Improving the Performance of Waste Handling Cranes by Optimisation-based Decision Rules

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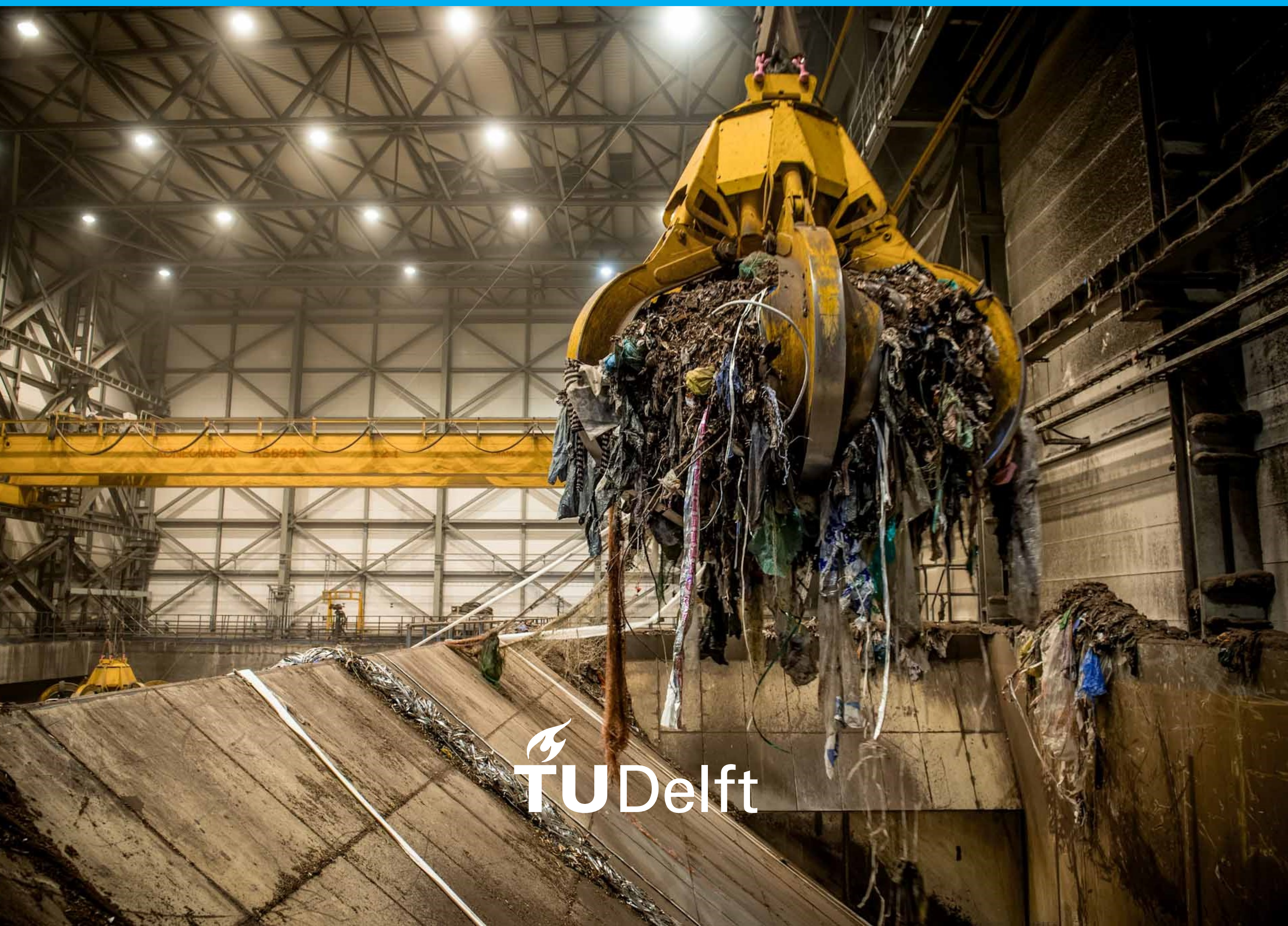

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by

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Abstract

Waste-to-energy is the process of generating energy from municipal waste. The most conventional energy recovery method is incineration, which takes place at a waste-to-energy plant. The incoming waste is collected in a bunker, where an overhead crane stacks and mixes the material before feeding it to the furnaces. The more homogeneous the waste reaches the furnaces, the more stable the incineration process. In automated mode, crane movements are controlled by the generation and execution of crane orders.

The waste crane scheduling problem is formulated as a mixed integer linear program, describing the scheduling of crane orders based on order characteristics such as type, origin and destination. The objective of the problem is to optimise the crane performance, which is interpreted as the minimisation of the total crane driving time while performing as many mixing orders as possible.

In the base model, simulated order schedules are resequenced. Given the type, origin and destination of the orders, the starting times are reconsidered. The obtained reductions in total driving time compared to the simulation model vary from 2% to 7%, depending on the crane strategy, whether stacking or mixing is allowed, and the maximum time between the generation and completion of feeding orders. Since the order types are given as input, the number of mixing orders is fixed.

In the extended model, the determination of the order characteristics is included in the scheduling process. Unfortunately, the size of the model increases so fast over time that 15 minutes proved to be the maximum length of a scheduling period for which a solution could be obtained. With a rolling horizon approximation, a stacking period of 10 hours has been scheduled.

Decision rules on the generation of orders are derived from the output of the optimisation models. These decision rules are implemented in the simulation model. The obtained results are assessed based on key performance indicators mainly related to the mix quality. The rules resulted in up to 35% more mixing orders, which translates into material being mixed more often, not necessarily in more material being mixed.

Preface

This thesis is my final work for the master Applied Mathematics at Delft University of Technology. It is the result of my graduation project, which I carried out at the Delft office of TBA Group. Though I only attended the office for 2.5 months due to the COVID-19 measures, I want to thank the simulation department for their hospitality and support. Especially, Manasse Hutte as my daily supervisor at TBA. Thank you for explaining and thinking along, in and outside our weekly catch-up meetings.

I also owe a big thanks to Theresia van Essen, my TU supervisor from the Optimisation group. Firstly, for pointing out TBA as a possibility for my graduation internship. Secondly, for the guidance and support over these months, in atypical times. Specifically, thank you for all the reading and (intermediate) feedback on my work.

To Dion Gijswijt and Eva Coplakova, thank you for being part of my thesis committee. I hope you find it an interesting and fun read.

Of course, this thesis could not have been realised without the advise and support from my family and friends. Thank you for, whether you could relate to my situation or not, being interested and invested in me and my project.

Nina Versluis
Delft, October 2020

Contents

Glossary

Term	**Description**
base model	MILP model in which scheduled orders are resequenced based on their characteristics to minimise driving time
bridge	part of crane moving horizontally along the rails
buffer time	time between release and due date of feeding order
completion time	time an order or job is completed
crane driving time	time crane is moving, i.e. handling and travelling
crane idle time	time crane is not driving
crane order	planned crane move
crane service area	bunker area where crane can be serviced
crane strategy period	time period in which a specific crane strategy is effective
crane working area	bunker area where crane is allowed to work
destination	end / drop location of order
drop zone	part of bunker along tipping bays
due date	time by which an order or job needs be completed
extended model	MIP model in which orders are generated and sequenced to minimise driving time and maximise mixing
feathering	dropping material while moving
feeding	moving waste from bunker to a hopper
feeding zone	bunker area where it is allowed to feed from
furnace	location where waste is incinerated
gantry	other word for bridge
handling time	time it takes to perform a crane order, i.e. to move from the origin to the destination of an order with loaded crane
hoist	part of crane moving vertically
hopper	location where mixed waste from the bunker is collected before incineration
incineration	waste-to-energy process involving the combustion of waste
integrality gap	relative difference between the upper and lower bounds on objective value
job	piece of work consisting of one or more tasks to be executed on one or more machines
mix/stack+feed strategy	mixing, except to drop zone, feeding and validating is allowed, stacking is not

mix+feed strategy	mixing, feeding and validating is allowed, stacking is not
mixed integer (linear) program	mathematical model in which an optimisation problem can be formulated (linearly)
mixing	moving waste around in the bunker
mixing zone	bunker area where it is allowed to mix to and/or from
order characteristics	type, origin, destination, start and completion time of an order
order generation	creating crane order with its characteristics
origin	start / pick-up location of order
processing time	time it takes to perform a job
quay crane scheduling problem	problem in which container / quay crane operations are sequenced
release date	time an order or job becomes available / is generated
scheduling problem	general problem in scheduling theory in which jobs have to be processed on machine(s)
sequence-dependent setup times	setup times that not only depend on the job, but also on preceding and/or succeeding job(s)
setup time	time it takes to setup a machine for a job
stack+feed strategy	stacking, feeding and validating is allowed, mixing is not
stacking	moving waste from drop zone further into the bunker
stacking zone	bunker area where it is allowed to stack to
storage zone	bunker area excluding drop zone
tipping bays	area next to bunker, from where trucks dump waste
total driving time gain	reduction in crane driving time obtained in base model instance
travelling time	time it takes to move to the origin of a crane order (from destination of preceding order) with unloaded crane
trolley	part of crane moving horizontally perpendicular to the rails
validating	checking waste level in the bunker
waste bunker	location where waste is collected, stored and mixed
waste crane	overhead crane mounted on rails at the bunker walls
waste crane scheduling problem	problem in which waste crane performance is optimised provided that waste-to-energy process continues
waste-to-energy	process of generating energy from municipal waste
yard crane scheduling problem	problem in which container yard crane operations are sequenced

Abbreviation	**Description**
ASRS	automatic storage and retrieval system
KPI	key performance indicator
MI(L)P	mixed integer (linear) program
(Q/W/Y)CSP	(quay/waste/yard) crane scheduling problem
SDST	sequence-dependent setup times
WTE	waste-to-energy

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Chapter 1

Introduction

Worldwide, population growth, urbanisation and rising living standards are the reality, with an increase in consumption as a consequence. The corresponding increase in the production of domestic and commercial waste puts a strain on waste management [1]. Specifically on landfilling, the traditional treatment of (non-recyclable) waste. The requirement of land and environmental issues such as the emission of methane gas contribute to the unsustainability of landfilling [2].

An alternative approach is waste-to-energy (WTE), the process of generating energy from municipal waste. WTE is considered to be a sustainable waste management method and the best after the front-end strategies to reduce, reuse and recycle waste [3]. This is supported by the vast reduction in waste volume (up to 90%) and the energy flow back to the municipality [4].

Throughout the world, several technologies to recover energy from waste are implemented. The most conventional methods are incineration, gasification, pyrolosis and anaerobic digestion. Each technology has its own field of application, e.g. incineration combusts dry waste, while anaerobic digestion is a natural process mainly applied on wet waste [2, 5, 6].

Incineration is the most established energy recovery method and is therefore the WTE process considered in this thesis. Therewith, the more general WTE is used interchangeably with incineration, as is often the case in the field of waste management [5, 6].

1.1 Waste-to-Energy

The waste incineration takes place in a WTE plant. The main parts of a WTE plant are the waste bunker, the incinerator furnaces, the generators and the flue. These parts are related to the four main stages of the WTE process, namely material process, combustion, power generation and environmental controls. An overview of the process is given in Figure 1.1.

The waste is delivered by garbage trucks, which dump their load into the waste bunker. Inside the bunker, the material is processed, i.e. collected, stored and mixed, before it is fed to the hoppers that lead to the furnaces. With the combustion of the waste in the incinerators, water is heated to generate steam. Subsequently, the steam is converted into electricity and heat by steam turbines and power generators. As part of environmental controls, the released gas is cleaned before emitted through the flue pipe. Also, metals are recovered and building materials, such as cement and asphalt, are supplemented from the bottom and fly ashes.

Inside the waste bunker, the material is handled by waste cranes. These overhead cranes consist of three parts: the bridge, the trolley and the hoist. The bridge (or gantry) is mounted

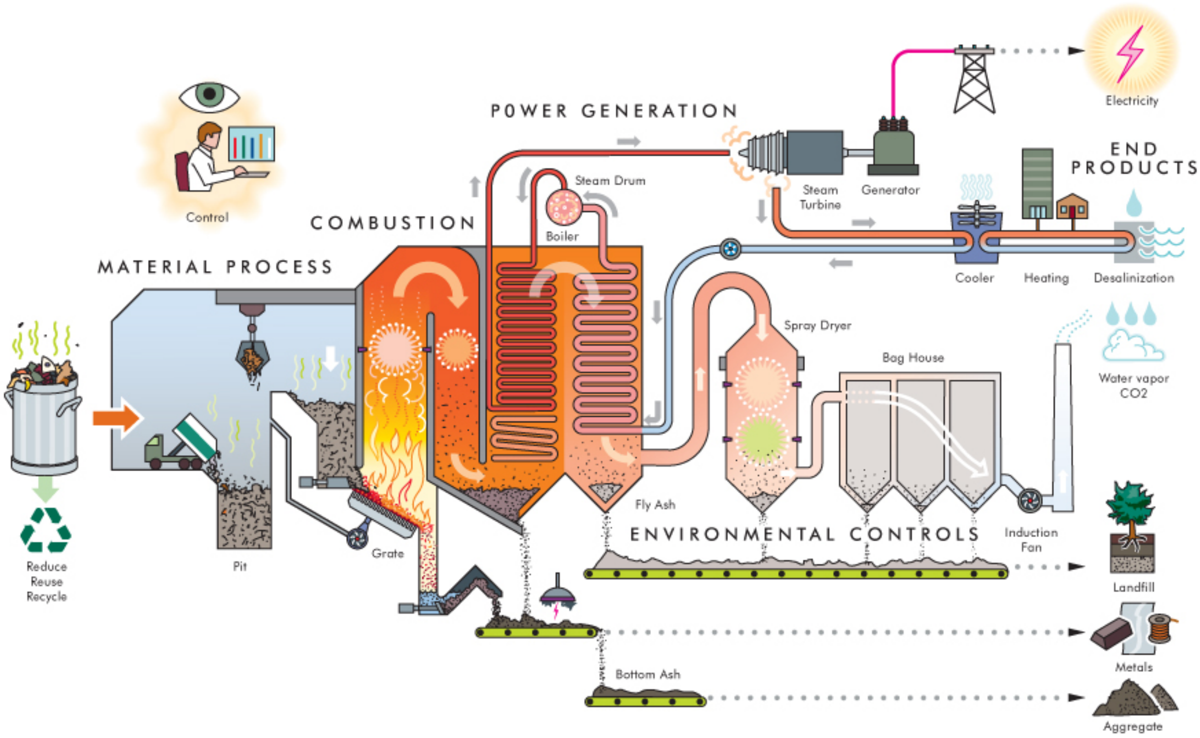


Figure 1.1: Overview of waste-to-energy process [4].

to the wall on both sides and moves along rails, the trolley moves over the bridge and the hoist, which includes the grab, hangs down from the trolley. Hence, each part moves in a distinct direction (forward-backward, left-right and up-down, respectively), making it possible to manoeuvre in three dimensions. In Figure 1.2, the crane parts with their moving direction are indicated.

Herewith, waste handling cranes can perform the different types of movements that are required in a waste bunker: feeding, stacking and mixing. During a feeding move, waste is transferred from the bunker to a hopper. For stacking, waste is moved from the drop zone to the storage zone further into the bunker. The waste is mixed by bringing waste from one spot to another inside the bunker. Figure 1.3 shows the different areas in and around the bunker.

Figure 1.2: Waste handling crane with bridge (1), trolley (2) and hoist (3) with their moving direction (adjusted from [7]).

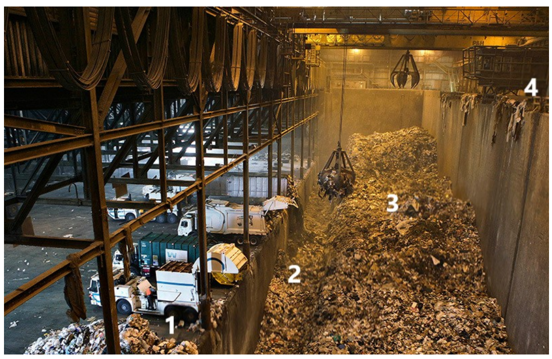


Figure 1.3: Waste bunker with tipping bays (1), drop zone (2), storage zone (3) and hoppers (4) (adjusted from [8]).

1.2 Scope and Outline

This thesis focuses on the performance of the waste handling crane within the WTE process. To answer the question *'In what way can optimisation-based decision rules improve waste crane performance?'*, an optimisation model describing the waste crane operations is formulated. From the outcomes of several computational experiments, an existing simulation model is complemented. The simulation model is under development at TBA Group, a company specialising in container terminal and warehousing operations.

In Chapter 2, the waste crane scheduling problem (WCSP) is introduced. After a specification of the context, the simulation model used as reference is described. Subsequently, related literature is discussed in Chapter 3, before mathematical formulations of the WCSP are given in Chapter 4. Firstly, in Section 4.1, a base model is formulated in which output from the referred simulation model is rescheduled. In Section 4.2, the model is extended to no longer require external input. In Chapters 5 and 6, the solution methods and experiments used to obtain results are discussed, after which the results are presented and decision rules derived. The effects of the established decision rules on the simulation model is reviewed in Chapter 7. The thesis is concluded with a discussion of the presented work and recommendations for further research in Chapter 8.

Chapter 2

Background

The essential operation of the WTE process is the incineration. Waste incineration is a 24/7 operation that is considered to be optimal when it is stable, i.e. with as little temperature fluctuation as possible, as this leads to a higher burning rate and cleaner process [9].

Important factors for stable combustion are the homogeneity and moisture of the waste as well as the feeding rate [9,10]. Although a large part of the performance of the furnaces does not depend on the cranes, these factors do relate to crane actions. Homogeneity of the waste can be accomplished by mixing the waste better, while the feeding rate relies on the constant delivery of waste from inside the bunker. The moist level of the waste can be diminished by letting the waste rest inside the bunker for a minimum number of days. However, it is also important to keep the waste moving, in order to prevent spontaneous fires.

2.1 Crane Movements

Between the feeding, stacking and mixing movements a crane performs, a clear difference in priority exists. The priority levels follow from the (implied) urgency of the move. Feeding moves are based on the amount of waste in store for the furnaces, which need a constant flow of waste. Therefore, feeding is prioritised. Stacking is related to the waste level in the drop zone, where high levels lead to tipping bay blockages. Hence, stacking moves come second. Although performing mixing moves is crucial for a good process, there is no necessity to perform a specific mixing move within a certain time window. This makes that both stacking and feeding come before mixing.

For a move, waste is picked up from an area in the bunker where it can, e.g. stacking moves can only start from the drop zone, and dropped on another position. Waste is typically dropped from a couple of meters above waste level, which can be done in two ways. Either all the material lands in an area of dimensions similar to the open grab, or it is feathered, i.e. dropped while moving the bridge and/or trolley, which results in better spreading of the material. Typically, the first type of dropping is done when stacking, while mixing moves often include feathering.

2.2 Bunker Layout

Waste bunkers come in different dimensions and layouts. The dimensions of the bunker are related to the number of hoppers, which determines the required capacity, and the number of tipping bays. An example of a typical bunker layout is shown in Figure 2.1. Herein, the tipping bays are located on the long side (above) and the hoppers are situated across the bunker on the other long side (below). Other possibilities are that the tipping bays are situated on the long side and the hopper(s) on the short side, or vice versa, or that the bunker area consists of separate bunkers.

Depending on the bunker dimensions, several, typically one or two, waste cranes handle the material in the bunker. If two or more cranes are operating in the bunker, they can have their own dedicated working area, or work in non-specified areas that might overlap. In the latter case, the cranes can move almost everywhere, taking into account a minimum distance between the cranes of approximately one meter and the fact that cranes cannot overtake each other. These restrictions follow from the way the cranes are mounted, which usually is on the same rails, as is also the case in Figure 1.2.

In general, waste bunkers feature an extra crane as backup. To minimise the probability of crane failure, the cranes are only in service for a certain period of time, e.g. a week, after which they are out of service to undergo maintenance if necessary. When out of service, the cranes are stationed in crane service areas, while staying mounted on the rails. As Figure 2.1 shows for a bunker with three cranes, the outer cranes can be serviced outside the bunker, while the middle crane is stationed above the bunker. This leaves the middle part of the bunker unreachable when the middle crane is out of service.

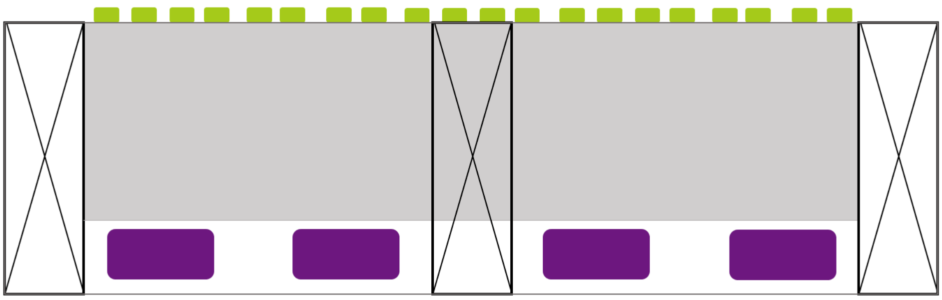


Figure 2.1: Layout of bunker (grey), with tipping bays (green) and hoppers (purple). Black rectangles indicate the crane service areas.

