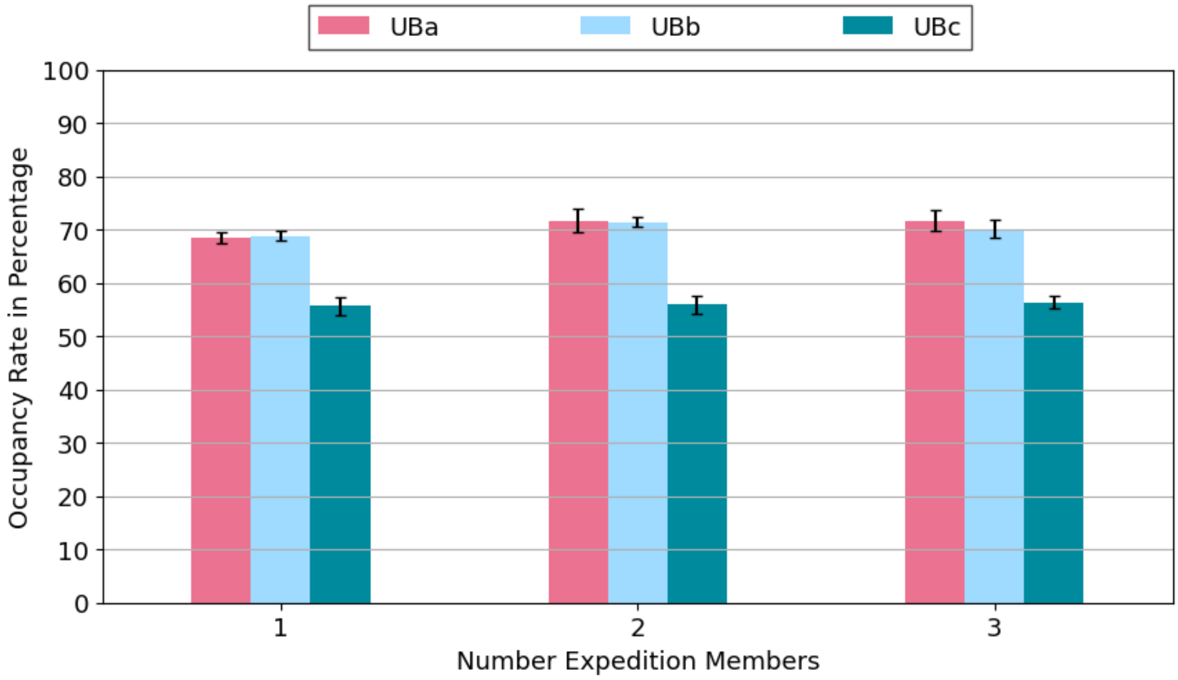
(a) Occupancy Rate Unloading Bays - Truck Scenario 2



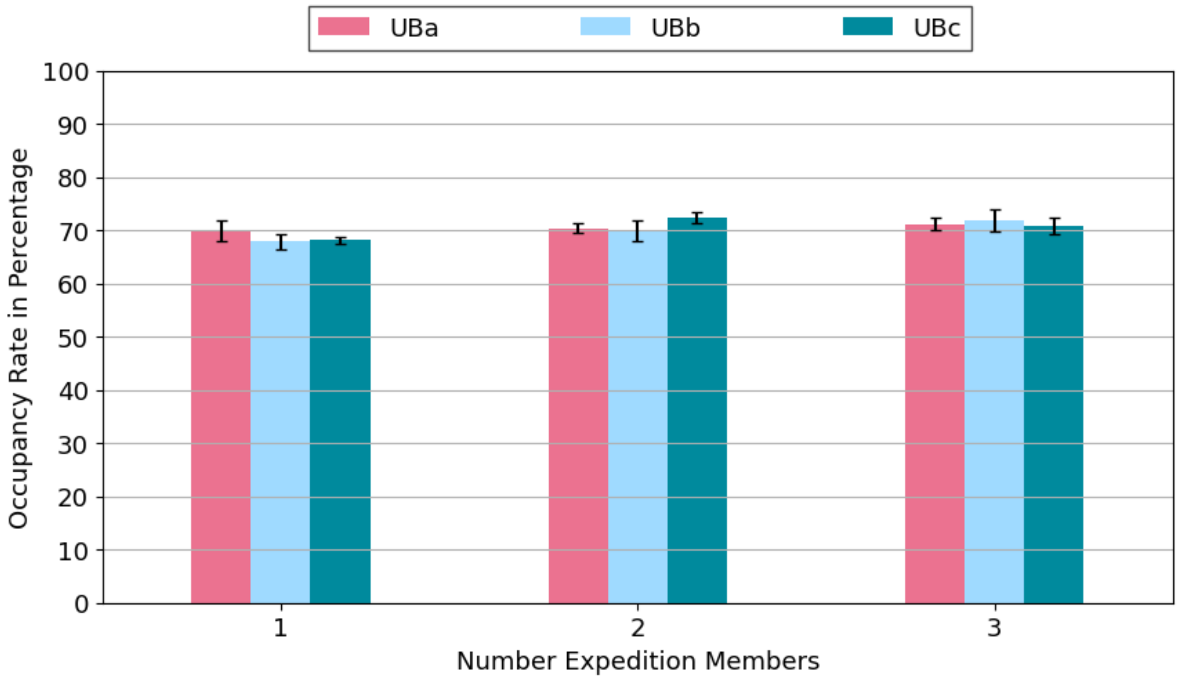
(b) Occupancy Rate Unloading Bays - Truck Scenario 2a