2.3 Automatic Crane Operations

Waste handling cranes can be operated in various modes: manual, semi-automated and automated. Night operations are often fully automated, while some sites use manual operators during daytime. For an automatic crane system, explicit information is required. For example, when which crane is available and what its working area is, as well as the areas to mix to and feed from [9]. When multiple cranes are operative simultaneously, tipping bays and hoppers are assigned to a specific crane, such that only one crane will work on it. In the bunker itself, an overlap in the crane working areas can exist.

In automatic setting, the crane movement is controlled by the generation of orders for feeding, stacking and mixing. The different types of orders are generated based on their priority level and bunker zones, as for each period of time feeding, stacking and mixing zones are specified to indicate from where waste may be picked up and where it can be dropped. For example, feeding orders are typically generated when the waste inside a hopper drops below a certain level, and executed as soon as possible.

In generating crane orders, the level of the waste material in the bunker plays an important role. In general, the origin and destination of moves are generated as stated in Table 2.1. However, with respect to the waste levels, manual mode has a large benefit over automated mode. Manual moves can be very short, as crane drivers actually see the waste levels. In automated mode, the exact material levels are unknown. With variable grab sizes, tumbling and compression of the waste, knowing where waste is picked up and dropped is not enough.

Therefore, an additional feature is required to keep track of the exact waste levels. Validating moves are an example of such an additional feature. With these moves, the waste level at a certain point in the bunker is measured by letting the hoist drop down until it touches waste. Validating orders are performed after a specific number of drops at the same spot. Another solution is the installation of lasers into the bunker area. This is, however, an attribute that is seldom installed because of the expenses.

Order Type	Origin	Destination
feeding	highest point in feeding zone	hopper drop spot which generated the order
stacking	highest point in dropping zone	lowest point in stacking zone
mixing	highest point in mixing zone	lowest point in mixing zone

Table 2.1: Example rules to determine origin and destination per order type.

2.4 Simulation Model

TBA Group has developed a WTE simulation model within their TIMESquare simulation library. This tool simulates container (and bulk) terminal operations on a detailed level. Based on an exemplary WTE plant, the simulation model is explained. Figure 2.2 shows the two-dimensional visualisation of the modelled bunker area.

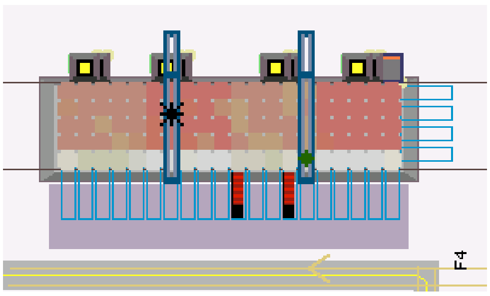


Figure 2.2: Still of two-dimensional visualisation of bunker area.

The 100 x 25 x 39 m waste bunker is modelled as a 20 x 5 grid, where each grid square of 5 x 5 m has a certain (waste level) height. The bunker is divided into three zones: the drop zone, the stacking zone and the feeding zone. The drop zone runs along the tipping bays and is one square deep. The rest of the bunker is divided into four areas of 4 by 5 squares, which are alternately assigned for stacking and feeding. Figure 2.3 shows a possible configuration.

Depending on the time of the day, different crane strategies are operative. Three basic strategies are modelled: ‘stack+feed’, ‘mix+feed’ and ‘mix/stack+feed’. In the first strategy period, during and leading up to the opening hours, only stacking moves are performed besides the continuous feeding. After opening hours, when the mix+feed strategy is effective, mixing moves are performed on the storage stack including the adjacent drop zone grids, and no stacking is done. In the early morning, mixing moves are no longer performed to the drop zone. During the mix/stack+feed' strategy period, mixing from the drop zone is still allowed, which can be viewed as stacking moves, beside the mixing within the stacking zone.

Each day, after a cycle through the strategies, the assignment of stacking and feeding areas is reversed. So the stacking zones of one day, are the feeding zones for the next day, and vice versa.

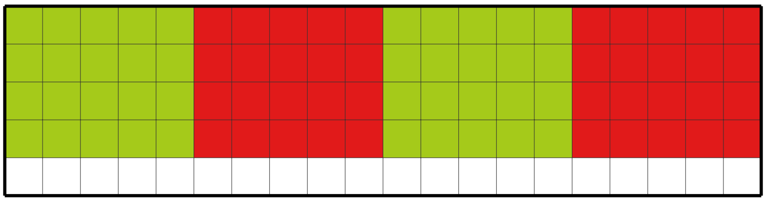


Figure 2.3: Grid of bunker with drop zone (white), stacking zones (green) and feeding zones (red).

Trucks, Hoppers and Orders

The arrivals of dump trucks are modelled based on given hour and day arrival patterns with a fixed, but slightly varying, number of trucks arriving each week. Trucks are assigned to a random tipping bay (one out of the twenty), but with preference for bays adjacent to a stacking area. The amount of waste (in tonnes) a truck delivers, is modelled by a uniform probability distribution on the interval [15,25]. The full load is assumed to land in the adjacent grid square, during a dumping time (in minutes) drawn from the discrete uniform probability distribution on [10, 20].

Hoppers and their corresponding furnace are seen as one object. Each hopper has two drop spots, which are modelled as separate furnaces. The waste level in each hopper is updated during the continuous burning process. This process is characterised by the burning speed, which is distributed according to a uniform distribution. Whenever the waste level drops below the set threshold, a feeding order is generated for the specific drop spot.

Non-feeding crane orders are generated at the moment a crane is done with a previous order. A validation order for a specific grid is requested if the previous stacking or mixing move was the fifth to end on that grid since the last validation. Stacking and mixing moves are generated when the crane becomes idle, so only if there are no validation moves or feeding moves requested earlier.

All orders but validation orders include an origin and destination, as described in Table 2.1. Feeding moves always start from a feeding stack and end in a hopper. Stacking moves go from the drop zone to a stacking zone, while mixing moves both start and end in the mixing zone. The mixing zone includes the stacking zone and, depending on the operative strategy, the adjacent drop zone grids. Note that the locations of an order lie within the same bunker half.

Cranes

The model features three cranes. At any moment, two cranes are in service, while the third is in maintenance. Each crane operates two weeks, after which it is a week out of service. The active cranes both cover half the bunker: a stacking zone, a feeding zone and the adjacent drop zone grids and hoppers. In the middle of the bunker, the cranes can block each other, as a minimum distance of two grids is required. Moreover, as the cranes are assumed to be mounted on the same rail, four grids in the middle of the bunker cannot be reached when the middle crane is out of service. Figure 2.4 shows the consequences for the stacking and feeding zones.

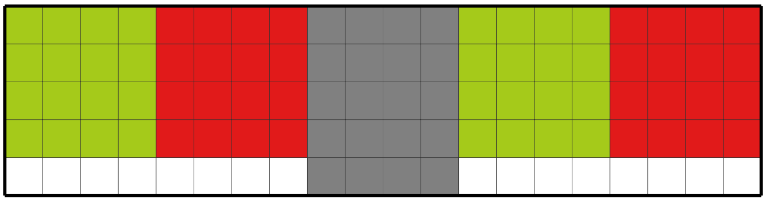


Figure 2.4: Grid of bunker when middle crane in service, with drop zone (white), stacking zones (green) and feeding zones (red) and closed area (grey).

The exact crane movements, within performing the four types of orders, are based on the crane specifications. This comprises the maximum speed and acceleration of each of the three parts, but also the grab closing and opening times and the (maximum) grab content. The grab content is expressed in number of waste pieces and follows a probability distribution based on order type. The normal distributions, which are truncated at 0 and twice the mean, have the same mean, but the standard deviation depends on the order type. The differences in variation are mainly derived from the differences in waste density and waste mixture. Waste that is being stacked is newly delivered, so minimally compressed and not mixed, while waste that is being fed has been compressed and mixed, resulting in more homogeneous waste. Content is assumed to be grabbed and released at the centre of a grid slot.

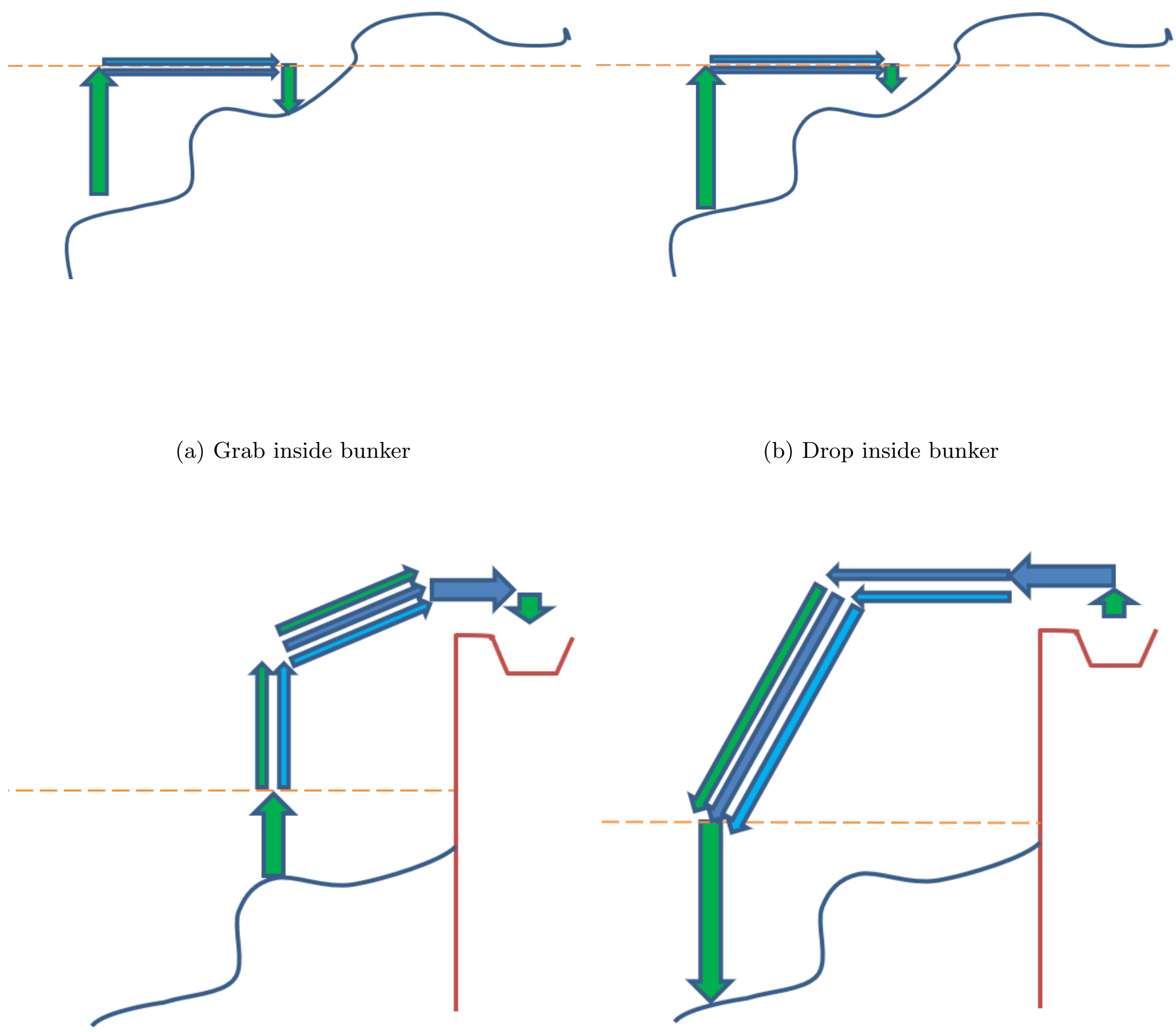
The route of the crane during an order execution is determined by the following driving strategy. The maximum waste level in the rectangle, generated by the (x and y components of the) origin and destination of the move, is used as reference height. The trolley and bridge only move when the hoist is above the driving height, which is set at three meters or more above the reference height, or five meters above pick up or drop level. During the rest of the route, the three crane parts can move simultaneously. Dropping of the waste is done at five meters above waste level.

Four types of driving moves are shown in Figure 2.5. For a grab inside the bunker, the hoist lifts to the driving height, whereafter the trolley and bridge move to the pick up grid and subsequently the hoist lowers to waste level. A drop inside the bunker goes similarly, but the hoist only lowers to five meter above the waste level of the drop grid. To move to the hopper, the hoist lifts up to the driving height, where the bridge starts moving while hoisting is continued. When the trolley can continuously move to hopper, it starts to move, after which the hoist is lowered into the hopper. Moving from the hopper starts with lifting up the hoist, whereafter the trolley starts moving and, as soon as the hoist is above the bunker, the bridge starts gantrying. When the hoist can continuously lower down, it starts to do so.

2.5 Waste Crane Scheduling Problem

In the waste crane scheduling problem (WSCP), crane orders are scheduled per operational crane such that the WTE process can continue. The two main aspects of the WCSP are order sequencing and order generation.

The sequencing of the orders is based on the order characteristics, i.e. type, origin, destination, handling and travelling time, which are determined with the generation of orders. The (combinations of) order characteristics are based on the external processes of waste delivery and



(a) Grab inside bunker

(b) Drop inside bunker

(c) To hopper

(d) From hopper

Figure 2.5: Crane driving moves with hoist (green), bridge (light blue), trolley (dark blue) and driving height (dashed line).

waste incineration as well as the waste levels.

The handling time represents the time it takes to move waste within an order, i.e. the time the crane needs to drive loaded from the origin to the destination of the order. The travelling time indicates the driving time in between two orders, i.e. the time to move empty from the destination of one order to the origin of the next. The crane driving time comprises the handling and travelling times of all orders within a strategy period, and therewith depends on the generated locations of the orders.

The objective of the WCSP is to optimise the crane performance. Although the crane performance can be interpreted as the crane's mechanical specifications, here, it is explained as the quality of the crane operations with respect to the crane and the WTE process.

An important aspect of the crane performance is the power consumption, which is related to the travel distances and therewith to driving times. Hence, minimising crane driving times would contribute to the improvement of crane performance. Moreover, reducing driving distances increases the lifetime of the cranes.

For the process, however, the focus lies on the number and type of orders being handled. While feeding and stacking are required for the continuation of the WTE process, mixing is only done when neither feeding nor stacking is necessary. Albeit a low priority level, mixing is key in the quality of the WTE process as the more homogeneous the waste reaches the hoppers, the more stable the incineration. Therefore, mixing is included in the objective of the WCSP.

The two aspects of minimising crane driving times and maximising the number of performed mixing orders go hand in hand. When minimising the handling and travelling times of scheduled orders, e.g. prompted stacking and feeding orders, time is cleared for additional mixing orders.

Chapter 3

Related Work

To the best of our knowledge, waste crane scheduling has only been considered by Mackin and Fujiyoshi [9]. The main focus of their research is the homogeneity level of the waste reaching the incinerator. The waste homogeneity is quantified by the waste mix value, which indicates the number of times a piece of waste has been moved. Another point of focus is the surface levelling. During the operations, the maximum height difference of adjacent stacks is set at five meters. Moreover, the goal is to finish the scheduling period with a surface as flat as possible. Hence, the objective is to increase the waste mix value uniformly and to level the surface, while keeping the drop zone clear and the hoppers fed.

The authors propose a genetic algorithm for the scheduling of crane operations, which was tested in a WTE plant during weekend nights. Compared to data of manual operations, the number of occurrences of the favoured mix value increased and the variation in mix values was diminished, resulting in a more constant homogeneity level. However, with the reduction in variation and therewith of high waste mix values, the average mix value of the incinerated waste was more than twice as small as when manually operated.

With only one paper available on waste crane scheduling, it is necessary to look broader into literature. On one hand, the waste crane scheduling problem can be seen as a variation of the general crane scheduling problem. On the other hand, the problem can be related to scheduling theory. Literature on crane scheduling and sequencing is reviewed in Section 3.1 and Section 3.2, respectively.

In Table 3.1, waste crane scheduling terms are related to general scheduling terms. In scheduling theory, jobs have to be processed on machines. Analogously, in waste crane scheduling, orders have to be handled by cranes. Moreover, the setup time, the time it takes to switch

Waste Crane Scheduling	Scheduling Theory
crane	machine
order	job
due date	due date
release date	release date
handling time	processing time
travelling time	setup time
completion time	completion time

Table 3.1: Terms in waste crane scheduling and related terms in scheduling theory.

from the processing of one job to the processing of the next, can be related to the travelling time, the time it takes the crane to move from one order to the next.

3.1 Crane Scheduling

In 1981, Lieberman and Turksen [11] published the first paper on crane scheduling. Since the mid-2000s, the crane scheduling problem (CSP) is studied more extensively, mostly in the context of the following three fields of application: container terminals, e.g. [12–18], warehouses, e.g. [19–21], and production, e.g. [22–24].

Crane scheduling is related to the research areas of queueing theory and machine scheduling [16]. It can be subdivided into crane assignment and request sequencing [21]. Therewith, the challenge is to assign and schedule jobs, while, typically, maximising the throughput or minimising the waiting time.

The CSP can be studied in two different states: static (offline) or dynamic (online/real-time). In the static problem, the release dates of the jobs are known beforehand. In this offline case, a mixed integer program (MIP) of the problem can be formulated and solved to optimality [15, 16, 21, 22]. When jobs/orders only become known at their release date, the problem is dynamic. In this case, (incomplete) branch-and-bound methods or principle-based (decision rules) algorithms are used to find a solution [11, 16, 22].

3.1.1 Container Terminals

At container terminals, (at least) two types of cranes are operative: quay cranes and yard cranes. The cranes have a crucial role in the flow of containers at a terminal. A typical container flow is depicted in Figure 3.1. Vessels arrive at the berth, where quay cranes unload the containers onto trucks or automated guided vehicles. The containers are transported to the storage yard, where yard cranes unload the container into the yard. If containers are to be further transported over land, yard cranes also load containers to trucks in the transfer area on the landside. Otherwise, the containers traverse the inbound route in opposite direction to be loaded unto an outbound vessel.

In the quay crane scheduling problem (QCSP), a sequence of (un)loading tasks to be performed by a fixed number of quay cranes has to be determined. The available quay cranes are distributed over the berth to serve docked ship(s). A vessel can be unloaded by multiple cranes, but, generally, a crane is assigned to a specific vessel as long as it is (un)loading. The quay cranes are mounted on a rail parallel to the quay, which results in the impossibility of overtaking and a minimum safety distance [12]. Generally, the objective of the QCSP is to minimise the total

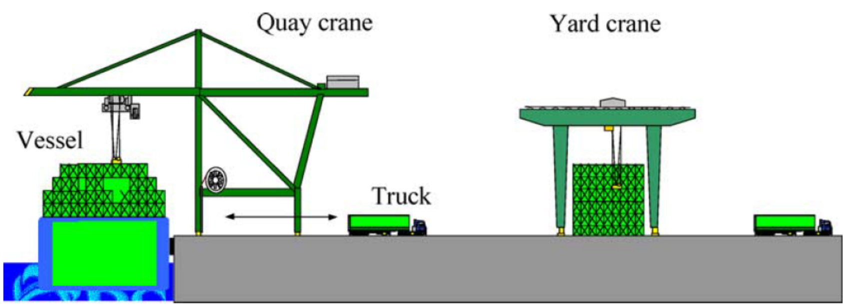


Figure 3.1: Quay and yard crane in container terminal flow [15].

completion time of the operations [13, 14]. This is in line with the terminal's goal to minimise the vessel waiting times [15].

For the (static) QCSP, various heuristics and exact algorithms have been proposed to solve the problem [15]. For example, Al-Dhaheri and Diabat [14] present a mixed integer program (MIP) formulation for the problem, like Daganzo [16] did in a first consideration of the crane scheduling problem.

In the yard crane scheduling problem (YCSP), the operations required in the storage yard are sequenced. These crane operations comprise the retrieving and delivering of containers from and to (seaside and landside) transfer areas, as well as shuffling moves, if necessary. A container yard is divided into zones, with each zone featuring one or two cranes, typically. When two cranes are employed in the same area, the movement restrictions depend on the sizes and types of cranes. E.g., rail-mounted cranes with the same width cannot overtake each other, while they can if they are mounted on rails of different width.

For the YCSP, an MIP can be formulated with objectives such as minimising delayed work, the (job) waiting times or the maximum completion time [15,17]. In general, yard crane scheduling is about maximising the throughput. In the case of different release dates of the jobs, a single machine and the objective to minimise the total completion time, the problem is NP-complete.

3.1.2 Warehouses

In warehouses, products are stored in large storage areas. Automatic storage and retrieval systems (ASRSs) often perform the tasks to store and retrieve the products that arrive or are requested. Important components of an ASRS are the racks, structures wherein products are stored; cranes, that move, pick up and drop off loads; aisles, the space between racks where the crane can move; and the input/output points, from where and whereto the products are moved by the crane [19].

Typically, one crane is employed in each aisle. In that case, it comes down to a single-machine scheduling problem. Boysen and Stephan [20] classified single-crane ASRS scheduling problems based on varying layouts and characteristics, as well as different objectives. Besides the traditional objectives of minimising the makespan or the tardiness of the storage and retrieval jobs, the minimisation of the crane's (empty) travel distance can also be a valid objective [20].

The scheduling problem of warehouse cranes is often seen as a composition of two optimisation problems: the local assignment problem and the crane scheduling problem, which are generally solved sequentially.

The sequencing of the ASRS requests is comparable to a special case of the travelling salesman problem (TSP). While the TSP is a strongly NP-hard problem, some ASRS crane scheduling instances are polynomial solvable. This mainly depends on their objective function. For example, when considering total tardiness or the weighted number of late jobs, the problem is NP-hard [20]. When the objective is set to the minimisation of the travel time, only the empty crane travel is to be considered as loaded travel is constant. In this case, the problem's solution can be derived from the results of the corresponding transportation problem [20]. More specifically, travel time models have been studied for single-crane instances [19].

Among the considered solution methods are MI(L)P formulations and heuristics such as local search, priority rules and genetic algorithms [19–21].

3.1.3 Production Lines

In production, hoisting cranes are used to transfer products from one machine in the production line to another. The hoists move on one track above the machines and, therefore, cannot overtake each other. A typical example is the production of circuit boards, where cranes carry jobs from one chemical processing tank to the next [22, 23]. Figure 3.2 shows the setup of a circuit board assembly line.

Scheduling in a production line can be considered as a flow-shop problem with setup times from the crane actions required in between the process of operations [22]. In general, the jobs (or their operations) have different release and due dates, while they have comparable processing times and have to follow the same route determined by the machines.

Typically, the objective in hoist scheduling is to maximise the throughput [22, 23]. In case a cyclic schedule is required, e.g. per day, maximising the throughput corresponds with the minimisation of the cycle time. The hoist scheduling problem belongs to the class of strongly NP-hard problems [24].

Cyclic scheduling problems can be formulated as MIPs and exact solutions can be obtained by branch-and-bound methods [22]. Another way to study the CSP is through simulation based on heuristics. Thesen and Lei [23] propose a scheduling system based on heuristic decision rules, while Ge and Yih [22] developed a heuristic algorithm derived from insights obtained by a mathematical programming formulation.

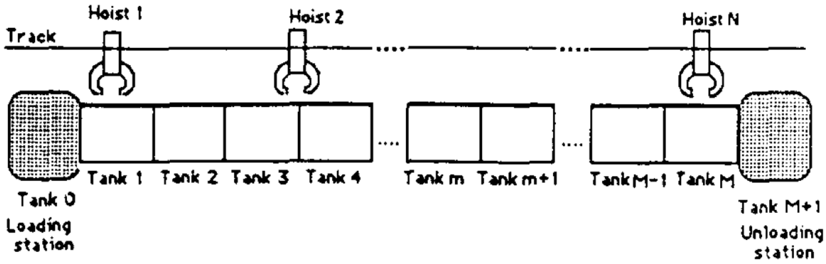


Figure 3.2: Hoist cranes in a circuit board production line [23].

3.2 Sequencing

From both the description of the WCSP in Chapter 2 and the other instances of the general CSP mentioned in Section 3.1, it is clear that the CSP mainly involves sequencing.

In scheduling theory, sequencing problems are scheduling problems in which the order of the to be processed jobs is to be determined [25, 26]. With single-machine scheduling, the TSP and precedence-constrained machine scheduling among its instances, sequencing problems are one of the most intensively studied problems in combinatorial optimisation [25]. This comparison also shows that sequencing problems are NP-hard.

In literature, setup times have been frequently considered negligible, or considered as part of the processing times. However, in real-life, setup times are often important and required to be taken into account separately [27, 28].

Scheduling with separable setup times can be split into two categories: problems with sequence-independent setup times and problems with sequence-dependent setup times [27]. In the first type of scheduling problems, the time to setup a machine only depends on the job to be processed next, while the second category comprises problems in which the setup time depends on both the job to be processed and the preceding job.

Typically, scheduling problems with sequence-dependent setup times (SDST) are modelled, for example as a MIP, to minimise the maximum completion time or tardiness if due dates are included [25,28]. Sequencing problems with SDST are both solved exactly and approximated by solving techniques such as heuristics, including genetic algorithms, and branch-and-bound [28].

3.3 Contributions

The WCSP is a real-life problem that has barely received attention in scientific literature. This in contrast with other aspects of WTE, such as the incineration process and environmental impact, which are researched in chemical and environmental science.

The related subjects of crane scheduling and sequencing have been studied more extensively. The relevance of these research areas is supported by the central subject of scheduling orders that are generated based on external supply and demand processes, for handling by cranes or machines.

A discrepancy between general crane scheduling and waste crane scheduling lies in the view on the handled material. Containers and products are considered as individual items, generally, with a fixed route and/or delivery time. In waste crane scheduling, the individual waste pieces are not relevant. The pieces are as good as interchangeable, and the smallest material unit is a crane grab. Hence, on individual level, waste pieces do not have a route or side constraints to adhere to.

The most important point of contrast is related to waste homogeneity and mixing. Mixing in itself is comparable to shuffling in crane scheduling, e.g. housekeeping in container yards or pre-sorting in ASRSs. However, the function of mixing, improving the waste homogeneity, proves to be rather unique. In general, shuffling is minimised in optimisation models, while mixing is an essential aspect of the WCSP.

The one paper on waste crane scheduling does focus on the homogeneity level of the waste. The proposed waste crane scheduler uses a genetic algorithm in which waste mix management is prioritised. The research, however, mainly focused on the practical side. The applied approach is described, but no (mathematical) model is formulated.

The main contribution of this thesis is the mathematical modelling of the waste handling crane operations as part of the WTE process. For the case of one operational crane, an exact MIP is formulated. Additionally, a first step in solving the linearisation of the model is taken. Also, from the obtained results, decision rules on the generation of orders are derived to complement a WTE simulation model.

Chapter 4

Modelling

In the modelling of the WCSP, the two focus points are order scheduling and order generation. In scheduling, the sequence of the crane orders and the start and completion times are determined based on the order characteristics. The characteristics, such as order type, origin, destination, handling and travelling time, are determined with the generation of the orders.

In Section 4.1, a base case of the WCSP is modelled. In this base model, the orders are not generated within the model. Instead, the orders and their characteristics are assumed to be known beforehand. Hence, by solving the model, a given list of orders is rescheduled.

Subsequently, the order generation is included into the model. With the order characteristics included as variables instead of parameters and the resulting interaction between sequencing and generation, the model becomes more dynamic. This model extension is described in Section 4.2.

The models are formulated as mixed integer programs (MIP), which is common for (crane) scheduling problems (see Chapter 3). In both models, only the case of one operational crane is considered.

4.1 Base Model

In the base case of the WCSP, a list of crane orders for one crane is rescheduled based on the order characteristics. These characteristics include order type, origin and destination. With the orders and their characteristics known beforehand, the focus lies on the crane driving times.

The (re)scheduling of the crane orders is formulated as a mixed integer linear program (MILP). The model assumptions are listed below. These are among the most significant assumptions for scheduling problems with sequence-dependent setup times [28].

- All orders have to be executed.
- No cancellation: each order has to be handled until completion.
- No preemption: each order, once started, has to be completed before another order can be handled by that crane.
- Handling times are independent of the schedule.
- Travelling times are dependent of the schedule.
- The crane may be idle.
- The crane can handle at most one order at a time.

- The crane is always available (there are no breakdowns).

4.1.1 Components

In this section, the required input parameters and the variables to obtain the output of the model are specified. First of all, let n be the number of orders, and $J = \{1, ..., n\}$ the set containing them. Each order $j \in J$ is of a specific type, i.e. feeding, stacking, mixing or validating. Hence, set J can be partitioned into set J^f of feeding orders, set J^s of stacking orders, set J^m of mixing orders, and set J^v of validating orders.

The first parameter of the model is $M \in \mathbb{R}_+$, a large positive number. The second parameter is only related to the feeding orders. Feeding orders have a hard deadline, its due date, before which they have to be completed. Therefore, buffer time $b \in \mathbb{R}_+$ is introduced, which indicates how much time is allowed between the release and due date of a feeding order.

The other parameters represent the order characteristics given as input. Each order $j \in J$ has a release date $q_j \in \mathbb{R}_+$ and a handling time $h_j \in \mathbb{R}_+$. The handling time of an order is directly derived from its origin and destination as it represents the time the crane needs to move loaded from pickup to drop. All components (x, y and z) of the origins and destinations are provided by the input schedule. Note that the z-component, the waste level, depends on the sequencing of the orders with the same (x,y) origin or destination. Hence, the input waste height should be considered an approximation. This note on the waste level is also relevant for the travelling times between the orders: $t_{ij} \in \mathbb{R}_+$ represents the time it takes the crane to move empty from the destination of order $i \in J$ to the origin of order $j \in J$. Note that t_{ij} is not necessarily equal to t_{ji}, and that the travelling time to the first scheduled order is neglected.

The last parameters are related to the number of available, i.e., released and not yet completed, orders. For stacking and mixing orders, $n_p \in \mathbb{N}$ represents the number of orders of the same type that is available at the same time. Subsequently, for each order $j \in J$, order $p_j \in J$ is defined such that j is the n_p^{th} order of the same type after p_j, with respect to the ordering from the input data. So, if p_j is the first stacking order, then j is the $(n_p + 1)^{\text{th}}$ stacking order.

The model variables are divided into decision variables and auxiliary variables. The binary decision variables f_j, l_j and x_{ij} with $i, j \in J$ determine the sequencing order. If f_j $(l_j) = 1$, then order $j \in J$ is the first (last) order in the sequence. Variable x_{ij} takes value 1 if order $j \in J$ is scheduled directly after order $i \in J$, and 0 otherwise.

Decision variable $c_j \in \mathbb{R}_+$ represents the completion time of order $j \in J$. The value of the variable represents the time at which the corresponding order has been fully executed, i.e. the crane has dropped the waste at the destination.

The auxiliary variables represent the release dates. The release date $r_j \in \mathbb{R}_+$ of order $j \in J$ follows from the original release date q_j and the (variable) completion dates of other orders. For feeding orders, the release dates stay the same, while for stacking, mixing and validating orders the release date becomes dependent on the completion date of related orders: p_j, if $j \in J^s \cup J^m$, and $j - 1$, if $j \in J^v$.

In Table 4.1, the model components are summarised.

4.1.2 Constraints

The constraints of the MIP are given in Equations (4.1) to (4.11).

Firstly, the binary decision variables are defined correctly. Constraints (4.1) and (4.2) enforce that exactly one order is scheduled as the first order and exactly one order is scheduled as the

Sets

$J = \{1, .., n\}$	set of orders
$J^f \subset J$	subset containing feeding orders
$J^s \subset J$	subset containing stacking orders
$J^m \subset J$	subset containing mixing orders
$J^v \subset J$	subset containing validating orders

Parameters

$M \in \mathbb{R}_+$	large positive number
$b \in \mathbb{R}_+$	time between due date and release date feeding orders
$q_j \in \mathbb{R}_+$	original release date order $j \in J$
$h_j \in \mathbb{R}_+$	handling time of order $j \in J$
$t_{ij} \in \mathbb{R}_+$	travelling time from order $i \in J$ to order $j \in J$
$n_p \in \mathbb{N}$	number of stacking or mixing orders that is available at the same time
$p_j \in J$	order for which order $j \in J^s \cup J^m$ is the n_p^{th} order of same type w.r.t. original ordering

Decision Variables

$f_j \in \{0, 1\}$	1 if order $j \in J$ is scheduled as first order, 0 otherwise
$l_j \in \{0, 1\}$	1 if order $j \in J$ is scheduled as last order, 0 otherwise
$x_{ij} \in \{0, 1\}$	1 if order $j \in J$ is scheduled directly after order $i \in J$, 0 otherwise
$c_j \in \mathbb{R}_+$	completion time of order $j \in J$

Auxiliary Variables

$r_j \in \mathbb{R}_+$	release date of order $j \in J$

Table 4.1: Base model components.

last order. Also, an order is either the first (last) or it has a predecessor (successor), as constraint set (4.3) ((4.4)) implies.

Subsequently, the relations of the auxiliary variables are set by constraint sets (4.5) to (4.7). For the release dates, it is assumed that J is sorted non-decreasingly based on q_j, the release dates obtained from the input. The release date of a feeding order, r_j with $j \in J^f$, is directly obtained from the input data as it is set equal to the original release date q_j. For stacking order $j \in J^s$, the release date is set to equal the completion time of order p_j, the order for which j is the n_p^{th} next stacking order based on q_j, i.e., the $(n_p + 1)^{\text{th}}$ stacking order is released at the completion time of the first stacking order, the $(n_p + 2)^{\text{th}}$ stacking order at the completion of the second stacking order, etc. The release dates of mixing orders are determined likewise. Herewith, it is ensured that always n_p stacking (mixing) orders are available, creating more rescheduling options, while honouring the original order of release dates as much as possible. Validating orders are dependent on the mixing or stacking order that generated it. Hence, the release date of a validating order, r_j with $j \in J^v$, is set equal to the completion date of the previous order, c_{j-1}.

Concerning the completion time variables, constraints (4.8) guarantee that the time between the release date and the completion time of an order is at least the sum of the travelling time to the order from the previous order and its handling time. Validating orders are generated when a fixed maximum number of mixing or stacking orders are dropping at a certain location without an order starting from that location in between. Hence, the validating order can be considered a pair with the previously generated order. Therefore, validating orders are to be handled immediately after release (which is the completion time of the previous order), as is ensured by Constraints (4.9). Note that the travelling time from a mixing or stacking order to the validation order it generated equals 0 seconds.

Constraints (4.10) state that feeding orders are to be completed before their due date, which is set to be a certain buffer time after its release date. This ensures that the hopper requesting waste gets a new load before the level in the hoppers gets too low.

The minimum time between the starting time, which equals the completion time minus the handling time, and the completion time of the preceding order, is the travelling time from the first scheduled order to the later scheduled order (Constraints (4.11)).

$$\sum_{j\in J} f_j = 1 \tag{4.1}$$

$$\sum_{j\in J} l_j = 1 \tag{4.2}$$

$$f_j + \sum_{i\in J} x_{ij} = 1, \qquad \forall j \in J \tag{4.3}$$

$$l_j + \sum_{i\in J} x_{ji} = 1, \qquad \forall j \in J \tag{4.4}$$

$$r_j = q_j, \qquad \forall j \in J^f \tag{4.5}$$

$$r_j = c_{p_j}, \qquad \forall j \in J^s \cup J^m \tag{4.6}$$

$$r_j = c_{j-1}, \qquad \forall j \in J^v \tag{4.7}$$

$$r_j + h_j + \sum_{i\in J} t_{ij} x_{ij} \leq c_j, \qquad \forall j \in J \tag{4.8}$$

$$r_j + h_j = c_j, \qquad \forall j \in J^v \tag{4.9}$$

$$r_j + b \geq c_j, \qquad \forall j \in J^f \tag{4.10}$$

$$c_i + t_{ij} + h_j - M(1 - x_{ij}) \leq c_j, \qquad \forall i, j \in J \tag{4.11}$$

4.1.3 Objective

The objective of the WCSP is to optimise the twofold crane performance. Since the crane orders are input in this base model, the aspect of maximising the number of mixing orders is not applicable. This leaves the minimisation of the crane driving times as the objective of the base model.

The crane driving time consists of the handling and the travelling time. The handling time of an order is fixed by its origin and destination, leaving the travelling time the only aspect of interest when optimising crane performance by minimising driving times. Therefore, minimising the total travelling time is set as the model objective, see Equation (4.12).

$$\text{minimise} \sum_{i,j\in J} t_{ij} x_{ij} \tag{4.12}$$

4.2 Extended Model

In the extended model of the WCSP, the order generation is included in addition to the order sequencing. Herewith, all order characteristics become decision variables.

In the MIP formulation of this more inclusive version of the WCSP, a list of blank orders is initialised. The length of this list is an upper bound on the number of orders that can be executed in the considered time period.

Orders are generated by assigning characteristics, such as order type, starting time, origin and destination, to an order in the list. Note that the sequencing of the orders is already fixed by the list of blank orders. The combinations of order characteristics are assigned based on the strategy periods and waste levels. Herein, the external processes of truck arrivals and waste incineration are important factors.

In practice, the goal is to deliver the waste as homogeneous as possible to the hoppers for a stable combustion, provided that the WTE process as a whole can continue. Hence, the model objective is to perform as many mixing moves as possible. With the minimisation of the crane driving times, extra time is created to perform mixing orders. Additionally, when no mixing is done, e.g. during opening hours, the crane is spared and energy saved. However, when solely minimising the total driving time, only the orders incentivised by (external) processes will be generated. The truck arrivals and the incineration are the incentives for stacking and feeding orders, respectively. With no such incentive for mixing orders, the maximisation of the number of mixing orders is added to the objective function.

4.2.1 Components

Compared to the base model, the extension has both changed and additional components. The changed components mainly concern the order characteristics. The additional components are related to the external processes of truck arrivals and waste incineration, as well as to the waste levels.

Below, the changed and additional components are described per category. A full overview of the model components is given in Table 4.2.

Sets

The set of orders J can be viewed as a finite list of order numbers. The four types of orders, feeding, stacking, mixing and validating, are captured in set R by their first letter, i.e., f, s, m and v, respectively. The set of (x,y) locations L includes fictional location 0. $L \setminus \{0\}$ can be partitioned into three subsets: the drop zone L^d, the rest of the bunker L^b and the hoppers L^h. Also, the set of moments in time T and its subset T^a containing the truck arrival times are defined.

Additionally, the sets $Q^s \subset R \times L \times T$ and $Q^c \subset R \times L \times T$ are introduced. The first set, Q^s, contains all allowed combinations of the characteristics order type $r \in R$, origin $l \in L$ and starting time $t \in T$, while Q^c is the set of allowed combinations of order type $r \in R$, destination $l \in L$ and completion time $t \in T$. Whether a combination is allowed or not is determined based on the strategy period. For example, feeding orders are allowed at any time, and always end in a hopper, while stacking orders can only start from a drop zone location in a stack+feed period.

Parameters
The first group of parameters concerns the waste levels. For each location $l \in L$, the minimum level $w_l^{min} \in \mathbb{R}_+$, the maximum level $w_l^{max} \in \mathbb{R}_+$ and the initial waste level $w_l^{init} \in \mathbb{R}_+$ are given. Also, the level above which a drop location is closed for trucks is denoted by $w^d \in \mathbb{R}_+$.

Secondly, parameters related to the validating orders are introduced. The maximum number of drops before validation is required is given by $n^{max} \in \mathbb{N}$, and the initial number of drops at location $l \in L$ by $n_l^{init} \in \mathbb{N}$.

Thirdly, the time dependent parameters are described. The time it takes a truck arriving at time $t \in T$ to dump its content into the drop zone is given by the integer z_t, and the resulting height of its content by $u_t \in \mathbb{R}_+$. Although a positive correlation between the dumping time z_t and the truck content height u_t can be expected, this has not been observed in the input data. The incineration rate is expressed in height per time unit and represented by $v_t \in \mathbb{R}_+$, with $t \in T$.

Lastly, parameter $g_j^r \in \mathbb{R}_+$ represents the grab heights of order $j \in J$ of type $r \in R \setminus \{v\}$.

Decision Variables
The model contains three binary decision variables, of which two are related to order characteristics. Binary variable s_{jrlt} takes value 1 if order $j \in J$ is assigned the combination of characteristics concerning the start of an order $(r, l, t) \in Q^s$, while binary variable c_{jrlt} takes value 1 if order $j \in J$ is assigned the order characteristics related to the order completion $(r, l, t) \in Q^c$.

The third decision variable is binary variable y_{tl}, with $t \in T^a$ and $l \in L$, which is related to the truck arrivals. If $y_{tl} = 1$, then the content of the truck arriving at time $t \in T^a$ is dumped at drop zone location $l \in L_d$. If $y_{tl} = 0$, it is not.

Auxiliary Variables
From the decision variables s_{jrlt} and $c_{jr'l't'}$ with $j \in J$, $(r, l, t) \in Q^s$ and $(r', l', t') \in Q^c$, the origin $o_j \in L$, destination $d_j \in L$, starting time $s_j \in T$ and completion time $c_j \in T$ of order $j \in J$ are defined as variables. Subsequently, the auxiliary variables handling time $h_j \in \mathbb{N}$ and travelling time $t_j \in \mathbb{N}$ of order $j \in J$ are derived from its origin o_j and its own destination d_j (for handling time), or the destination of its predecessor d_{j-1} (for travelling time). For the first order, the travelling time is neglected.

The variable $w_{lt} \in \mathbb{R}_+$ represents the waste level at location $l \in L$ at time $t \in T$. For the generation of validating orders, the variable $n_{lt} \in \{0, 1, .., n^{max}\}$ with $l \in L \setminus L^h$ and $t \in T$ is introduced. Integer variable n_{lt} represents the number of drops performed at location l at time t since the last validation at location l. The binary variable a_{lt} with $l \in L \setminus L^h$ and $t \in T$ takes value 1 if $n_{lt} < n^{max}$, and value 0 if $n_{lt} = n^{max}$.

4.2.2 Constraints

The constraints of the extended model are categorised in the different model aspects: order characteristics, truck arrivals, waste levels and validating orders. For each topic, the related constraints are described and given.