Figure D.6: Additional Results for Experiment 5

D.7. Additional Results Experiment 6

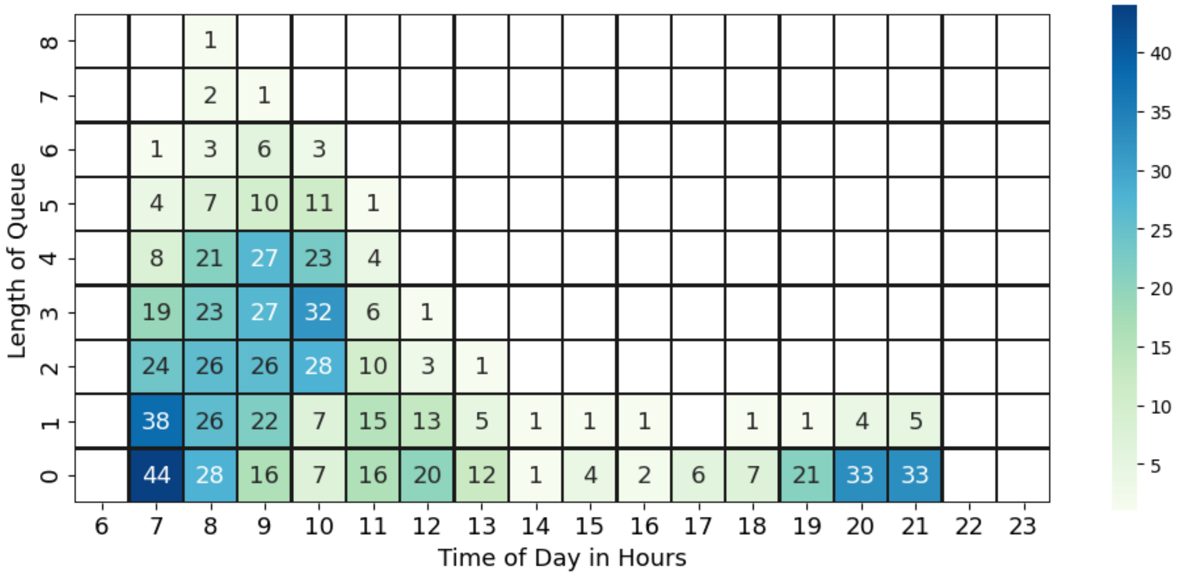


(a) Occupancy Rate Unloading Bays - Truck Scenario 2

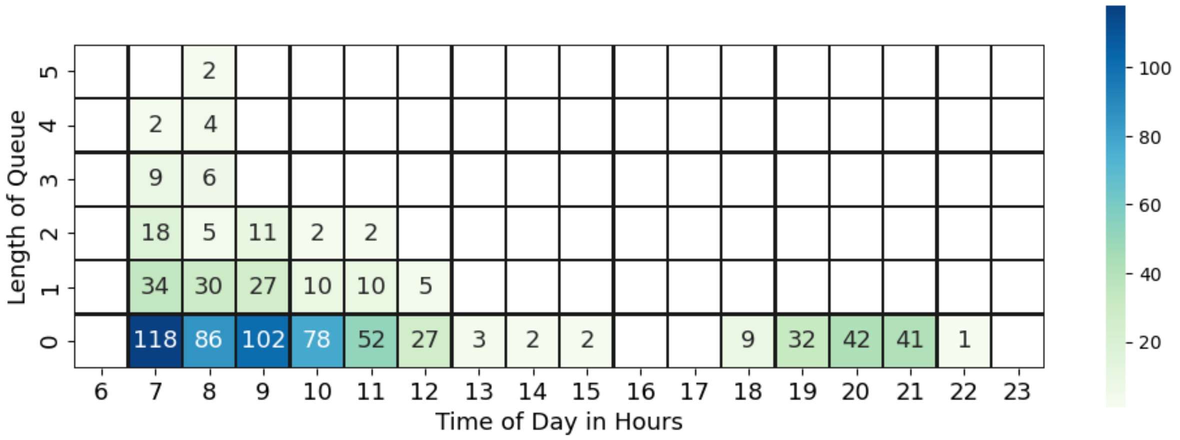


(b) Occupancy Rate Unloading Bays - Truck Scenario 2a

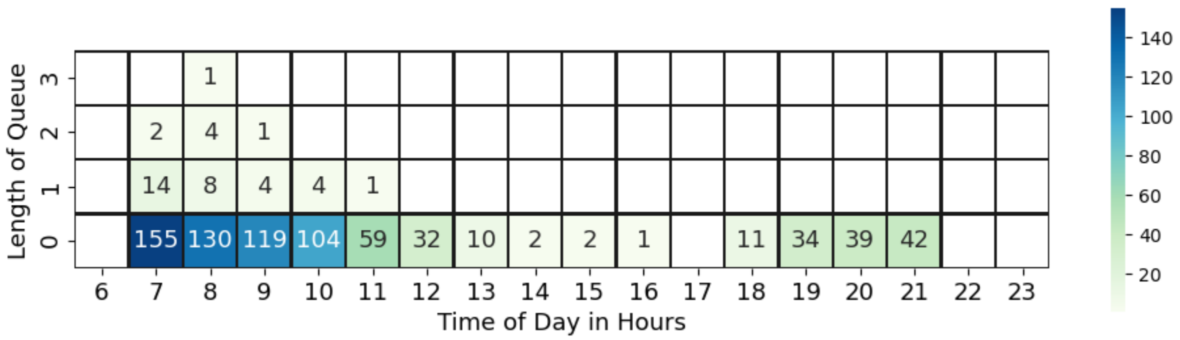
Figure D.7: Additional Results for Experiment 6



(a) 1 Expedition Member

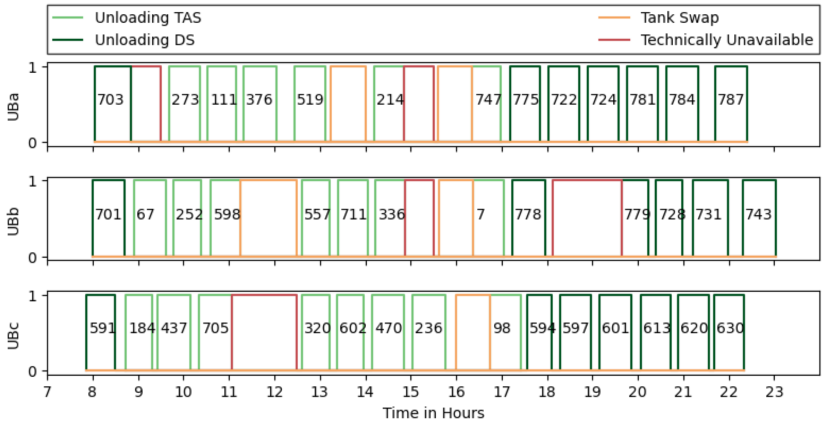


(b) 2 Expedition Members

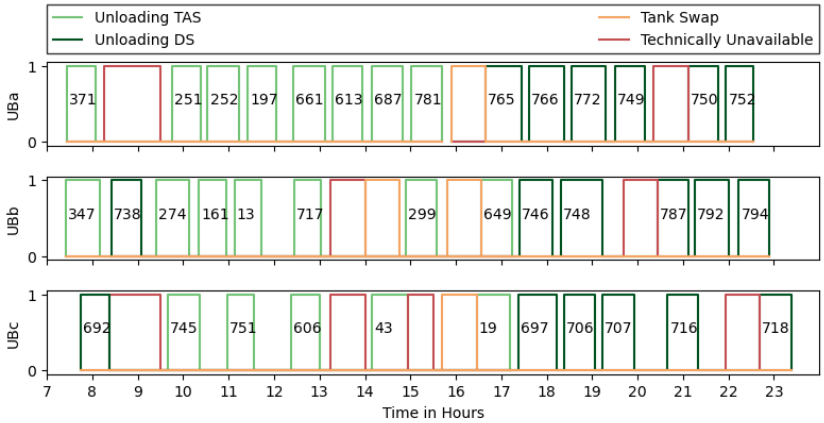


(c) 3 Expedition Members

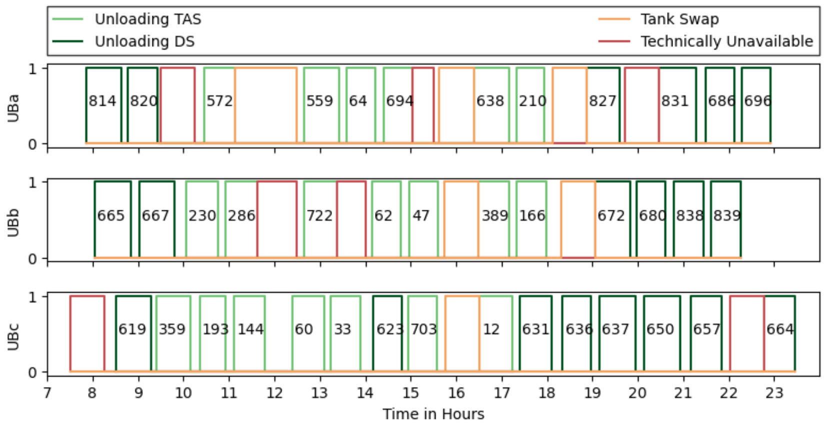
Figure D.8: Heatmaps of Queue at Expedition - Truck Scenario 2



(a) Example 1 of Occupation Unloading Bays



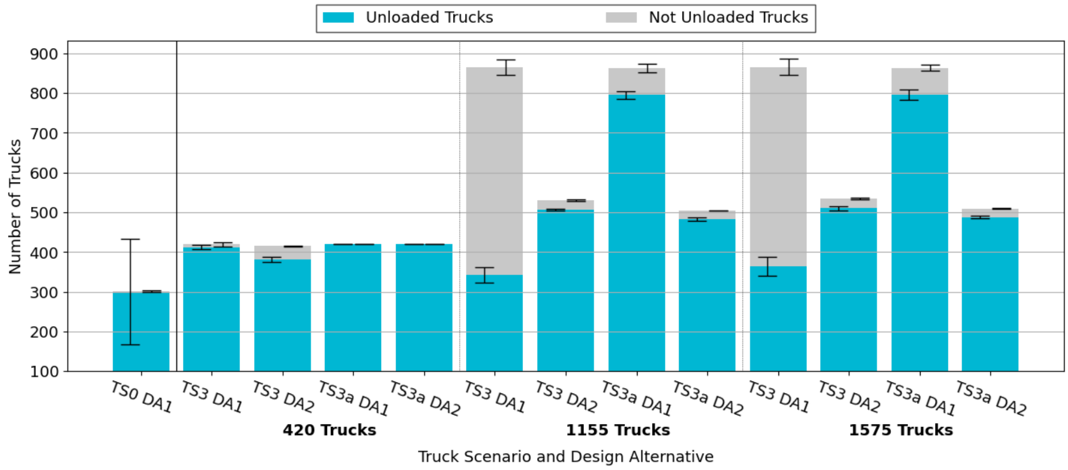
(b) Example 2 of Occupation Unloading Bays