Sets

$J = \{1, 2, ...\}$	set of orders
$R = \{f, s, m, v\}$	set of order types
$L = \{0, 1, 2, ...\}$	set of (x,y) locations
$L^d \subset L$	subset containing drop zone locations
$L^b \subset L$	subset of non drop zone bunker locations
$L^h \subset L$	subset containing hopper locations
$T = \{0, 1, ...\}$	set of moments in time
$T^a \subset T$	subset containing truck arrival times
$Q^s \subset R \times L \times T$	set of allowed combinations of order type, origin and starting time
$Q^c \subset R \times L \times T$	set of allowed combinations of order type, destination and completion time

Parameters

$w_l^{min} \in \mathbb{R}_+$	minimum waste level at location $l \in L$
$w_l^{max} \in \mathbb{R}_+$	maximum waste level at location $l \in L$
$w_l^{init} \in \mathbb{R}_+$	initial waste level at location $l \in L$
$w^d \in \mathbb{R}_+$	maximum dumping waste level
$n^{max} \in \mathbb{N}$	maximum number of drops before validating
$n_l^{init} \in \mathbb{N}$	initial number of drops at location $l \in L$
$z_t \in \mathbb{N}$	dumping time of truck arriving at time $t \in T^a$
$u_t \in \mathbb{R}_+$	content of truck arriving at time $t \in T^a$
$v_t \in \mathbb{R}_+$	incineration rate at time $t \in T$
$g_j^r \in \mathbb{R}_+$	grab height of order $j \in J$ of type $r \in R$

Decision Variables

$s_{jrlt} \in \{0, 1\}$	1 if order $j \in J$ has $(r, l, t) \in Q^s$ as its characteristics, 0 otherwise
$c_{jrlt} \in \{0, 1\}$	1 if order $j \in J$ has $(r, l, t) \in Q^c$ as its characteristics, 0 otherwise
$y_{lt} \in \{0, 1\}$	1 if truck arriving at $t \in T^a$ dumps at drop location $l \in L^d$, 0 otherwise

Auxiliary Variables

$o_j \in L$	origin of order $j \in J$
$d_j \in L$	destination of order $j \in J$
$s_j \in T$	starting time of order $j \in J$
$c_j \in T$	completion time of order $j \in J$
$h_j \in \mathbb{N}$	handling time of order $j \in J$
$t_j \in \mathbb{N}$	travelling time from order $j - 1 \in J$ to order $j \in J \setminus \{1\}$
$w_{lt} \in \mathbb{R}_+$	waste level at location $l \in L$ at time $t \in T$
$a_{lt} \in \{0, 1\}$	1 if an order is starting at $l \in L \setminus L^h$ at time $t \in T$, 0 otherwise
$n_{lt} \in \mathbb{N}$	number of orders with destination $l \in L \setminus L^h$ handled at time $t \in T$ since last order with origin $l \in L \setminus L^h$

Table 4.2: Extended model components.

Order Characteristics

Crane orders are defined by its characteristics. Hence, order $j \in J$ is assigned an order type, origin, destination, starting time and completion time by Constraints (4.13) and (4.14). If less orders than included in J are handled, the last order(s) will remain blank, i.e. without characteristics assigned. Unassigned orders receive fictional location 0 as their origin and destination (Constraints (4.17) and (4.18)) and (fictional) late starting and completion times (Constraints (4.19) and (4.20)). Herewith, the starting time of the last assigned order is (strictly) smaller than the starting time of the first unassigned order (Constraint (4.25)).

With the characteristics spread over two sets of variables, s_{jrlt} and $c_{jr'l't'}$ with $j \in J$, $(r, l, t) \in Q^s$ and $(r', l', t') \in Q^c$, these variables need to be related to one another. In Constraints (4.14), it is emphasised that the order types coincide. Additionally, Constraints (4.15) and (4.16) ensure, respectively, that for validating orders, the origin and the destination are the same, and for mixing orders, the origin and the destination are different. For the other order types, this already follows from the allowed characteristics combinations.

For further use, origins, destinations, starting and completion times are extracted from the assignment variables by Constraints (4.17) to (4.20). To be able to schedule blank orders at the end, $M \in \mathbb{R}$ in Constraints (4.19) and (4.20) should be equal to or larger than the makespan of the assigned orders. From the origins and destinations, the crane driving times are calculated based on crane specifications and the driving strategy. By Constraints (4.21) and (4.22), the handling time of order $j \in J$ is given by the non-linear function f_h of its origin o_j and its destination d_j, and the travelling time of order $j \in J$ is given by the non-linear function f_t of the destination of its predecessor d_{j-1} and its own origin o_j. The z-components of the origin and destination can be obtained (non-linearly) from the waste levels at the origin at the starting time and at the destination at the completion time, respectively. However, the completion time of an order is determined via its handling time (Constraints (4.24)) and its starting time depends on its travelling time (Constraints (4.25)). Hence, in Constraints (4.21), the waste level at the order's destination is approximated by the destination's waste level at the order's starting time, and in Constraints (4.22), the waste level at the order's origin is approximated by the origin's waste level at the completion time of the preceding order. In practice, neither the waste level at the destination changes during handling nor the waste level at the origin during travelling: crane dropping is not possible (only one crane) and with truck dumping the waste level is updated upon arrival (Constraints (4.33)). Constraints (4.21) and (4.22) are linearised in Section 5.2.

In case origin $o_j = 0$, i.e. order $j \in J$ is blank, both $h_j = 0$ and $t_j = 0$ by definition. Herewith, the starting and completion times of all blank orders can be equal. The travelling time to the first order is neglected, hence t_1 is set to 0 by Constraint (4.23).

Constraints (4.24) ensure that the difference between the starting and the completion time equals the handling time. The characteristics are assigned to a specific order based on its starting time, i.e. such that the starting time relation agrees with the order sequence in the initialised list. With one crane that can handle at most one order at a time, the difference in starting times of subsequent orders needs to be at least the sum of the handling time of the first and the travelling time of the second, as ensured by Constraints (4.25).

$$\sum_{(r,l,t)\in Q^s} s_{jrlt} \leq 1, \qquad \forall j \in J \qquad (4.13)$$

$$\sum_{l,t|(r,l,t)\in Q^s} s_{jrlt} = \sum_{l,t|(r,l,t)\in Q^c} c_{jrlt} \qquad \forall j \in J,\ r \in R \qquad (4.14)$$

$$\sum_{t|(v,l,t)\in Q^s} s_{jvlt} = \sum_{t|(v,l,t)\in Q^c} c_{jvlt} \qquad \forall j \in J,\ l \in L \tag{4.15}$$

$$\sum_{t|(m,l,t)\in Q^s} s_{jmlt} \leq \Big(1 - \sum_{t|(m,l,t)\in Q^c} c_{jmlt}\Big) \qquad \forall j \in J,\ l \in L \tag{4.16}$$

$$o_j = \sum_{(r,l,t)\in Q^s} s_{jrlt} l, \qquad \forall j \in J \tag{4.17}$$

$$d_j = \sum_{(r,l,t)\in Q^c} c_{jrlt} l, \qquad \forall j \in J \tag{4.18}$$

$$s_j = \sum_{(r,l,t)\in Q^s} s_{jrlt} t + M\Big(1 - \sum_{(r,l,t)\in Q^s} s_{jrlt}\Big), \qquad \forall j \in J \tag{4.19}$$

$$c_j = \sum_{(r,l,t)\in Q^c} c_{jrlt} t + M\Big(1 - \sum_{(r,l,t)\in Q^s} s_{jrlt}\Big), \qquad \forall j \in J \tag{4.20}$$

$$h_j = f_h(o_j, w_{o_j s_j}, d_j, w_{d_j s_j}), \qquad \forall j \in J \tag{4.21}$$

$$t_j = f_t(d_{j-1}, w_{d_{j-1} c_{j-1}}, o_j, w_{o_j c_{j-1}}), \qquad \forall j > 1 \in J \tag{4.22}$$

$$t_1 = 0, \tag{4.23}$$

$$s_j + h_j = c_j \qquad \forall j \in J \tag{4.24}$$

$$s_{j-1} + h_{j-1} + t_j \leq s_j, \qquad \forall j \in J \setminus \{1\} \tag{4.25}$$

Truck Arrivals

With Constraints (4.26) to (4.29), the truck arrivals are modelled. Firstly, by Constraints (4.26), it is emphasised that every arriving truck is assigned to a dump location. With Constraints (4.27), it is ensured that no truck dumps at a location that is closed because of a high waste level, i.e. a waste level above the maximum dumping height. The number $M_1 \in \mathbb{R}_+$ should take a value larger than $\max_{l\in L^d} w_l^{max} - w^d$ to ensure that the maximum waste level can be reached.

During the dumping time of a truck, no new truck can arrive at the same location (Constraints (4.28)). Also, the crane is not allowed at a location where is being dumped (Constraints (4.29)). Constraints (4.29) also state that during the dumping time a maximum of $M_2 \in \mathbb{R}_+$ orders can start from a location to which the arriving truck is not assigned. A suitable value for M_2 can be derived from the maximum dumping time and the minimum driving time of an order.

$$\sum_{l\in L^d} y_{lt} = 1, \qquad \forall t \in T^a \tag{4.26}$$

$$w_{lt} - w^d \leq M_1(1 - y_{lt}), \qquad \forall l \in L^d,\ t \in T^a \tag{4.27}$$

$$\sum_{t\leq t'<t+z_t} y_{lt'} \leq 1, \qquad \forall l \in L^d,\ t \in T^a \tag{4.28}$$

$$\sum_{j\in J}\sum_{r\in R}\sum_{t\leq t'<t+z_t} s_{jrlt'} \leq M_2(1 - y_{lt}), \qquad \forall l \in L^d,\ t \in T^a \tag{4.29}$$

Waste Levels

The first constraints concerning waste levels are static constraints containing the waste level parameters. With Constraints (4.30), the initial waste levels are set for bunker and hoppers, while the minimum and maximum waste levels are set with Constraints (4.31) and (4.32), respectively.

Secondly, the waste level updates are captured in Constraints (4.33) to (4.35). The waste level of a drop zone location $l \in L^d$ depends on four events. When a stacking order $j \in J$ starts from there, the level is decreased with the corresponding grab height g_j^s. Likewise, the level is increased (decreased) with grab height g_j^m when mixing order $j \in J$ ends (starts) at $l \in L^d$. Additionally, when a truck arriving at time $t \in T$ is assigned to location $l \in L^d$, the waste level at $l \in L^d$ is increased with the corresponding truck content u_t. In reality, the truck content is dumped over the dumping time z_t, but since no order concerning this location is handled during this dumping time, this can be neglected in the model without consequences.

The waste level updates in the rest of the bunker, the stacking and feeding zones, and the hoppers are modelled similarly. For the rest of the bunker, the relevant events are the start of a feeding move, the start of a mixing move and the completion of a stacking or a mixing order. For the hoppers, only the completion of feeding orders and the incineration process is relevant.

Note that with these waste level updates, features as feathering, the tumbling of waste and waste density variation are not taken into account.

$$w_{l0} = w_l^{init}, \qquad \forall l \in L \tag{4.30}$$

$$w_{lt} \geq w_l^{min}, \qquad \forall l \in L,\ t \in T \tag{4.31}$$

$$w_{lt} \leq w_l^{max}, \qquad \forall l \in L,\ t \in T \tag{4.32}$$

$$w_{lt+1} = w_{lt} - \sum_{j \in J} g_j^s s_{jslt} + \sum_{j \in J} g_j^m c_{jmlt} - \sum_{j \in J} g_j^m s_{jmlt} + u_t y_{lt}, \qquad \forall l \in L^d,\ t \in T \tag{4.33}$$

$$w_{lt+1} = w_{lt} - \sum_{j \in J} g_j^f s_{jflt} + \sum_{j \in J} g_j^s c_{jslt} + \sum_{j \in J} g_j^m c_{jmlt} - \sum_{j \in J} g_j^m s_{jmlt}, \qquad \forall l \in L^b,\ t \in T \tag{4.34}$$

$$w_{lt+1} = w_{lt} + \sum_{j \in J} g_j^f c_{jflt} - v_t, \qquad \forall l \in L^h,\ t \in T \tag{4.35}$$

Validating Orders

In practice, the waste level cannot be exactly monitored. Hence, every once in a while the waste level at a certain location has to be measured by the crane. This is done when grabbing waste at the start of the move, or within the execution of a validating order.

For generating validating orders, the number of drops performed per location since the last time an order started is important. With Constraints (4.36), it is monitored whether an order is starting at origin $l \in L \setminus L^h$. Constraints (4.37) sets the initial number of drops for location $L \in L \setminus L_h$ to n_l^{init}. With Constraints (4.38) and (4.39), the minimum numbers of drops are set to 0 and the maximum number of drops to n^{max}.

Constraints (4.40) ensure that an order is starting at a location where the number of drops since the last order reaches n^{max}. From this and the minimum and maximum values, the value update of the number of drops is controlled by Constraints (4.41); when a drop is performed, the number of drops at the corresponding location is increased by one, and when an order has started from there, it is reset to 0.

$$a_{lt} = \sum_{j \in J} \sum_{r \in R} s_{jrlt}, \qquad \forall l \in L \setminus L^h,\ t \in T \tag{4.36}$$

$$n_{l0} = n_l^{init}, \qquad \forall l \in L \setminus L^h \tag{4.37}$$

$$n_{lt} \geq 0, \qquad \forall l \in L \setminus L^h,\ t \in T \tag{4.38}$$

$$n_{lt+1} \leq n^{max}(1 - a_{lt}), \qquad \forall l \in L \setminus L^h,\ t \in T \tag{4.39}$$

$$a_{lt} \geq n_{lt} - (n^{max} - 1), \qquad \forall l \in L \setminus L^h,\ t \in T \tag{4.40}$$

$$n_{lt+1} \geq n_{lt} - n^{max} a_{lt} + \sum_{j \in J} (c_{jslt} + c_{jmlt}), \qquad \forall l \in L \setminus L^h,\ t \in T \tag{4.41}$$

4.2.3 Objective

To support the generation of mixing orders while minimising the crane driving times, the model has become multi-objective. The first objective is the familiar minimisation of the total driving times, i.e. the cumulative handling and travelling times. The second objective is the maximisation of the number of mixing orders scheduled.

The two objective functions are combined into the objective function of the model given by Equation (4.42), in which $c_1 < 0$ and $c_2 > 0$ are predefined weight coefficients. During mixing periods, the second objective is leading, hence $c_2 \gg -c_1$. As the minimisation of the total driving time is in line with the maximisation of the number of mixing orders, a small contribution of the minimisation of the driving time in the objective will not lead to contradictory behaviour. For a non-mixing period, the value of the weight c_2 is irrelevant as the value of the second objective itself will be 0.

$$\text{maximise } c_1 \sum_{j \in J} (h_j + t_j) + c_2 \sum_{j \in J} \sum_{(l,t)|(m,l,t) \in Q^s} s_{jmlt} \tag{4.42}$$

4.2.4 Strengths and Limitations

In the description of the model, already a couple of model limitations have been mentioned. For example, the travelling time to the first order is not considered. Also, the model does not include feathering, tumbling or variation in the waste density other then taken into account in the grab heights. That every once in a while locations are digged out to avoid waste resting too long, is also not included. However, the most obvious drawback of the model is that it is designed to only consider one waste crane. With the model not supporting any kind of conflict between cranes, the incorporation of multiple cranes would require a substantial model extension.

Despite these limitations, the model is relative broad applicable as it is independent of bunker layout, strategy periods, opening hours and crane specifications. These aspects follow from the initialisation of the sets and parameters. The bunker layout is implicitly determined by the (sub)sets of locations, the minimum and maximum (dumping) waste levels, and the handling and travelling times functions. The crane strategies, e.g. whether mixing and stacking are allowed in the same period, are captured in the sets specifying allowed combinations of order characteristics. From these sets, also the intended feeding, stacking and mixing zones follow. The set of truck arrivals indicates the opening hours of the facility, and the grab heights and driving times channel the crane specifications into the model.

With this strong dependence on the input of the model, it is important that the input aspects are aligned. For example, around truck arrivals, stacking orders from the drop locations need to be allowed in order to avoid inconsistency in the modelled process.

Chapter 5

Solution Methods

In this chapter, solution methods for the base model (Section 4.1) and the extended model (Section 4.2) are presented. In Section 5.1, the implementation of the crane driving times used in both the base and the extended model is discussed. A linearisation of the non-linear constraints of the extended model is described in Section 5.2, and a rolling horizon method is introduced as heuristic approach in Section 5.3.

5.1 Crane Driving Times

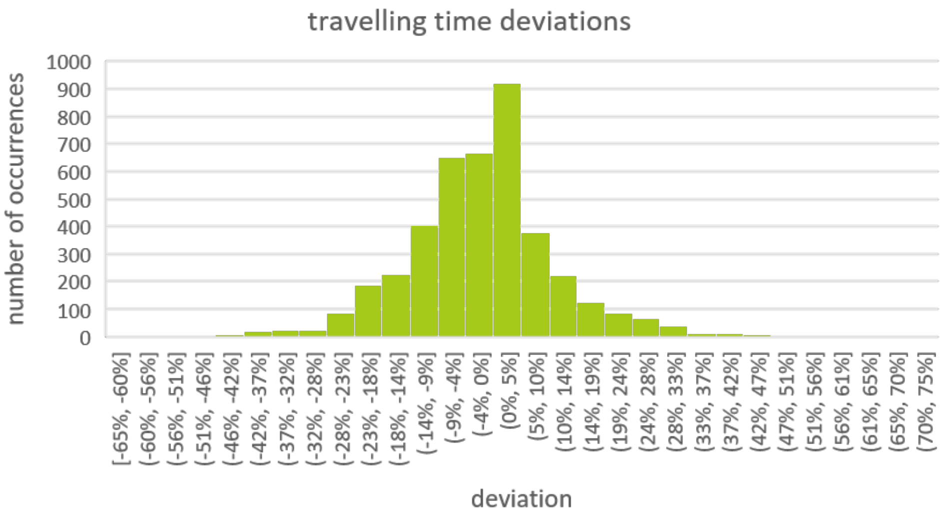
As mentioned in Chapter 4, the crane driving times, i.e. handling and travelling times, are determined from origins and destinations. For the handling time, the origin and destination of the move are, respectively, the origin and destination of the order. To determine the travelling time, the destination of an order and the origin of the succeeding order are taken as start and end positions, respectively.

The driving times are calculated based on the driving strategy described in Section 2.4. However, there are some differences. For example, the driving height is set at the maximum of the dropping height, which is five meter above the waste level of the destination, and three meters above the height at the origin. Herewith, the case where the waste level in the intermediate area is higher than the driving height is not taken into account, which can result in (slight) underestimations.

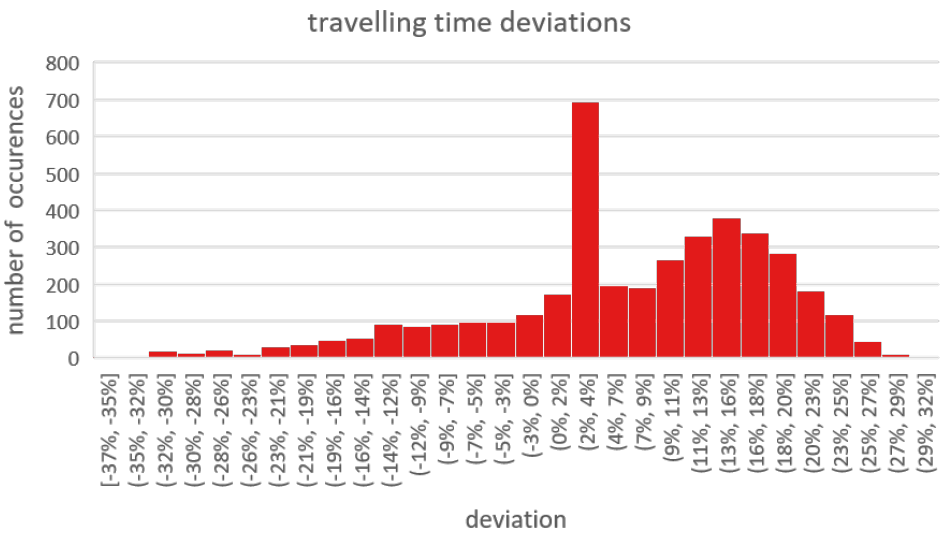
Figure 5.1 shows the deviations between travelling times, i.e. the calculated ones and the travelling times obtained from the simulation model. The differences are plotted per order type, i.e., feeding, stacking and mixing, where the travelling time to the order is considered. The larger (negative) deviations mostly originate from deviations in the simulation model due to the crane being blocked by the other crane. Note that the models in Chapter 4 only take one crane into consideration. The large deviation in travelling time of mixing orders has to do with the short travelling times when moving only one grid slot further.