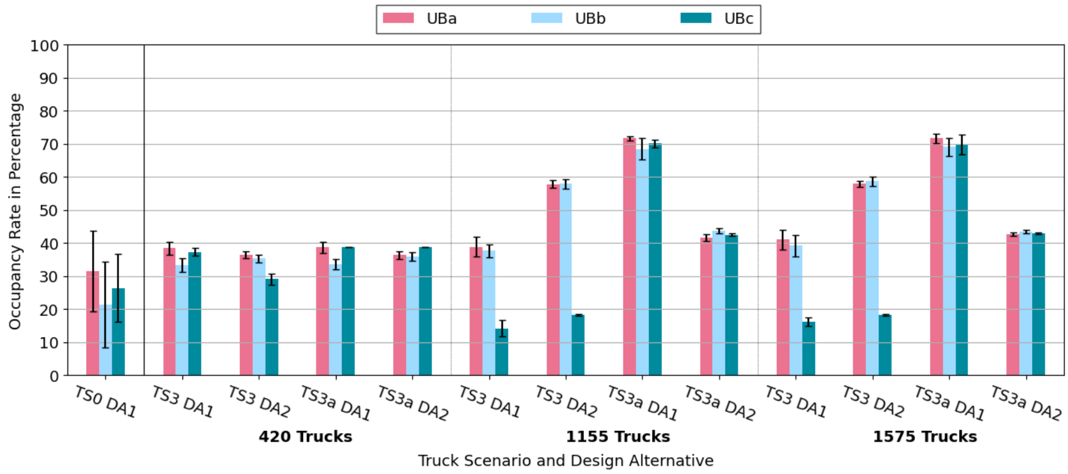
(c) Example 3 of Occupation Unloading Bays

Figure D.9: Examples of Daily Occupation Unloading Bays - Truck Scenario 2a Design Alternative 3 Trucknumbers Annotated

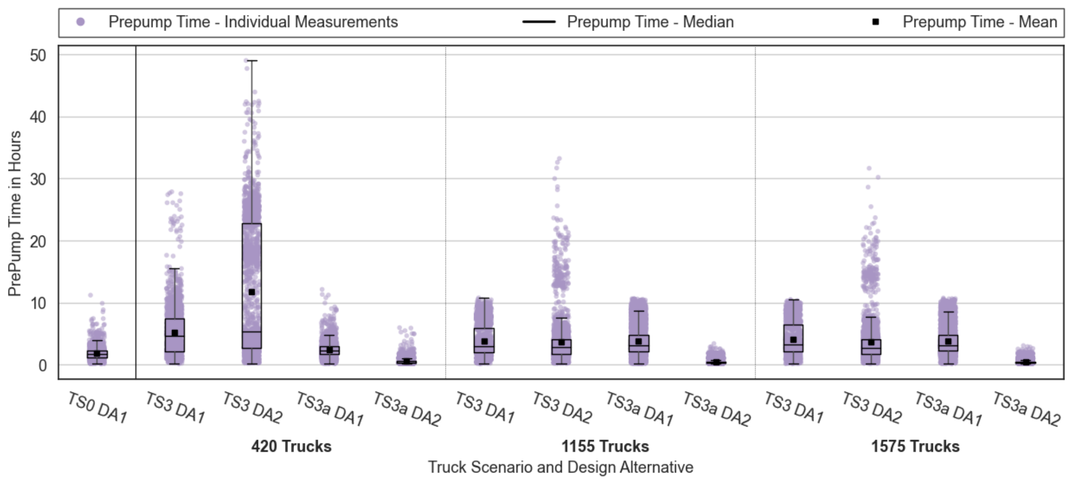
D.8. Additional Results Experiment 7



(a) Arrived Trucks, Divided into Unloaded and Not Unloaded Trucks

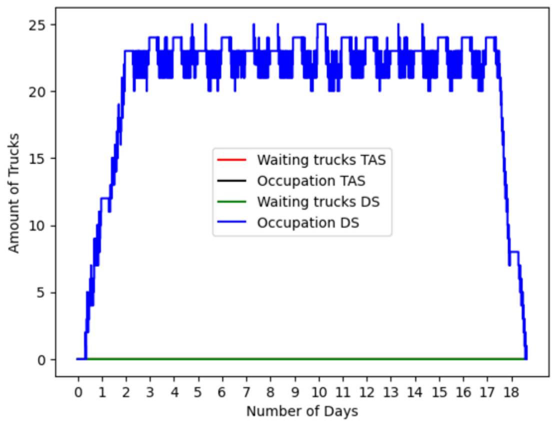


(b) Occupancy Rate Unloading Bays

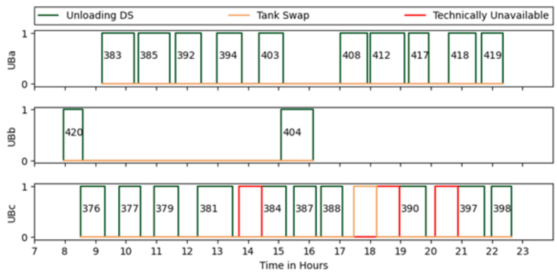


(c) Prepump Time

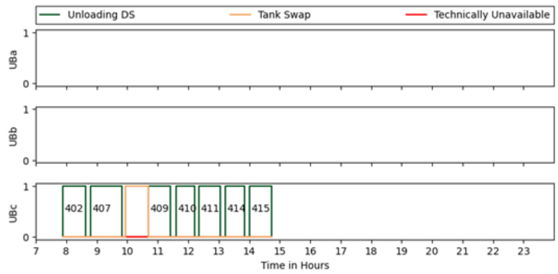
Figure D.10: Additional Results for Experiment 7