5.2 Extended Model Linearisation

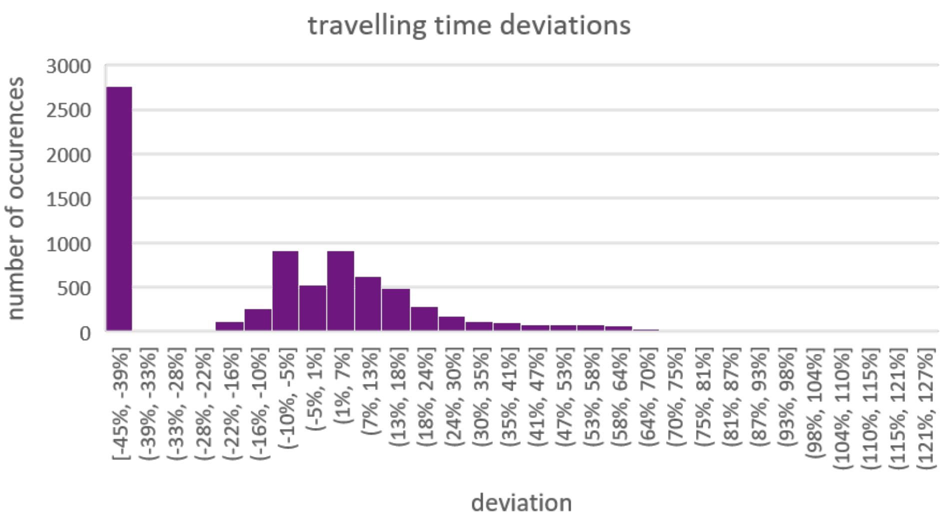
The extended model as described in Section 4.2 contains non-linear constraints concerning the crane driving times. The non-linearity of Constraints (4.21) and (4.22) lies both in the functions calculating the handling and travelling times and the retrieval of the waste level. With the linearisation of Constraints (4.21) and (4.22), a MILP model formulation can be obtained.



(a) feeding



(b) stacking



(c) mixing

Figure 5.1: Deviations between calculated travelling times and travelling times obtained from simulation model per order type: (a) feeding, (b) stacking and (c) mixing.

5.2.1 Additional Components

Two new variable sets are introduced to include the waste level at the origin and destination of the orders. The auxiliary variables are defined on the sets $D_1 \subset L \times K \times L \times K'$ and $D_2 \subset L \times K' \times L \times K$, with K the set of allowed origin heights and K' the set of allowed destination heights. With L the set of (x,y) locations, set D_1 contains the possible combinations of (x,y,z) origin $(l,k) \in L \times K$ and (x,y,z) destination $(l',k') \in L \times K'$ of an order, while set D_2 contains combinations of (x,y,z) destination $(l',k') \in L \times K'$ of an order and (x,y,z) origin $(k,l) \in L \times K$ of the next order as a combinations. Note that with K and K' being finite sets, the model linearisation leads to a discretisation of the waste levels for the driving times.

For each origin-destination combination $(l,k,l',k') \in D_1$, the handling time is calculated beforehand, represented by the parameter $ht_{lkl'k'}$. Likewise, $tt_{l'k'lk}$ is the precalculated travelling time for the destination-origin combination $(l',k',l,k) \in D_2$.

Auxiliary binary variable $od_{jlkl'k'}$ indicates whether order $j \in J$ has the (x,y,z) origin-destination combination $(l,k,l',k',) \in D_1$, if $od_{jlkl'k'} = 1$, or not, if $od_{jlkl'k'} = 0$. Similarly, auxiliary binary variable $do_{jl'k'lk} \in \{0,1\}$ takes value 1 if and only if (l',k') is the destination of order $j-1 \in J \setminus \{1\}$ and (l,k) the origin of order $j \in J$, with $(l',k',l,k) \in D_2$.

In Table 5.1, the additional model components regarding the linearisation are summarised.

Sets	
K	set of allowed origin waste levels
K'	set of allowed destination waste levels
$D_1 \subset L \times K \times L \times K'$	set of allowed combinations of origin and destination including waste levels
$D_2 \subset L \times K' \times L \times K$	set of allowed combinations of destination and origin including waste levels
Parameters	
$ht_{lkl'k'} \in \mathbb{N}$	handling time from origin $(l,k) \in L \times K$ to destination $(l',k') \in L \times K'$
$tt_{l'k'lk} \in \mathbb{N}$	travelling time from destination $(l',k') \in L \times K'$ to origin $(l,k) \in L \times K$
Auxiliary Variables	
$od_{jlkl'k'} \in \{0,1\}$	1 if order $j \in J$ has $(l,k,l',k') \in D_1$ as its origin and destination, 0 otherwise
$do_{jl'k'lk} \in \{0,1\}$	1 if order $j > 1 \in J$ has $(l',k',l,k) \in D_2$ as its prior destination and origin, 0 otherwise

Table 5.1: Additional components of linearised extended model.

5.2.2 Additional Constraints

With the additional model components, the driving times can be determined linearly, as Constraints (5.1) and (5.2) show. With these constraints, the handling time of order $j \in J$ is set equal to the driving time from the (x,y,z) origin to the (x,y,z) destination of the order. Similarly, it is ensured that the travelling time to order $j \in J \setminus \{1\}$ equals the driving time from the destination of the preceding order $j-1$ and the origin of order j.

$$h_j = \sum_{(l,k,l',k') \in D_1} ht_{lkl'k'} od_{jlkl'k'}, \qquad \forall j \in J \tag{5.1}$$

$$t_j = \sum_{(l',k',l,k) \in D_2} tt_{l'k'lk} do_{jl'k'lk}, \qquad \forall j > 1 \in J \tag{5.2}$$

In Constraints (5.3) to (5.8), the origin-destination variables are addressed. Constraints (5.3) and (5.4) define the variables: order $j \in J$ is assigned characteristics if and only if order j is assigned a combination of (x,y,z) origin $(l,k) \in L \times K$ and (x,y,z) destination $(l',k') \in L \times K'$ in which the (x,y) locations $l, l' \in L$ coincide with the origin and destination determined by decision variables s_{jrlt} with $(r,l,t) \in Q^s$ and $c_{jrl't}$ with $(r,l',t) \in Q^c$.

The z-components of the locations are determined by Constraints (5.5) to (5.8). With Constraints (5.5) and (5.6), the origin height $k \in K$ of order $j \in J$ is aligned with the waste level at the (x,y) origin $l \in L$ at the order's starting time $t \in T$. Similarly, the destination height $k' \in K'$ of order $j \in J$ is aligned with the waste level at the order's (x,y) destination $l' \in L$ at starting time $t \in T$ by Constraints (5.7) and (5.8). Note that, as in Constraint (4.21), the destination's waste level at completion is approximated by its level at the starting time.

Since the possible origin and destination heights are discrete and the waste level variables are continuous-valued, the height values equal the rounded up waste levels. Rounding down the waste levels would also be possible since only the driving times are affected by this, and the driving times are calculated based on the difference between the origin and destination heights, which in practice, is the same when rounding up or down (assuming equal steps between possible height values). In theory, one of the waste levels can equal its rounded value, in which case rounding up or down the other waste level results in different height differences.

$$\sum_{k,l',k' | (l,k,l',k') \in D_1} od_{jlkl'k'} = \sum_{r,t | (r,l,t) \in Q^s} s_{jrlt}, \qquad \forall j \in J,\ l \in L \tag{5.3}$$

$$\sum_{l,k,k' | (l,k,l',k') \in D_1} od_{jlkl'k'} = \sum_{r,t | (r,l',t) \in Q^c} c_{jrl't}, \qquad \forall j \in J,\ l' \in L \tag{5.4}$$

$$\sum_{k,l',k' | (l,k,l',k') \in D_1} od_{jlkl'k'} k \geq w_{lt} - M\Big(1 - \sum_{r | (r,l,t) \in Q^s} s_{jrlt}\Big), \qquad \forall j \in J,\ l \in L,\ t \in T \tag{5.5}$$

$$\sum_{k,l',k' | (l,k,l',k') \in D_1} od_{jlkl'k'} (k-1) < w_{lt} + M\Big(1 - \sum_{r | (r,l,t) \in Q^s} s_{jrlt}\Big), \qquad \forall j \in J,\ l \in L,\ t \in T \tag{5.6}$$

$$\sum_{l,k,k' | (l,k,l',k') \in D_1} od_{jlkl'k'} k' \geq w_{l't} - M\Big(1 - \sum_{r,l | (r,l,t) \in Q^s} s_{jrlt}\Big), \qquad \forall j \in J,\ l' \in L,\ t \in T \tag{5.7}$$

$$\sum_{l,k,k' | (l,k,l',k') \in D_1} od_{jlkl'k'} (k'-1) < w_{l't} + M\Big(1 - \sum_{r,l | (r,l,t) \in Q^s} s_{jrlt}\Big), \qquad \forall j \in J,\ l' \in L,\ t \in T \tag{5.8}$$

Constraints (5.9) to (5.14) concern the destination-origin variables. Constraints (5.9) and (5.10) define the variables. Order $j-1 \in J$ is assigned completion characteristics if and, if j is not the first blank order, only if order $j-1$ is assigned a combination of (x,y,z) destination $(l', k') \in L \times K'$. Herein, (x,y) destination $l' \in L$ coincides with the destination determined by decision variable $c_{j-1rl't}$ with $(r, l', t) \in Q^c$. Order $j \in J$ is assigned starting characteristics if and only if order j is assigned a combination of (x,y,z) origin $(l, k) \in L \times K$, in which (x,y) origin $l \in L$ coincides with the origin determined by decision variable s_{jrlt} with $(r, l, t) \in Q^s$.

Concerning the z-components of the preceding destination and of the origin, Constraints (5.11) to (5.14) are in line with the height constraints concerning the origin-destination variables (Constraints (5.5) to (5.8)). However, in these constraints, again the case of order $j \in J \setminus \{1\}$ being the first blank order has to be covered. Hence, in addition to whether order $j-1$ has assigned completion characteristics, whether order j is assigned starting characteristics is of interest.

$$\sum_{k',l,k|(l',k',l,k)\in D_2} do_{jl'k'lk} \leq \sum_{r,t|(r,l',t)\in Q^c} c_{j-1rl't}, \qquad \forall j \in J \setminus \{1\},\ l' \in L \tag{5.9}$$

$$\sum_{l',k',k|(l',k',l,k)\in D_2} do_{jl'k'lk} = \sum_{r,t|(r,l,t)\in Q^s} s_{jrlt}, \qquad \forall j \in J \setminus \{1\},\ l \in L \tag{5.10}$$

$$\sum_{k',l,k|(l',k',l,k)\in D_2} do_{jl'k'lk}k' \geq w_{l't} - M\Big(2 - \sum_{r|(r,l',t')\in Q^c} c_{j-1rl't'} - \sum_{(r,l,t)\in Q^s} s_{jrlt}\Big), \quad \forall j \in J \setminus \{1\},\ l' \in L,\ t' \in T \tag{5.11}$$

$$\sum_{k',l,k|(l',k',l,k)\in D_2} do_{jl'k'lk}(k'-1) < w_{l't} + M\Big(2 - \sum_{r|(r,l',t')\in Q^c} c_{j-1rl't'} - \sum_{(r,l,t)\in Q^s} s_{jrlt}\Big), \quad \forall j \in J \setminus \{1\},\ l' \in L,\ t' \in T \tag{5.12}$$

$$\sum_{l',k',k|(l',k',l,k)\in D_2} do_{jl'k'lk}k \geq w_{lt'} - M\Big(2 - \sum_{r,l'|(r,l',t')\in Q^c} c_{j-1rl't'} - \sum_{r,t|(r,l,t)\in Q^s} s_{jrlt}\Big), \quad \forall j \in J \setminus \{1\},\ l \in L,\ t' \in T \tag{5.13}$$

$$\sum_{l',k',k|(l',k',l,k)\in D_2} do_{jl'k'lk}(k-1) < w_{lt'} + M\Big(2 - \sum_{r,l'|(r,l',t')\in Q^c} c_{j-1rl't'} - \sum_{r,t|(r,l,t)\in Q^s} s_{jrlt}\Big), \quad \forall j \in J \setminus \{1\},\ l \in L,\ t' \in T \tag{5.14}$$

5.3 Rolling Horizon

The rolling horizon approach is a heuristic method for discrete-time dynamic optimisation problems such as production planning and scheduling [29, 30]. Closer related to the WCSP, in [31], a rolling horizon algorithm is applied to the MILP model of an instance of the yard crane scheduling problem.

With the rolling horizon method, an estimation for the modelled problem is build over a finite sequence of iterations. In each step, the solution obtained in the previous iteration is taken as starting point. From there, a solution for the next time period is obtained by solving the optimisation problem. This way, the schedule is updated and extended over the iterations.

Two important rolling horizon parameters are the scheduling horizon, or time window, and the time step. The scheduling horizon indicates the period of time for which a schedule is determined in an iteration, while the time step indicates the difference in time between the starting moments of iterations. If the time step equals the horizon, the schedule is only extended, not updated. If the time step is smaller than the horizon, the schedule can also be adjusted in the next iteration(s). The (finite) horizon is typically constant throughout, while the time step can be either constant or dependent on the 'local' schedule. Figure 5.2 shows the rolling horizon framework, including the scheduling horizon and time step.

The rolling horizon approach will be applied on the linearisation of the extended model. As total time period, the length of a specific crane strategy is taken. While the scheduling horizon is fixed, the time steps are dependent on the schedule as the starting time of the following iteration is set to equal the completion time of the first order scheduled in the previous iteration. In case no order is scheduled in an iteration, which can occur in a stacking period, the next iteration starts a fixed number of time units later.

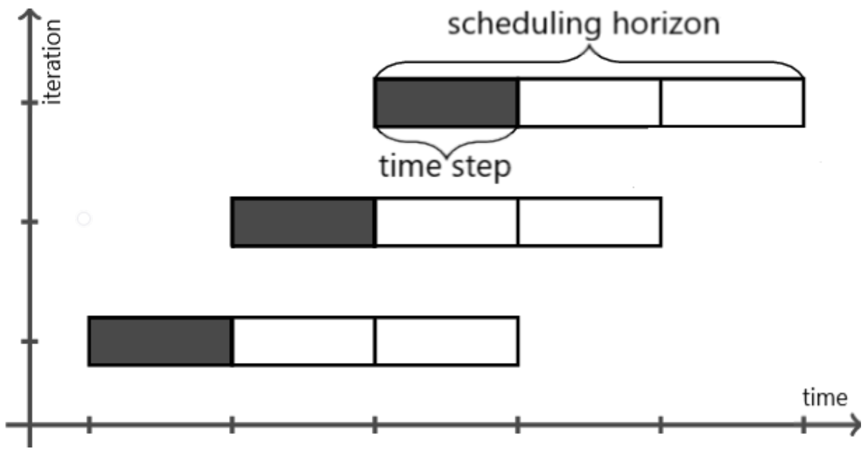


Figure 5.2: Rolling horizon framework (adjusted from [32]).

Chapter 6

Results

From the base model (Section 4.1) and the extended model (Section 4.2), results are obtained by implementing the MILP models in Python 2.7[1], with Gurobi 9.0.1[2] as solver. Gurobi uses a linear programming based branch-and-bound algorithm, including problem reductions, cutting planes, heuristics and parallel running [33].

The results of the base model and the extension are presented in Section 6.1 and Section 6.2, respectively. In Section 6.3, four decision rules are formulated based on the results.

6.1 Base Model

The implemented base model uses as input data originating from the simulation model as described in Section 2.4. Only one of the two cranes in the simulation model is considered. Because in the simulation model the cranes have separate working areas and limited interaction, considering one crane separately only has limited effect on the crane driving times as illustrated in Section 5.1.

The output of the simulation model is a list of orders handled over a period of 22 days, i.e. three weeks plus an additional day to setup the model. The output contains order characteristics, such as the order type, the release date, the origin and destination, and information on when the crane started travelling to the order or handling the order, as well as when the crane completed the order. An example of the input data is displayed in Figure 6.1.

type	cx_from	cy_from	cz_from	cx_to	cy_to	cz_to	request	start travel	start handling	end
feeding	27.5	2.5	13.8	11.5	-5.5	40	11	11	49.1794863	139.8147796
mixing	2.5	2.5	21.1	2.5	7.5	26.2	267.3769286	267.3769286	314.0800121	365.0696124
stacking	27.5	22.5	11.4	42.5	12.5	18.6	40836.64937	40836.64937	40877.79722	40937.81251
validate	42.5	12.5	14.3	42.5	12.5	14.3	40937.81251	40937.81251	0	40961.80285

Figure 6.1: Example of input data for base model. Per order, it states the type, origin (from), destination (to), release date (request), start travelling time, start handling time and completion time (end). The locations are in meters, the times in seconds.

[1] https://www.python.org/
[2] https://www.gurobi.com/

6.1.1 Instances

The different data sets used as input for the model, correspond to a specific strategy period of a specific day. The three strategy periods are 'stack+feed', 'mix+feed' and 'mix/stack+feed'.

In the first period, only stacking and feeding orders are generated. This 'stack+feed' strategy is effective from 07:00h. However, for the considered input instances, the start of the period is set to the moment of generating the first stacking order during opening hours, which lasts from 08:00h to 18:00h, an hour after closing. The second period lasts from closing hours until 02:00h at night. During this time only mixing and feeding orders are handled. The mix/stack+feed period is the last, and it lasts from 02:00h to 07:00h. The strategy in this period is similar to period 2, but mixing orders to the drop zone are no longer generated to clear the drop zone for the new day. The number of orders per strategy period are included in Table 6.1.

Out of the 22 days, 20 days are considered. As mentioned before, the first day is used to setup the model, and therefore, is not part of the actual simulation. Additionally, with days starting with period 1, and therewith running from 07:00h until 07:00h the next day instead of starting and finishing at 00:00h, the first and the last days cannot be fully used. In the third week, from day 14 on, the middle crane of the model is being serviced in the middle of the bunker. Herewith, the working area of the considered crane is slightly smaller than in the first two weeks.

A model instance corresponds to a data set and, additionally, a specific value of parameter b, the buffer time. The three considered values are 300, 600 and 900 seconds. Hence, feeding orders have to be completed within 300, 600 or 900 seconds after their release. The value of 300 seconds (5 minutes) corresponds to the target maximum time between the generation and the completion of a feeding order in the current (simulation model) settings.

Period	Minimum	Median	Maximum
stack+feed	257	303	331
mix+feed	247	312.5	328
mix/stack+feed	135	191.5	212

Table 6.1: Number of orders per strategy period in simulation model data.

6.1.2 Implementation Decisions

From Chapter 3, it follows that the WCSP as described in the base model can be seen as a sequencing problem with the travelling times as sequence-dependent set up times. Herewith, the WCSP is an NP-hard problem. Hence, to obtain results from the model, some altering and possibly restricting decisions are made for the base model implementation.

To ensure that a feasible integer solution will be found, an initial solution can be included in the model. For the model instances from Section 6.1.1, the input sequence, the simulation output, is set as initial solution. Also, a time limit of 3600 seconds (one hour) is set to avoid lengthy running times. Note that objective values obtained with a time limit are upper bounds on the optimal value, as the objective function is to be minimised.

The model size is brought down by eliminating sets of variables by fixing their values. For this, the best suited variables are the binary decision variables that indicate whether orders are scheduled directly after each other. Not every pair of orders can be sequenced after one another, e.g., feeding orders that need to be completed before a certain truck dump cannot be scheduled after a stacking order corresponding to that truck dump. To generalise this, a rescheduling window is introduced: a range of orders within which orders are allowed to be sequenced right after each other. For each pair of orders that lie further than this window apart, the variable indicating whether the orders are sequenced directly after one another is fixed at value 0, i.e., for $i, j \in J$ such that $|i - j| > window,\ x_{ij} = 0$. With this, the travelling times only have to be calculated for pairs of orders that lie within the rescheduling window.

The size of the rescheduling window is determined based on the number of orders of the same type that is available at the same time. This number is fixed at three ($n_p = 3$). This means that, for example, the fourth stacking (mixing) order is released at the completion of the first stacking (mixing) order. The rescheduling window should cover this number of available orders of one type at all circumstances. Hence, the window size is set to eight. This includes three stacking or mixing orders (either stacking or mixing is allowed in the model instances), a maximum of three validating orders, and possibly two feeding orders. Three is the maximum number of validating orders that three stacking or mixing orders can invoke. The number of included feeding orders follows from the expected time needed to execute the three stacking or mixing orders (and possible validating orders) in combination with the incineration rate.

Besides the elimination of the variables indicating that two orders that lie outside the rescheduling horizon are scheduled directly after each other, the model is speeded up by fixing variables for which the values are already set implicitly. For example, to enforce that an order cannot be scheduled after itself, or that validating orders cannot be the first order scheduled.

In the model objective, the makespan of the orders is incorporated. This ensures that orders are scheduled as soon as possible, without unnecessary delays. The maximum completion time is included with a factor of 0.0001, with which is contributes ten to a hundred times less than the total travelling time as the completion times are at most $\mathcal{O}(10^6)$ while the travelling times within a period sum up to at least $\mathcal{O}(10^3)$.

6.1.3 Output

For some instances, no integer solution was found within the time limit. In these cases, all with a buffer time of 300 seconds, the initial solution proved to be infeasible. On the other hand, several instances, of which all but one with a buffer time of 900 seconds, were solved to optimality within the time limit. The solver identifies solutions as optimal when the gap, the relative difference between the upper and lower bounds on the objective value, is smaller than or equal to 0.01%.

The output of the model from a feasible instance is a list of rescheduled orders. The output includes the original order number, the order type, the release date, starting and completion time (also from simulation), travelling time and the (x,y,z) origin and destination. As an example, the model output for the stack+feed period of day 2 is given in Appendix B.1.

From the output, two types of results can be obtained. First of all, the crane driving time gain (or reduction). Also, the schedule itself can be analysed. The results with respect to the driving times give an idea of the extent in which improvement is possible. The details of the schedule can contribute to the formulation of decision rules to improve the output of the simulation tool and with that, the results obtained in practice.

Total Driving Times

The results of the base model in terms of crane driving times are captured in Figure 6.2. The box plots show the ranges of total driving time gains per strategy period and buffer time. The driving time gain is calculated relative to the output of the simulation model, which also is the initial solution. In Table A.1, the total driving time gain per instance can be found. Note that only 30 out of the 180 instances are optimally solved within the time limit, and that for 28 instances, no integer solution, and hence no output, is obtained.

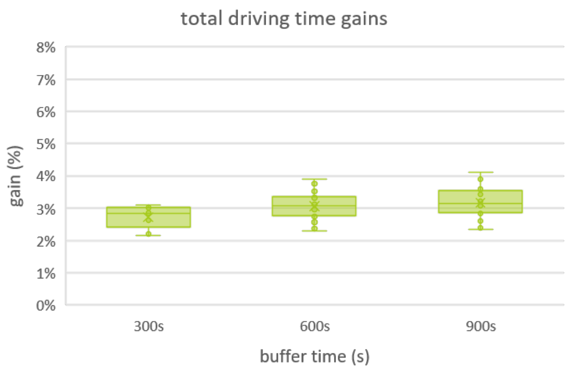
Additionally, in Figure 6.2 and Table A.1, the optimality deviation percentage of the solutions are included to illustrate the quality of the results. The optimality deviation of a solution indicates the difference between the obtained and the maximum total driving time gain. The extent to which the gains are maximal relies on the gaps of the initial and final solution, which are included in Table A.2 for each solved instance. The optimality deviation percentage is estimated based on the initial and final integrality gaps as follows:

$$\text{optimality deviation percentage} = \frac{\text{gap}_{final}}{\text{gap}_{initial}} \cdot 100\%.$$

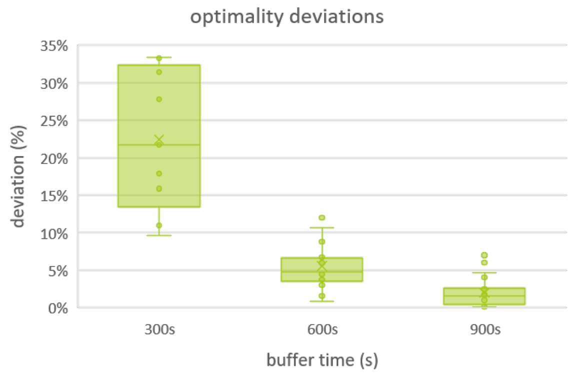
In case the initial solution is already classified as optimal, the deviation percentage is either undefined, if $\text{gap}_{initial} = 0\%$, or, if $0\% < \text{gap}_{initial} \leq 0.01\%$, close to 100%. This is not the case for any of the model instances. For the instances that are optimally solved, the optimality deviation percentage is at most 0.16%. The deviation percentage can be larger than 0% as solutions are considered optimal with a gap smaller than or equal to 0.01%. The larger optimality deviations originate from the contribution of the makespan in the implemented objective as well as from relatively good initial solutions. Also, the values of the integrality gaps are not exact. The initial gaps are rounded off to three significant figures and the final gaps to four decimals. The latter rounding did not effect the results as they are presented with only two decimals. The given percentages are to be considered as indicative values rather than exact results.

The total driving time gains vary from 1.97% to 7.63% over all instances. The gains are the smallest in the stack+feed period, while the gains under the mix+feed strategy are significantly higher. The differences in gains between the two mix periods are partly explainable by the difference in duration of the periods, since the mix+feed period is 60% longer than the mix/stack+feed period. However, the difference in gain is only about 32% (derived from the mean gains for buffer times of 600 and 900 seconds). The stack+feed and mix+feed periods have a similar number of orders, while the stacking period is around 20% longer. In the mixing periods, the orders are scheduled directly after each other. While stacking, the crane gets idle, which results in less rescheduling possibilities of orders as less orders are executed within the buffer time of a feeding order.

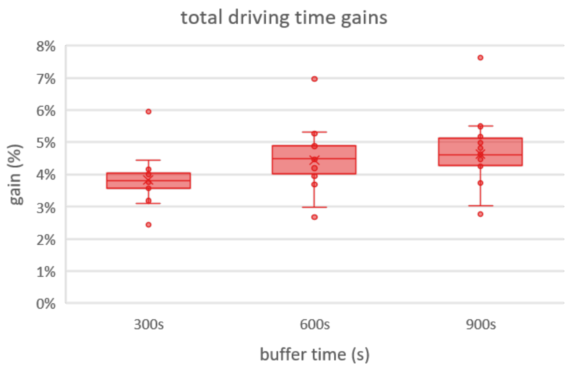
In Figure 6.3, for all instances, the total driving time gains under a buffer time of 900 seconds is plotted against the total number of orders per strategy period. In Figure 6.4, another trend is visible: the larger the buffer time, the larger the gains. This is to be expected, as a solution for an instance with a short buffer time is also a solution for a corresponding instance with a longer buffer time. For the two longer periods, the increase in gains from a buffer time of 300 seconds to a buffer time of 600 seconds is significantly larger, than between a buffer time of 600 and 900 seconds.



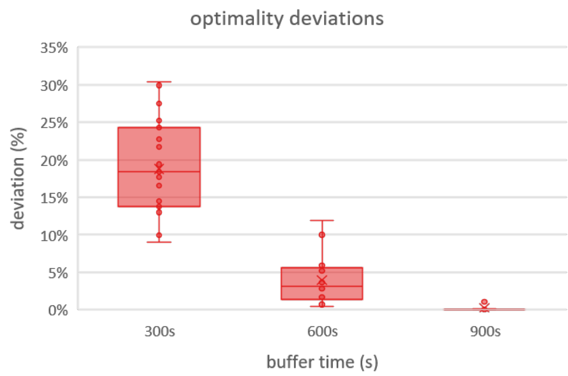
(a) total driving time gains stack+feed



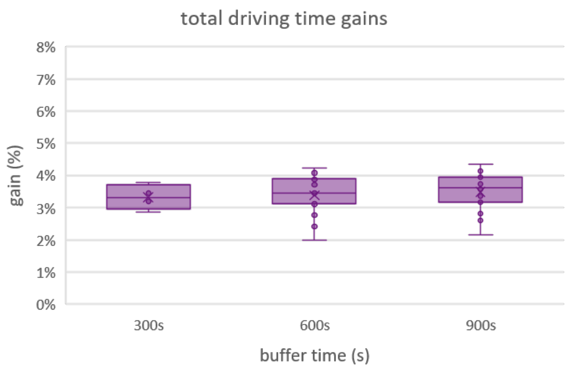
(d) optimality deviation stack+feed



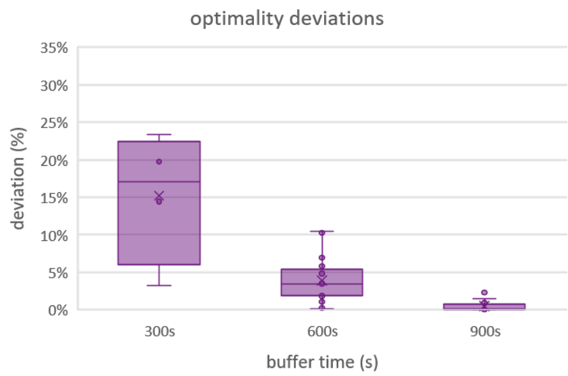
(b) total driving time gains mix+feed



(e) optimality deviation mix+feed



(c) total driving time gains mix/stack+feed



(f) optimality deviation mix/stack+feed

Figure 6.2: Box plots of total driving time gains (left) and optimality deviations (right) per buffer time (300, 600 and 900 seconds) for strategy periods stack+feed (top), mix+feed (middle), and mix/stack+feed (bottom).

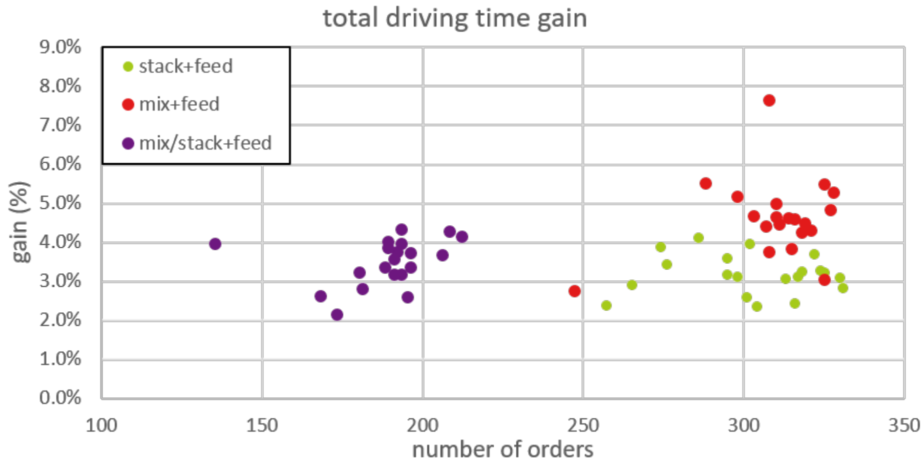


Figure 6.3: Total driving time gain versus number of orders for a buffer time of 900 seconds.

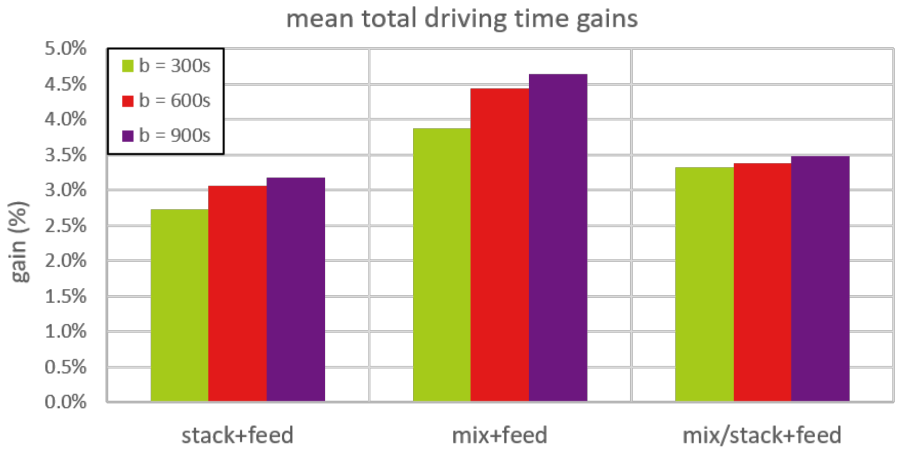


Figure 6.4: Mean total driving time gains per strategy and buffer time.

Remarks on Optimised Schedules

From the optimised instances, the resulting schedules are considered to identify patterns in the optimisation. The optimally solved instances are of the greatest interest. Three fully optimised schedules are considered specifically, namely for each strategy period, the instance with the largest gains under a buffer time of 900 seconds. Hence, for the stack+feed strategy, day 2 has been considered. For mix+feed, day 4, and for mix/stack+feed, day 19. Optimal schedules for those periods are added in Appendix B.1. Note that the optimal schedules are not unique.

In the optimised schedules, feeding orders are regularly clustered into groups of two or more. In the three specific optimal schedules, around 57% of the feeding orders is part of a group of two to five orders. Two factors that possibly prevent feeding order grouping are the restrictions in buffer time and rescheduling window. However, these factors seem to play a role in only about 40% of the cases of single scheduled feeding orders.

The last feeding order of a cluster typically ends in the hopper adjacent to the stacking or mixing zone. This holds for about 65% of the feeding order groups in the schedules of the three specified instances. A reason to deviate from this pattern, is when stacking is done from a non-priority drop location, i.e. from a drop location adjacent to the feeding zone. For feeding orders scheduled as first of a set, the tendency is to start relatively close to the stacking/mixing zone.

Right before a feeding order, stacking is often done towards the feeding zone. Before 77% of the feeding orders/order groups, the destination of the stacking order lies closer to the feeding zone than its origin and/or adjacent to the feeding zone. Moreover, in about 41% of those cases, the crane ends up adjacent to the feeding zone, while originating further away.

Similarly, while mixing after feeding, the crane moves away from the hopper towards the front of the bunker. Hence, the crane mostly moves in y-direction, starting from the origin as close as possible to the hopper (mainly in y-direction). At the start of a mixing period, after a stacking period, mixing orders end in the drop zone. This already determines the mixing away in y-direction for a period of time. But also after the drop zone is levelled up, the trend is that the destinations of mixing orders after feeding, are further to the front of the bunker, away from the hoppers, than their origins.

6.2 Extended Model

In order to obtain results from the extended model, the model needs to be set up via initialisation. The initialisation is discussed in Section 6.2.1, after which the full extended model is considered in Section 6.2.2, as well as a rolling horizon approach to the extended model (Section 6.2.3).

6.2.1 Initialisation

The input for the extended model comprises the sets and parameters from Table 4.2. In this section, the initialisation of the input components is discussed. The initialisation is based on the crane strategies, which effects both the considered time periods and the combinations of order characteristics. An overview of the initialisation values is given in Table 6.3.

Sets and Parameters
For the initialisation of order list J, the (maximum) number of orders in the intended time period needs to be estimated. This is done per strategy period. The number of feeding orders in a period is calculated based on the average incineration rate and the average height of a grab. For stacking orders, the averages of the number of truck arrivals, the truck content and the grab size are taken into account. The number of mixing orders are estimated based on the number of feeding orders and the (minimum) driving times of feeding and mixing orders. The maximum number of validating orders depend on the number of stacking or mixing orders in a period. Table 6.2 shows the estimated number of orders per strategy period. Also, the factor of the estimated number over the maximum number of orders from the simulation is included per strategy period. For the stack+feed strategy, the factor is only 1.04 because of the dependence on the external processes. For the other periods, the factor is about 1.6, giving space to perform additional mixing orders.

In the considered bunker, the drop zone and the hoppers are situated on opposite long sides. The bunker is modelled as a list of location numbers corresponding to (the midpoints of) a 5 by 5 meter grid, in which the left drop zone, the right drop zone, the left bunker half, the right bunker half and the hoppers are distinguished. The model of the bunker layout is displayed in Figure 6.5. Locations 1 to 5 correspond to the left drop zone and locations 6 to 10 to the right drop zone. The left bunker half contains locations 11 to 30, while the right half consists of locations 31 to 50. Locations 51 and 52 are the hoppers.

Strategy Period	Estimation	Factor
stack+feed	344	1.04
mix +feed	525	1.6
mix/stack+feed	325	1.56
day	1213	1.4

Table 6.2: Estimated maximum number of orders per strategy period and rate of estimation over maximum number of orders from simulation.

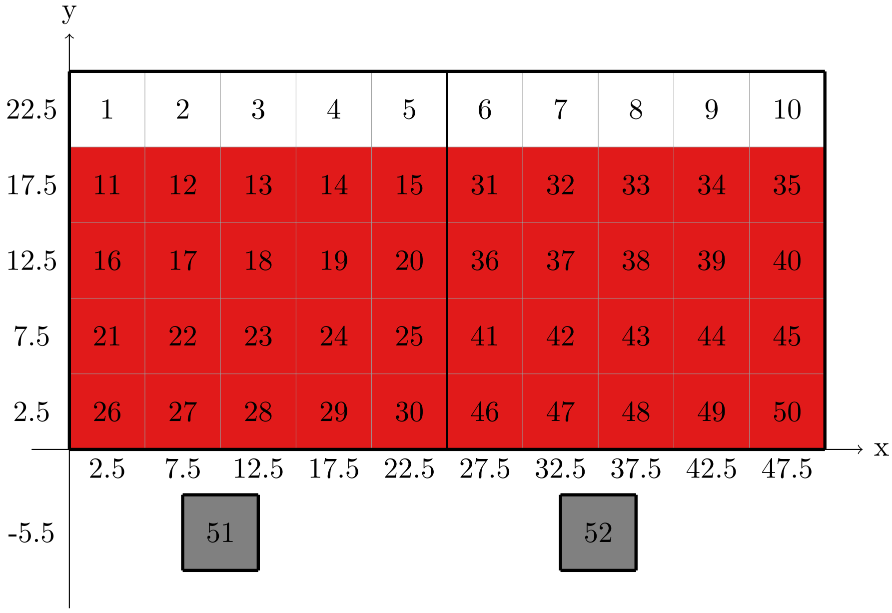


Figure 6.5: Model of bunker layout with location numbers. Drop zone (white), bunker zone (red) and hoppers (grey).

The allowed combinations of order characteristics depend on the strategy periods and bunker zones. For each of the four order types, allowed origins and destinations are considered per strategy period. The used time unit is a fixed number of seconds. All time-related parameters, i.e. truck arrivals, truck dumping times and driving times, are rounded to fit the time unit.

The truck arrival times are extracted from the simulation model, in which they follow hourly and daily patterns based on a number of trucks per week. This number is based on the average incineration rate and the average truck content. The dumping time (in minutes) and truck content (in tonnes) are drawn, independently of one another, from uniform distributions on the intervals [10, 20] and [15, 25], respectively. The incineration process is described by a uniformly distributed incineration rate with bounds at 5% from the mean of 37.5 tonnes/hour.

For the initial waste levels, values from the simulation models are used. To be more specific, the initial values are set equal to the waste levels after the setup day in the simulation. The minimum waste level in the bunker is set to a couple of meters above the bunker floor as the bottom waste is to compact to grab. This minimum level is also assumed for the hoppers. The overall maximum waste level is based on the bunker height. With the hoppers modelled in line with the bunker location, i.e. as square grids without incorporating its funnel-shape, the maximum waste height in the hoppers differs from the overall maximum level. The maximum hopper level is set such that the maximum hopper volume is aligned with reality. For the drop zone, additionally, the maximum dumping waste level is initialised to correspond to the relative height of the tipping bays, i.e. the height from which the truck dumps the waste into the bunker.

The grab sizes of the crane follow for each order type a normal distribution with a cut-off at 0 and two times the mean. The three grab size distributions share the same mean of 1.0368 meter, but differ in variation. The standard deviations are 0.15 for the feeding grabs and 0.25 for the stacking and mixing grabs.

Discretisation

The extended model contains non-linear constraints. These constraints concern the driving times, and more specific, the heights corresponding to the origins and destinations. Therewith, the model non-linearity is related to the waste level. Hence, for the linearisation of the model, all but the incineration related heights are considered in steps of one meter. Herewith, also the heights of the truck content and all grab sizes are rounded off.

Besides the waste levels, also the time is discretised with T a finite set of moments in time. To reduce the size of the model, the time unit is chosen as half the length of a validating order which corresponds to the minimum required travelling time. This time discretisation affects the truck arrival times, truck dumping times and the incineration rate.

Lengthening of Strategy Periods

The strategy periods for the completion of orders and the starting of validating orders are lengthened with the maximum handling time of a feeding order or of a combination of a stacking or mixing order and a validating order. This enables the assignment of completion related characteristics to orders that are being handled at the time a strategy period ends, and, if necessary, the start of a validating order following such an order.

With this, it can occur that an order starting shortly after a strategy transition is assigned a destination from the previous strategy. This does, however, not result in actual inconsistencies. For feeding orders it is no problem to be assigned a destination from the previous period as the set of feeding order destinations is the same in all strategies, and validating orders with starting characteristics from the new period and completion characteristics from the former period are ignored when the origin and destination do not agree.

Stacking and mixing orders are generated under separate strategies. Hence, mixing or stacking orders starting within the additional time period after the stack+feed or the mix/stack+feed period, respectively, are of a different type then the orders that are allowed to be assigned a destination from the former period.

This leaves the mixing orders starting in the beginning of the mix/stack+feed strategy with destination characteristics from the mix+feed period. In that case, it can happen that the mixing order is assigned a destination no longer allowed since the mixing destinations in the mix/stack+feed period are a subset of the mixing destination set under the mix+feed strategy. This would mean that the mixing order ends in the drop zone that is getting cleared in the mix/stack+feed period. So although there is a small inconsistency, it is unlikely to effect the rest of the process because of the time scale (one order versus a strategy period). Also, this is comparable to how it is done in practice.

Parameter	Value / Distribution	Unit
max # orders stack+feed	344	
max # orders mix+feed	525	
max # orders mix/stack+feed	325	
# drop zone locations (x,y)	10	
# bunker locations (x,y)	40	
# hopper locations (x,y)	2	
length stack+feed period	11	hours
length mix+feed period	8	hours
length mix/stack+feed period	5	hours
extra length time periods	120	seconds
truck arrival interval	from simulation model	
minimum waste level bunker	2	meter
minimum waste level hoppers	2	meter
maximum waste level rest bunker	39	meter
maximum waste level hoppers	6	meter
initial waste level drop zone	2 - 3	meter
initial waste level stack zone	10 - 11	meter
initial waste level feed zone	23 - 24	meter
initial waste level hoppers	2-4	meter
maximum dumping waste level	12	meter
maximum number of drops before validating	5	
initial number of drops	0	
dumping time	$\mathcal{U}_d$(10,20)	minutes
truck content	$\mathcal{U}(15, 25)$	tonnes
incineration rate	$\mathcal{U}(0.95 \cdot 37.50, 1.05 \cdot 37.5)$	ton per hour (per hopper)
feeding grab size	$\mathcal{N}(1.037, 0.15^2)$	meter
stacking/mixing grab size	$\mathcal{N}(1.037, 0.25^2)$	meter

Table 6.3: Parameter and initialisation values for the linearised extended model.