(a) Parking Lot Occupation



(b) Unloading Bays Day 17, Trucknumbers Annotated



(c) Unloading Bays Day 18, Trucknumbers Annotated

Figure D.11: Occupancy of Parking Lot and Unloading Bays - Truck Scenario 3a, Design Alternative 2, 420 Generated Trucks

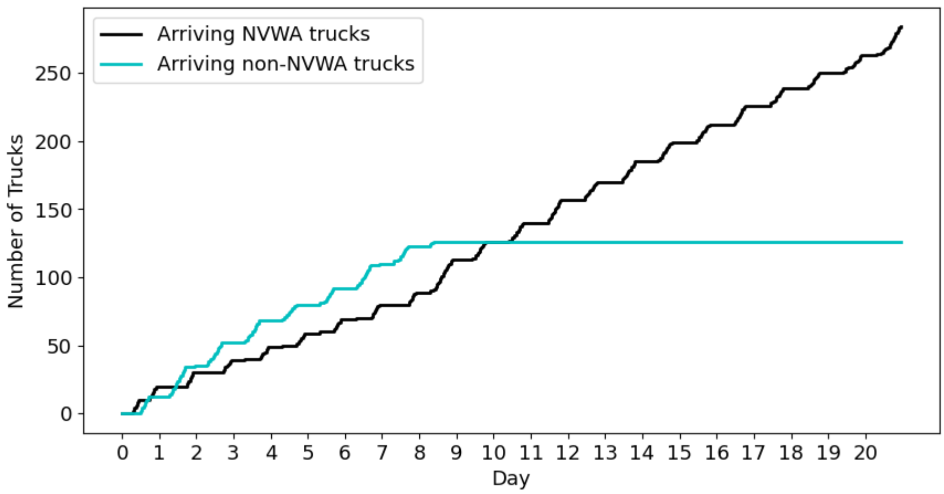
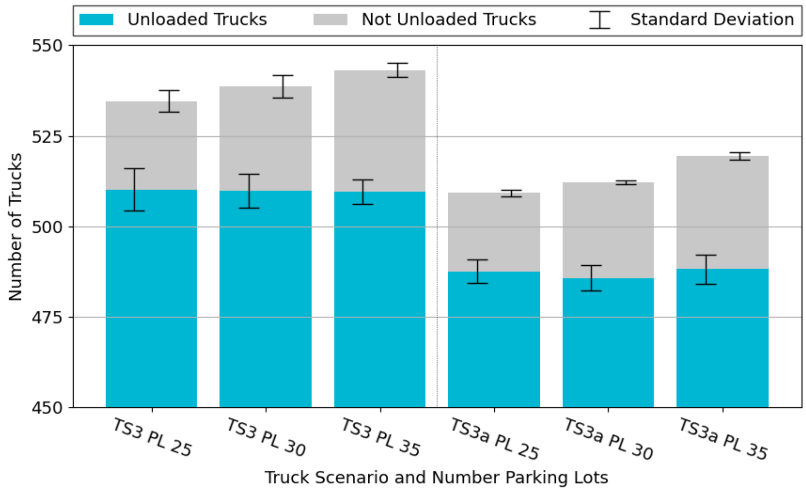
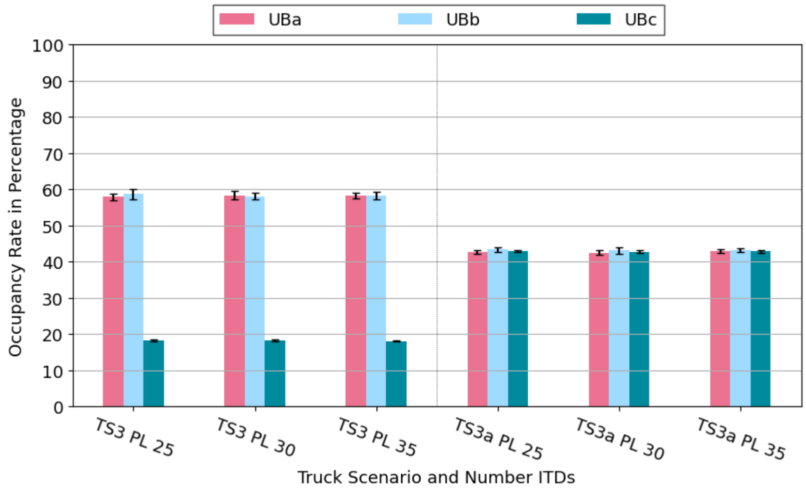


Figure D.12: Arrival of NVWA and non-NVWA Trucks - Truck Scenario 3, Design Alternative 2, 420 Generated Trucks

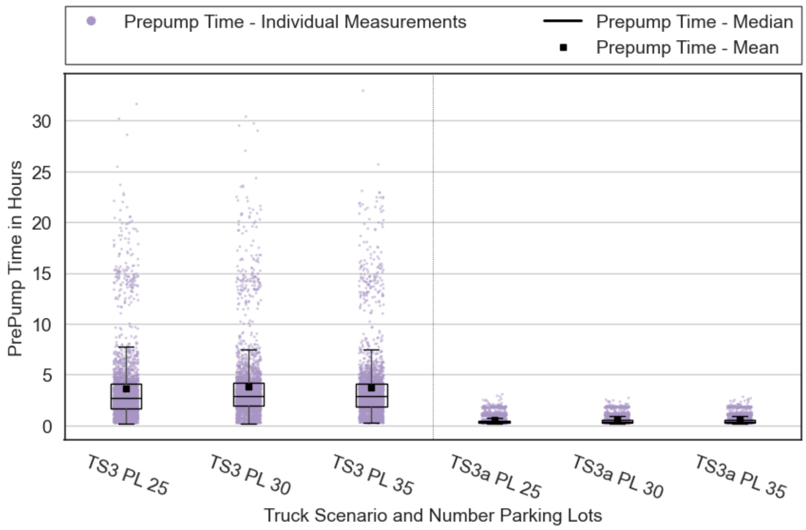
D.9. Additional Results Experiment 8



(a) Arrived Trucks, Divided into Unloaded and Not Unloaded Trucks



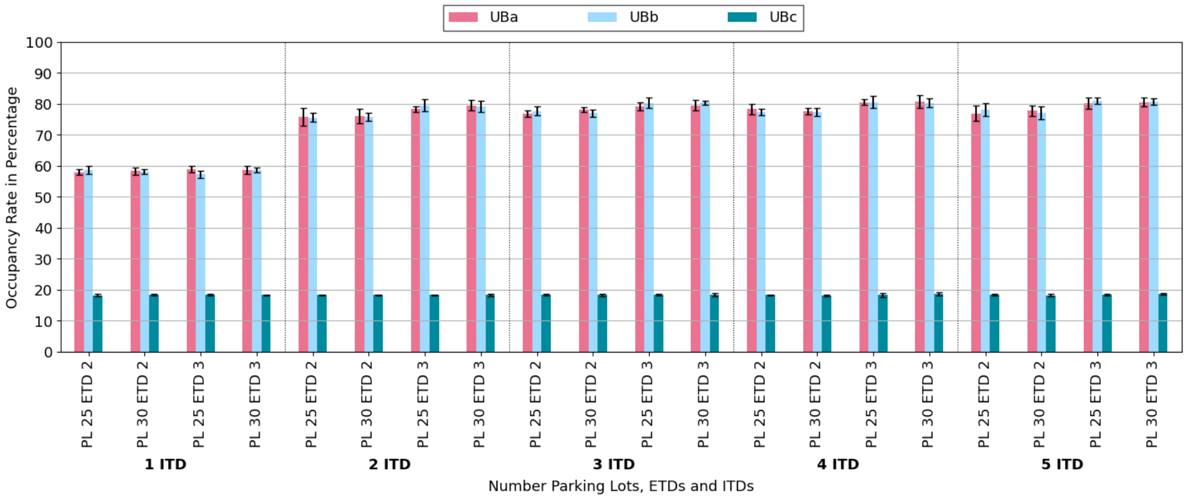
(b) Occupancy Rate Unloading Bays



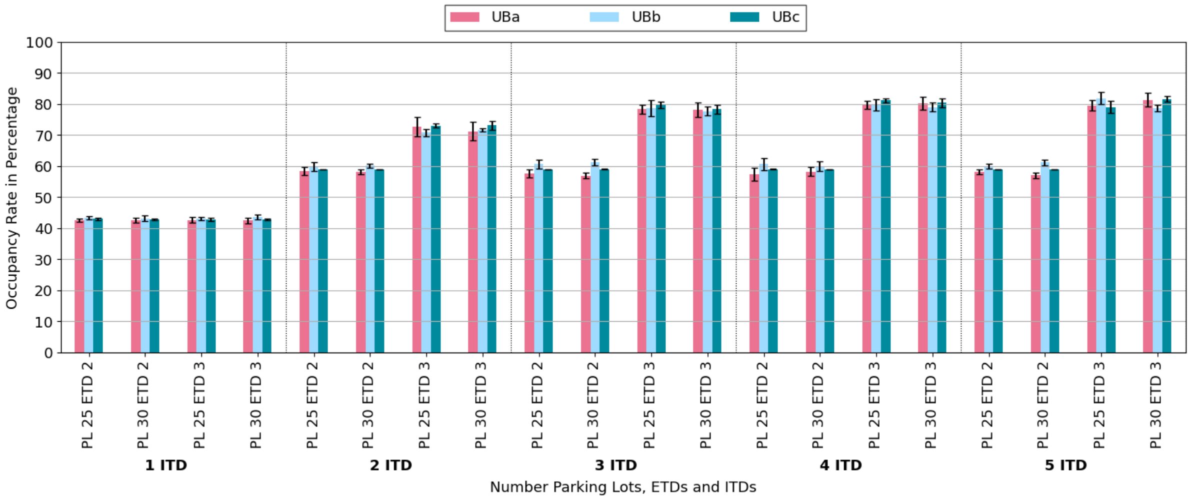
(c) Prepump Time

Figure D.13: Additional Results for Experiment 8

D.10. Additional Results Experiment 9