6.2.2 Full Model

The size of the model is mainly determined by the scheduling period. The longer the period, the more orders can be scheduled, the larger the range in waste levels, but mainly, the more possible start and completion times. The latter increases the number of model variables (and constraints) through the sets of possible combinations of order types, locations and times. The size of the full model increases so fast that a memory error occurs already for a period of 20 minutes. Note that the (maximum) number of orders and the range of waste levels has been limited as much as possible without proposing additional restrictions.

For a period of 15 minutes, a solution could be obtained when including an initial solution. However, 15 minutes is less than the average truck dumping time and only slightly more than the average incineration time of a grab. Hence, stacking orders following a truck arrival are not incorporated in the truck drop location assignment, resulting in random assignments. Also, the impact of multiple feeding orders cannot be explored as feeding orders are only generated when the minimum level is going to be reached within the time period.

The running time for a 15-minute period is varied to investigate the integrality gap. After one day (24 hours), the final integrality gap is 16.4%. With a time limit of 5 days (120 hours), the gap only slightly improves to 15.6%. The difference in gap is caused by further sharpening the upper bound on the objective, rather than the improvement of the solution itself.

To test the model nonetheless, separate aspects of the model are considered. The test on the validating component of the model led to a new insight. When setting the number of drops at time 0 to $n_l^{max} - 1$ for all bunker locations ($n_{l0} = n_l^{max} - 1,\ \forall l \in L^b$) during a mixing period, no validation orders were scheduled. Instead, mixing orders originating from bunker locations to drop zone locations are initialised.

6.2.3 Rolling Horizon

As alternative to the consideration of the extended model as full optimisation model, the rolling horizon approach described in Section 5.3 is considered as heuristic. In this manner, output for a full strategy period can be obtained.

With the rolling horizon model considering only short periods moving over time through iterations, two new main parameters need to be identified: the scheduling horizon and the time step. Based on the optimisation results, including program running times, the scheduling horizon is set to 7.5 minutes (half the length of the maximum period length in Section 6.2.2), corresponding to a maximum of five orders. The time step between two consecutive iterations relies on the scheduled orders, if any, as the start of the next iteration is set at the completion of the first scheduled order in the current iteration.

As for the rest, the model initialisation, including the discretisation and period lengthening mostly remains as described in Section 6.2.1. The differences lie in the order list J, which is initialised as having length five, and in the lengthening of the scheduling period per iteration instead of the full strategy period. The parameter values that are affected by the adjustments with regard to the general linearisation in Section 6.2.1, are shown in Table 6.4.

Parameter	Value / Distribution	Unit
max # orders scheduling horizon	5	
initial waste level drop zone	2	meter
initial waste level stack zone	10 / 11	meter
initial waste level feed zone	23 / 24	meter
initial waste level hoppers	2.7 / 3.2	meter
truck content	$\mathcal{U}_d(15, 25)$	tonnes
feeding/stacking/mixing grab size	1	meter

Table 6.4: Parameter and initialisation values for the rolling horizon approach on the extended model, altered with respect to Table 6.3.

Iterations

After the model initialisation, the model runs through a finite number of iterations in which an order schedule is generated by extending and altering the list of already planned orders. For this, each iteration requires input from the previous iteration. Of course, the new moment in time needs to be passed on. The starting time of the next iteration equals the completion time of the first scheduled order. If no order is scheduled, which can happen when mixing is not allowed and feeding and stacking are not necessary, the time is set towards the end of the scheduling horizon, but leaving time for (two) feeding orders as they might need to finish soon after the end of the scheduling horizon.

After each iteration, the model is updated. Additional model components such as the crane location, waste levels, number of drops and drop zone status are included to pass the information on the model status. Also, orders that were planned after the first order, if any, are passed on to serve as starting solution for the next iteration.

Stack+Feed Period

For the stack+feed strategy period, a schedule is generated with the rolling horizon method. Although the rolling horizon method did lead to a full schedule, which is presented in Appendix C, the output is rather insignificant. On top of the various simplifications, from waste level and time discretisation to using a very short scheduling horizon, there was little room left for optimisation within the time limit of 1000 seconds for the optimisation part of each iteration. The obtained schedule for a ten hour period is the result of a five day run. Because of this long running time, in combination with the insignificant results, only one run has been done. Also, no mixing periods are considered as the model would be even larger due to more possible combinations of order characteristics.

In order to make the rolling horizon model work for the stack+feed period, some adjustments need to be made. The first alteration follows from the rolling horizon characteristic of procrastination. In general, orders will only be generated if necessary within the scheduling horizon. Hence, stacking orders will only be scheduled when the drop locations are running full. However, waiting with stacking until all drop locations are full will result in trucks that cannot be assigned a dump location, as well as full(er) drop locations at the end of the strategy due to less stacking orders being scheduled. Hence, for the rolling horizon model to run smoothly, a stacking incentive is added in the same manner as mixing orders already are, i.e. by incorporating the maximisation of the number of generated stacking orders in the objective. The weight coefficient of the driving times is set to align with the scale of the number of stacking orders. As a downside of this intervention, orders of different types will now only be planned if there is no easy way around them, as they are inferior to stacking orders. However, (non-stacking) orders are already delayed because of the minimising of the handling time. Note that is also what happens in practice.

As Equation (6.1) shows, also the starting times are added to the rolling horizon model objective, but with a very small factor. This to prevent orders that are earlier available to be scheduled further into the period. Herewith, no idle time is build in unnecessary, leaving more time for orders in the following iterations. In the same line, it needs to be prevented that a stacking order that only becomes available too close towards the end of the scheduling period is scheduled as first order. As it can happen that soon after the scheduling horizon of an iteration, two feeding orders are required, it is ensured by Constraint 6.2 that at the end of the horizon, the driving time of two feeding orders is kept free from starting stacking orders. This is in correspondence with the maximal 'shift forward time' after an iteration in which no orders are scheduled. It only needs to be enforced for the first order as that is the only one scheduled in that iteration.

$$\text{maximise} \sum_{j \in J} \sum_{(l,t)|(s,l,t) \in Q^s} s_{jslt} - 0.001 \sum_{j \in J} (h_j + t_j) - 0.000001 \sum_{j \in J} s_j \tag{6.1}$$

$$\sum_{l|(s,l,t) \in Q^c} c_{1slt} = 0, \ \forall t > \text{horizon} - 2 \cdot \text{feeding driving time} \tag{6.2}$$

Counting from the first stacking order after opening hours, as in base model instances, to an hour after opening hours, the generated schedule in Appendix C comprises a total of 267 generated orders, of which 83 feeding orders, 163 stacking orders and 21 validating orders. With 267 orders, the size of the schedule lies in the lower range of the stack+feed base model instances originating from the simulation model.

In line with the (stacking order) procrastination, the first validating order is generated after about 4.5 hours. As they are only scheduled when necessary, validating orders are put on hold until all 'stack to' locations have reached the maximum number of drops without consequences ($n^{max} - 1$). Apparently, it is 'cheaper' to drive further in a stacking order than to insert a validating order. This indicates that the differences in driving times are smaller than the length of a validating order. Although it suits the rolling horizon method, the stack+feed schedule from the simulation model of which the by the base model rescheduled output can be found in Appendix B.1, shows practically the same patterns. The first validation order is scheduled after just over 4.5 hours, the same number of stacking orders is scheduled and only one validating order more. Over all 20 simulated stack+feed schedules, however, the average number of stacking orders per validating order lies about 20% lower.

At the end of the strategy period, the two drop locations the furthest away from the stacking zone are (almost) full, while the other drop locations are not more than one truck dump filled. This shows that the truck dump location assignments are done randomly, which corresponds with the fact that the truck dumping time exceeds the scheduling horizon. While the model can look back over a longer period via the information on open/blocked drop locations, it is not possible to look further ahead than the scheduling horizon.

6.3 Decision Rules

From the analysis of the results of the base model in Section 6.1.3 and the extended model in Section 6.2.2 and Section 6.2.3, a set of decision rules is established. Note that both models only consider the case with one waste crane.

Rule 1 (Feeding 1)**.** *If a crane is assigned a feeding order, also feed other hopper(s).*

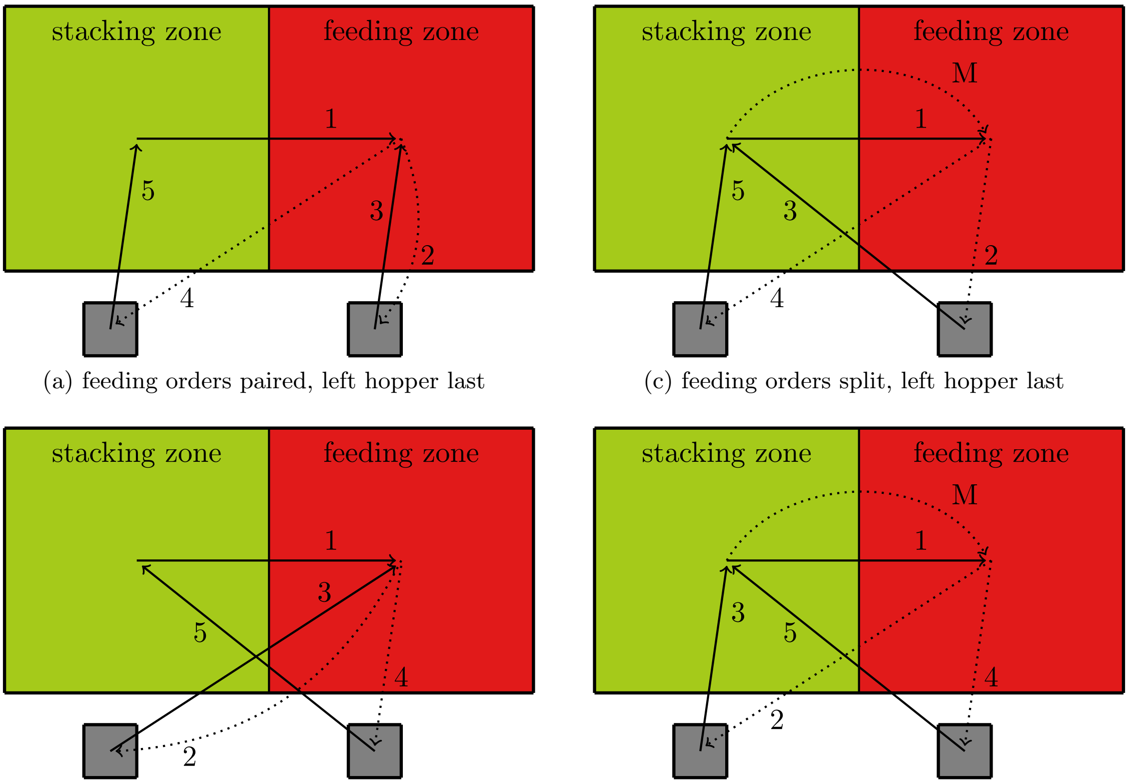
In the base model, feeding orders are often grouped to reduce the crane driving times. The scheduling horizon in the rolling horizon model is too short to either support or contradict this.

Feeding orders are typically generated when hoppers are running low in the waste supply. The threshold is set relatively high in order to keep the passage from the hopper to the furnace airtight. Still, enough hopper capacity remains to receive more waste in a shorter period of time. Moreover, as Figure 6.6 (left versus right) shows in distance, pairing feeding orders reduces the total travelling time around these orders.

Rule 2 (Feeding 2)**.** *When executing a group of feeding orders, end with one to the hopper closest to the stacking zone.*

In the base model, almost every cluster of feeding orders ends with an order to the hopper adjacent to the stacking (mixing) zone. Only in clusters of a larger number of feeding orders, this is not necessarily the case. Again, the scheduling horizon in the extended model cannot be used to derive rules for feeding orders.

When grouping more than two feeding orders, there certainly is time to move a second order to the hopper adjacent to the stacking zone, leaving time to perform the orders to the other hopper first. Figure 6.6 (above versus below) supports possible gains in travelling time.



(a) feeding orders paired, left hopper last (c) feeding orders split, left hopper last

(b) feeding orders paired, left hopper first (d) feeding orders split, left hopper first

Figure 6.6: Schematic driving routes when performing two feeding orders while mixing (or stacking). The feeding orders are paired (left) or split (right), and the hopper adjacent to the stacking zone (here: left hopper) is last (top) or first (bottom). Travelling routes are solid, handling and non-feeding routes are dotted. (1) travelling to first feeding order, (2) handling first feeding order, (3) travelling from first feeding order, (4) handling second feeding order, (5) travelling from second feeding order, (M) mixing order in between feeding orders.

Rule 3 (Locations)**.** *While handling an order, move away from the previous destination and towards the next origin.*

Both in the base and extended model, the tendency is to start relatively close to the destination of the previous order and to end in the direction of the origin of the next order. For example, for mixing orders following a feeding order it is preferred to have the destination lying further away from the hopper than the origin, and hence, to move away from the hopper. In this manner, not only the origin of the next order is taken into account for the current destination, but also its own origin.

Of course, for stacking and feeding, the origin and destination, respectively, are given as input. This means that for the starting location of a feeding order both the previous and current destination are relevant, while for the destination of a stacking order mainly its own origin will be taken into account.

Rule 4 (Validating)**.** *If mixing is allowed, mix from the location that requires validation.*

In the extended model, no validating orders are executed during mixing strategies. Instead, mixing orders originating from locations with a maximum number of drops are generated.

Validating orders are included to verify the waste level as this is uncertain (in reality) because of varying grab sizes and waste tumbling. However, the waste level at a location is also validated when a crane grabs from it, i.e. when an order starts from that location. During stacking, no orders are allowed to start from the location where orders end. However, while mixing, orders are allowed from any possible destination inside the bunker. Hence, indeed, validating orders are not necessary for waste level validation during mixing periods.

Chapter 7

Simulation Results

In this chapter, the decision rules established in Section 6.3 are translated into the simulation model. In Section 7.1, the model cases are presented. The base case of the simulation model is described, after which the decision rules are interpreted and incorporated into four simulation cases. In Section 7.2, the key performance indicators are introduced, and in Section 7.3, the location scoring weight factor, as part of decision rule 3, is determined. The effects of the decision rules are discussed per model case in Section 7.4.

7.1 Model Cases

The decision rules derived from the base and extended model in Section 6.3 are incorporated in a follow-up of the simulation model described in Section 2.4. The deviations between the follow-up model and the model presented in Section 2.4 are described in Section 7.1.1.

The decision rules are incorporated in four different simulation model cases. Feeding rules 1 and 2 are combined in case 1, while location rule 3 and validating rule 4 are considered separately in cases 2 and 3, respectively. Case 4 includes all four rules. Both in case 2 and case 4, rule 3 is only implemented for mixing orders. With the focus on mixing, the implementation for the other order types is considered out of scope. An overview of rules per case is given in Table 7.1.

	Rules			
Case	1	2	3[1]	4
1: feeding	x	x		
2: locations			x	
3: validating				x
4: all	x	x	x	x

Table 7.1: Overview of decision rules incorporated in simulation model cases.

7.1.1 Base Case

The base case of the follow-up simulation model is based on the exemplary case described in Section 2.4. Hence, two active cranes are considered in a 100 x 25 x 39 meter bunker with a drop zone, alternating stacking and feeding zones and four hoppers. In addition to the 20 x 5 'location grid', the new model has an overlying 'waste grid' of 1 x 1 meter grid slots. This

[1]only for mixing orders

finer grid supports the incorporation of waste tumbling. Based on a maximal angle between the heights at adjacent slots, dropped waste spreads over multiple slots.

As in the former version of the simulation model, three weeks are simulated. However, in the follow-up, the first full week is set-up, so only two weeks of data is to be considered. Because of this, the case that a crane is being serviced in the middle of the bunker is omitted.

7.1.2 Decision Rules

The decision rules on feeding, locations and validating are translated into the simulation model. Per rule, the interpretation of the rule is given.

Rule 1 (Feeding 1):
In the simulation model, a feeding order is generated when somewhere in a hopper the waste level drops below a predefined threshold. The order is assigned to the drop spot closest to that lowest point. Applying decision rule 1, in addition to this one order, feeding orders for all drop spots of all hoppers within the crane work zone are generated. Hence, groups of four orders are generated, and planned to be executed. During execution, it is ensured that only the orders that will not overload the hoppers are carried out. A margin of 1.5 meter is taken into account.

Rule 2 (Feeding 2):
In the simulation model, generated (feeding) orders are selected to be executed mainly based on its time of generation.

For a cluster of feeding orders to conclude with an order to the hopper adjacent to the stacking zone, the orders to that hopper are postponed when the waste level in the concerned hopper has not yet reached the threshold and an order to the other hopper in the crane work zone is available.

Rule 3 (Locations):
In the simulation model, the origin and/or destination of an order is determined based on waste levels, in correspondence with the example rules mentioned in Table 2.1. So, for mixing orders, the location in the 'mix from zone' with the maximum waste level is set as the orders origin, and the location in the 'mix to zone' with minimum waste level as its destination.

When determining the origin location for a mixing order according to the new decision rule, all locations from where it is allowed to mix are scored based on the (x,y) distance to the destination of the previous order of the crane and the difference between the waste level at this location and the maximum waste level in the 'mix from zone'. Subsequently, the destination of the mixing order is determined. The locations are scored similarly, but for the (x,y) distance its own origin is used, and for the difference in waste level, the minimum level in the 'mix to zone' is considered. The origin of the following order cannot be taken into account in the determination of the destination because, in the simulation model, at the moment of generating an order, the following order is not yet known.

Because (x,y) distances are around a dozen meters and level differences typically a couple of meters, the (x,y) distance is scaled by a factor 0.1. Equation (7.1) shows the general formula for the scoring of the locations, with λ representing the weight factor between the scaled (x,y) distance and the waste level difference. The value of λ is determined in Section 7.3.

$$\text{score} = \lambda \cdot \text{scaled (x,y) distance} + (1-\lambda) \cdot \Delta(\text{waste level}) \tag{7.1}$$

In a similar way, the destinations of stacking orders and the origins of feeding orders can be adjusted. For feeding orders, both the destination of the previous order and of the feeding order itself can be taken into account.

Rule 4 (Validating):
In the simulation model, validating orders are generated for a specific grid slot when the number of drops since an order started from that slot has reached the set maximum (of five). With this decision rule, before generating a validating order, it is checked whether or not mixing orders are allowed. If it is allowed, instead of a validating order, a mixing order is generated for the concerned grid slot. With this, it is ensured that the mixing order starts from the location that requires validation.

7.2 Key Performance Indicators

The effects of the decision rules on the simulation model are reviewed based on key performance indicators (KPIs). The KPIs mainly concern the crane driving times, the number of orders and the mix quality. In Table 7.2, the KPIs are listed and described. Figure 7.1 shows the categorisation of the KPIs.

The first two sets of KPIs, the driving time KPIs and the number of orders KPIs, are mainly quantitative measures. For each order type, feeding, stacking, mixing and validating, the average driving time is calculated.

The third group of KPIs are the mixing KPIs. Besides the average driving time of mixing orders and number of mixing orders, a more qualitative aspect is considered in the 'mixed share' KPI. This KPI represents the average share of waste that has been mixed (once or more times) before it is fed. Note that the average number of times waste is mixed depends on the number of mixing orders and the variable amount of waste delivered.

Table 7.2 also includes whether or not an increase in KPI value is viewed as a positive effect. Keeping in mind that the focus lies on crane performance, including waste homogeneity, the desired and undesired effects are clear. Desired effects are decreasing driving times, increasing number of mixing orders, and increasing share of waste that is mixed. Undesired effects are an increasing number of non-mixing orders (feeding/stacking/validating).

From the decision rules on feeding, locations and validating, no effect on the driving time of validating orders or the number of feeding and stacking orders is to be expected. The driving time of validating orders only depends on the crane specifications, including the grab size. The number of feeding and stacking orders are directly related to the incineration and the truck arrivals, respectively, two factors outside the scope of the decision rules.

7.3 Location Scoring Weight Factor

The location scoring weight factor λ in Equation (7.1) is determined based on trial runs with 20 replications. With the (x,y) distance already scaled down to the same order of magnitude as the waste level difference, $\lambda = 0.5$ can be considered as equilibrium. Note that for this value, 1 meter of waste level difference and 10 meters of (x,y) distance contribute equally as much to

KPI	Description	Positive Effect
feeding driving time	average driving time of feeding order	decrease
stacking driving time	average driving time of stacking order	decrease
mixing driving time	average driving time of mixing order	decrease
validating driving time	average driving time of validating order	-
feeding orders	total number of feeding orders	-
stacking orders	total number of stacking orders	-
mixing orders	total number of mixing orders	increase
validating orders	total number of validating orders	decrease
mixed share	average share of fed waste that has been mixed	increase

Table 7.2: Simulation model KPIs, their description and whether a decrease or increase in KPI value is a positive effect.