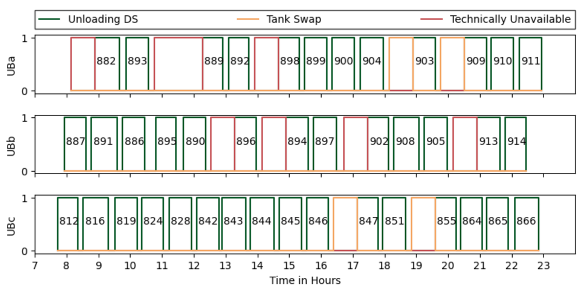


(a) Occupancy Rate Unloading Bays - Truck Scenario 3

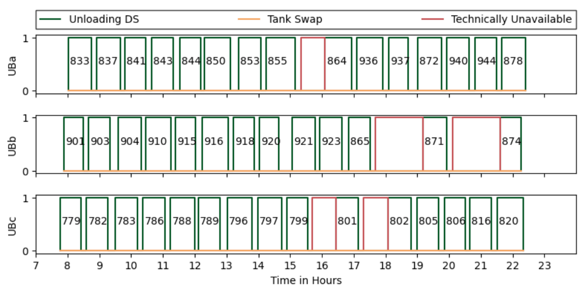


(b) Occupancy Rate Unloading Bays - Truck Scenario 3a

Figure D.14: Additional Results for Experiment 9



(a) Example 1 of Occupation Unloading Bays



(b) Example 2 of Occupation Unloading Bays

Figure D.15: Examples of Daily Occupation Unloading Bays - Truck Scenario 3a Design Alternative 2 Trucknumbers Annotated