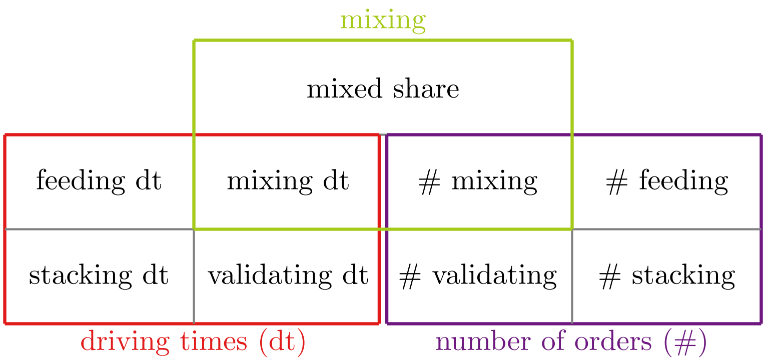


Figure 7.1: Overview of KPIs per category: mixing (green), driving times (red) and number of orders (purple).

the score. The smaller λ, the more the focus shifts towards the waste levels, and hence, closer to the base case, which corresponds to a scoring factor of $\lambda = 0$. The larger λ, the more the focus shifts towards the (scaled) distance, away from the base model.

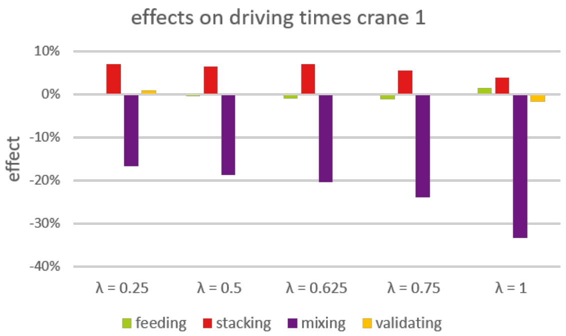
The considered location scoring weight values are $\lambda = 0.25$, $\lambda = 0.5$, $\lambda = 0.625$, $\lambda = 0.75$ and $\lambda = 1$. From Equation (7.2) it follows that for values $\lambda = 0.25$ to $\lambda = 0.75$, 30, 10, 6 and 3.33 meter of (x,y) distance, respectively, contribute as much as 1 meter waste level difference to the score of a location (as defined in Equation (7.1)).

$$\#\text{m (x,y) distance contributing as much as 1 m level difference} = \frac{(1-\lambda)}{0.1\lambda}. \tag{7.2}$$

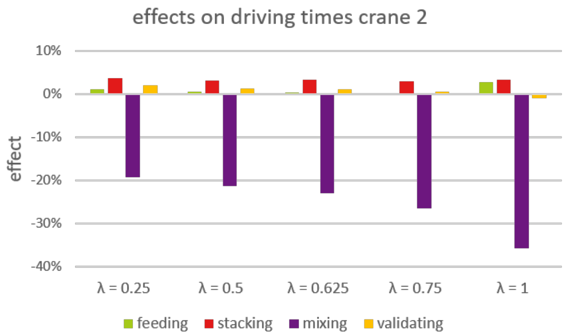
Figure 7.2 shows the effects of the runs on the driving times, number of orders and mixing KPIs listed in Section 7.2 relative to the base case of the simulation model. From the results concerning the mixing KPIs (Figures 7.2e and 7.2f), several trends can be observed. The larger λ, the larger increase in total number of mixing orders and the larger decrease in the average driving time of mixing orders. The increase in number of mixing orders grows faster than the decrease in mixing driving times.

For the larger values of λ, the larger λ, the larger the decrease in the share of mixed waste. A plausible explanation would be that due to the shorter distances, the crane mixes more often in the same area, and more superficial. This does, however, not explain why the trend does not continue for $\lambda = 0.25$. This trend concerning the mixed share is an undesirable trend as a decrease in mixed share is unfavourable for the waste homogeneity. However, for all λ, a negative effect on the mixed share KPI is observed. For $\lambda = 0.5$, this effect is the smallest (-4.97% and -6.37%), closely followed by $\lambda = 0.625$ (-6.15% and -6.71%).

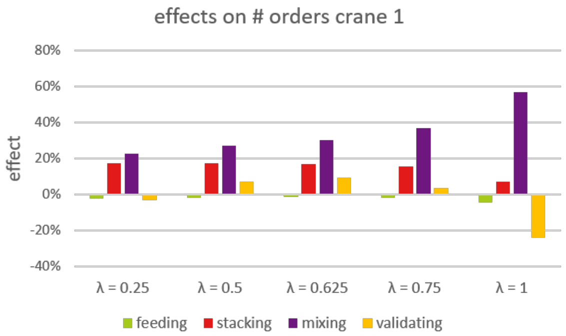
Regarding the KPIs on driving times (Figures 7.2a and 7.2b) and number of orders (Figures 7.2c and 7.2d), the significant increase in number of stacking orders and stacking driving times are remarkable. Concerning the number of stacking orders, a slight trend can be detected: the larger λ, the smaller the increase. Though an increase in number of stacking orders is unanticipated, it is not considered as a negative effect since stacking can be seen as a special case of mixing. This effect does not contribute to the discussion on the value of λ as it depends on the waste delivery, stacking grab sizes and waste tumbling. The other non-mixing KPIs do not show remarkable deviations for certain λ values.



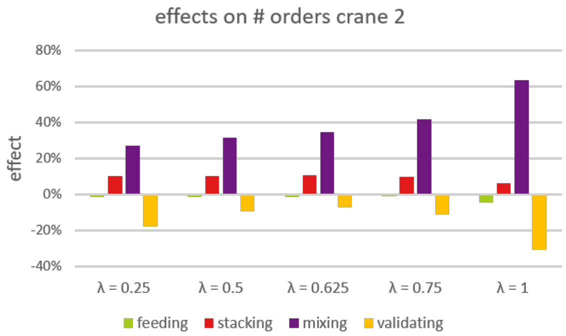
(a) effects on driving times crane 1



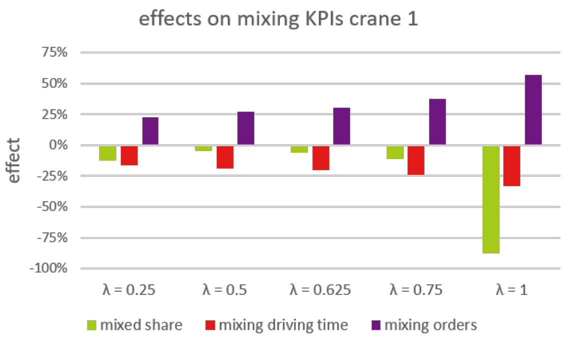
(b) effects on driving times crane 2



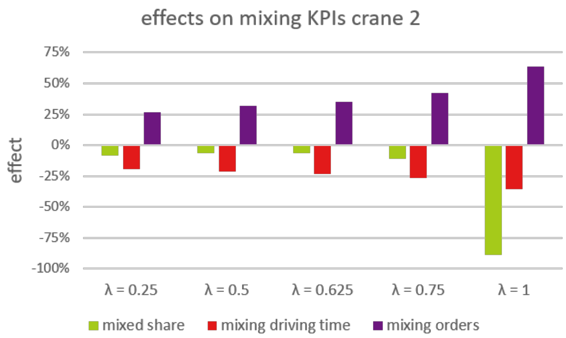
(c) effects on number of orders crane 1



(d) effects on number of orders crane 2



(e) effects on mixing KPIs crane 1



(f) effects on mixing KPIs crane 2

Figure 7.2: Effects of decision rule 3, relative to $\lambda = 0$, on driving times, number of orders and mixing KPIs for several values of location scoring weight factor λ, based on 20 replications.

As candidate location scoring weight factor, $\lambda = 0.5$ is proposed. This value scores the best, or the least bad, on the mixed share KPI, while showing substantial positive effects on the mixing driving times and the number of mixing orders. Also, no deviations on other KPIs are observed for this value. The effects of the location decision rule will be discussed further in Section 7.4.

7.4 Effects of Decision Rules

The results of the model cases with respect to the KPIs are presented in Figure 7.3, per KPI category and crane. For each case, including the base case, 20 replications are done. Per case, the averaged results are analysed and compared to the outcomes of the base case.

Whether or not a result is significant can be determined based on the effects on KPIs on which no effect is to be expected. Overall, the decision rules should have no effect on the driving time of validating orders, or the number of feeding and stacking orders. Hence, the measured effects on these KPIs are a result of limited testing, and therewith, they indicate an insignificant effect size.

In theory, the two cranes should show the same behaviour. Indeed, the trends in Figure 7.3 are very similar. However, the sizes of the effects do show significant differences. In absolute terms, crane 1 structurally performs more mixing and less stacking orders than crane 2. Feeding and validating driving times are longer for crane 1, while the driving times of stacking and mixing orders are shorter. Also, under crane 1, the share of mixed waste is smaller. In relative terms, however, the increases and decreases on these KPIs are more varying.

The inclusion of the decision rules in the simulation model has limited effect on the model run time. In Table 7.3, the average run time of a replication is given per model case. For cases 2 and 3, the model run time has somewhat increased, with 2.4% and 1.9%, respectively. The run time of cases 1 and the all-including case 4 have decreased with 2.6% and 4.8%, respectively. However, the changes in run time are subject to the used server and its occupation. In combination with the limited number of replications, the observed run time differences are not significant.

	Base Case	Case 1	Case 2	Case 3	Case 4
Run Time	04:23h	04:16h	04:29h	04:27h	04:10h

Table 7.3: Average replication run time per model case.

Case 1: Feeding

The clustering of feeding orders has resulted in small decreases in driving time of feeding, stacking and mixing orders, as is to be expected when shortening the travelling distances (Figure 6.6). The decrease in the driving times of mixing and feeding orders contribute to the generation of extra mixing orders, which in its turn boosts the mixing KPI ‘mixed share’, i.e. increases the rate of waste pieces that are mixed before fed.

The changes in the total number of feeding orders are insignificant, supporting the implementation. On the validating orders KPI, a significant effect is observed. The number of validating orders dropped. This can (partly) be explained by the increase in number of mixing orders. With more mixing orders being handled, it becomes more likely to prevent a validating order by mixing from a location that would otherwise require validation.

Note that the generating of feeding orders per four can lead to feeding order clusters consisting of a multiple of four orders. This happens when a drop spot runs low while it has an order scheduled that was generated previously by another drop spot, but not yet executed. Typically, the clusters consist of four to twelve orders, but every now and then, more than twelve orders are grouped, up to 24. It takes about 50 minutes to execute a cluster of 24 orders, after which no feeding orders are scheduled for 3.5 hours. The extensive clustering can be prevented by setting a maximum number of not yet handled orders per hopper.

Case 2: Locations

The location rule for mixing definitely shows the largest effects. The large positive effects, up to 30%, on mixing driving times and number of mixing orders stand out. This strong positive effects do, however, not translate into a larger amount of waste being mixed. Even a decrease in mixed share, the KPI for waste homogeneity, can be observed. This means that a selective share, mostly at the surface, is mixed more often.

An unanticipated side effect is the significant increase in number of stacking orders and their average driving time. The number of stacking orders depends on the amount of waste delivered, the stacking grab sizes and the amount of waste tumbling back into the drop zone. The first two can be considered external factors, with which the location rule has no relation. The latter factor, however, can be partly seen as a consequence of the location decision rule as there might be mixed closer to the drop zone because of the waste level difference with the drop zone and continuous tumbling. In any way, this explanation does not support the size of the increment . The tumbling and (re-)stacking can be considered as extra mixing, so the effect on the number of stacking orders is not seen as a disadvantage. The increase in stacking driving time is likely to be a side effect of the increase in number of stacking orders. With handling more stacking orders, waste needs to be stacked further away, i.e. higher and further into the bunker, which lengthens the driving time.

Though out of scope, the location decision rule can be extended to the destinations of stacking orders, and origins of feeding orders. Especially for the feeding orders, the destination of the preceding order can be incorporated in the determination of the origin. From the strong results for the mixing orders, a significant decrease in the driving time, more specifically the travelling time, of feeding orders can be expected.

Case 3: Validating

The main result of the validating decision rule, rule 4, is the decrease in total number of validating orders. Although the decrease is substantial, the effect is relatively small considering that mixing is allowed for more than half the time. However, in the base case, most validating orders are scheduled during stacking because with mixing, already validating orders are prevented.

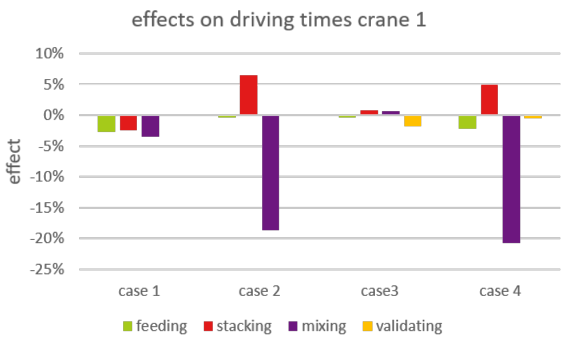
Compared to the considerable decrease in number of validating orders, the increase in number of mixing orders is minimal. This can be explained by two factors. Firstly, the driving time of a mixing order is substantially longer than the driving time of a validating order. Secondly, the presented results are the relative effects. In the mixing periods, between the total number of mixing orders and the total number of validating orders, there is a minimum factor corresponding to the maximum number of drops before validating. Together, these two factors explain the difference in scale of the effect.

Though the substitute mixing orders have a fixed origin, no significant increase in the average mixing driving time is visible. This is probably due to the small number of extra mixing orders.

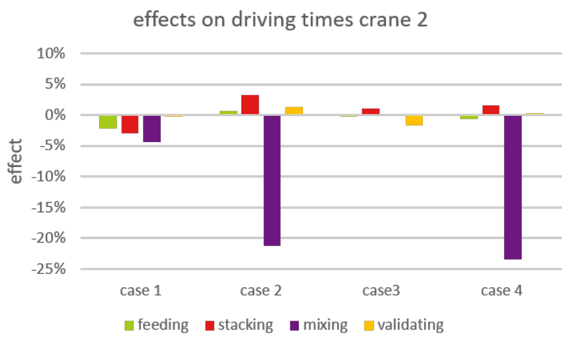
Case 4: All

For this case, in which all decision rules are combined, the effects on most KPIs are an accumulation of the effects of the separate rules. Only for the number of validating orders and the mixed share, this does not seem to hold. The effect on the validating order KPI is less favourable than the accumulation, though still substantial.

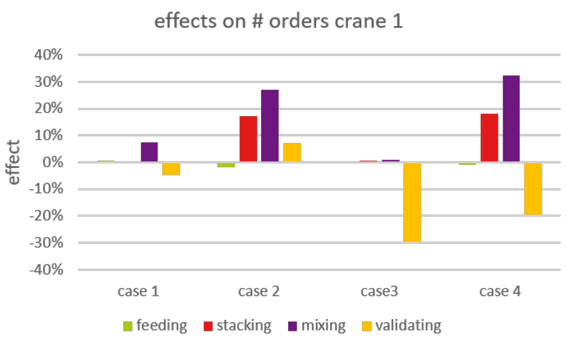
For the mixed share KPI, the effects per crane deviate somewhat from each other. For both, the mixed share has decreased further. The negative effect under crane 1 has increased significantly, while under crane 2, the additional decrease is limited.



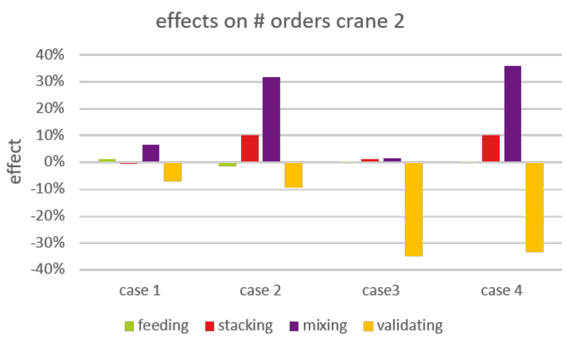
(a) effects on driving times crane 1



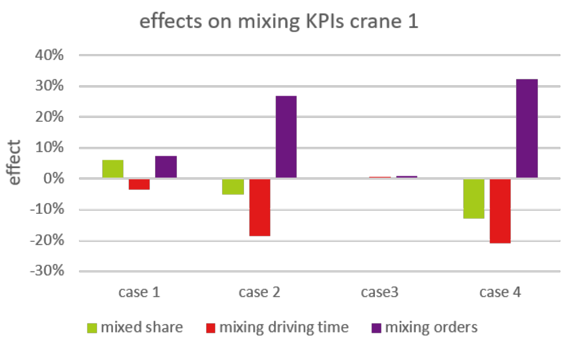
(b) effects on driving times crane 2



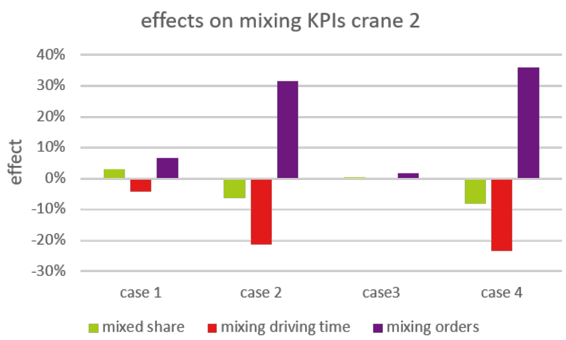
(c) effects on number of orders crane 1



(d) effects on number of orders crane 2



(e) effects on mixing KPIs crane 1



(f) effects on mixing KPIs crane 2

Figure 7.3: Effects of decision rules on average crane driving times (per order type), total number of orders (per order type) and mixing KPIs (average number of times waste is mixed, average share of waste that is mixed, average driving time of mixing orders, average number of mixing orders) in simulation model, based on 20 replications per case.

Chapter 8

Discussion and Conclusions

In this thesis, the way in which optimisation-based decision rules can improve the performance of waste handling cranes is studied. Herefore, the waste crane scheduling problem (WCSP) is formulated, which describes the crane operations within the context of the waste-to-energy process.

With only one paper found on the subject of waste crane scheduling, related work on crane scheduling and sequencing is considered. Based on the literature, a mixed integer (linear) programming (MILP) is chosen as modelling framework. Two different models are constructed: the base model and the extended model.

In the base model, crane orders scheduled by TBA's simulation model are resequenced. In the extended model, the generation of the orders is included. In both models, one crane in considered. The results of the two models are used to derive decision rules that control the generation and scheduling of waste crane orders. The performance of implementing the decision rules is obtained by including them into the simulation model.

After the research and the obtained results are discussed extensively in Section 8.1, the main conclusions and recommendations for future work are presented in Section 8.2 and Section 8.3, respectively.

8.1 Discussion

The results of this research on the improvement of the performance of waste handling cranes, and the research itself are discussed by addressing the three main models: the base model, the extended model and the simulation model. Additionally, the waste homogeneity is addressed.

Base Model

In the base model, output from the simulation model is rescheduled for one crane to minimise the crane driving times. With the rescheduling of instances corresponding to a strategy period containing 135 to 331 orders, total driving time gains up to 7.63% were obtained. However, only 30 out of 180 instances were solved to optimality. Moreover, for 28 instances, no integer solution was found within a time limit of one hour.

For all instances of the latter kind, the buffer time, the maximum time between the generation and the completion time of a feeding order was set at 5 minutes (300 seconds). With the schedule from the simulation model set as initial solution, this shows that the (in practice) aimed time of 5 minutes cannot always be attained. As buffer time values, also 10 and 15 minutes are considered.

In practice, however, 15 minutes is not a reasonable value as it is close to the average incineration time of a feeding grab and therewith, an airtight connection to the furnaces cannot be assured. Nonetheless, it gives an idea of the effect of the buffer time on optimal solutions.

Lengthening the feeding buffer time to 10 minutes, resulted in feasible solutions for all periods. The increase in gain between a buffer time of 5 and 10 minutes is substantial, especially for the longer periods. The further improvement in gain when applying a buffer time of 15 minutes is significantly less. This can be explained by the fact that more than half of the periods were solved to optimality with a 15 minute buffer, and hence, already for the 10 minute buffer, the solutions were close to optimal, leaving little room for improvement. However, the largest difference in increase in gain is obtained for the stacking period, of which only 10% was optimally solved.

Overall, the stacking periods show the smallest gains over the three strategy periods, even though it is the longest period with, jointly, the highest number of orders. This supports the idea of the flexibility of mixing over stacking, with shorter driving times and varying origins.

A set of modelling choices is responsible for the non-optimal outcomes. A main factor is the model running time limit of one hour. With a longer running time, or more computational power, of course, more instances would be solved to optimality. However, the modelled problem being NP-hard, the time limit should probably be so much increased that running all instances would not be feasible anymore. The number of optimally solved instances is also dependent on the 'optimisation speed' of the solver. However, Gurobi is known as a fast and competitive MILP solver. So, not much improvement is to be expected by switching solver.

Furthermore, the quality of the results is influenced by the (re)scheduling window. With the rescheduling window, only orders that were at most eight orders apart in the original sequence from the simulation model are allowed to be sequenced directly after each other. Herewith, especially the freedom in deciding on mixing locations is limited. In theory, mixing orders and their origin and destination are independent of time, though the state (waste levels, start/end of period) should be taken into account to some extent. Feeding and stacking orders are much more time dependent, as their generation is dependent on the boundary processes of waste delivery and incineration. Introducing the rescheduling window improved the running time - optimality rate, but without it, the gains for the mixing periods might be larger. On this, no experiments were conducted.

Extended Model

The extended model combines the generation and the sequencing of orders. A significant drawback of the model is that it is formulated for the case of one crane. However, for the rest, the model is rather general as the input determines the modelling aspects such as the bunker layout, strategy periods, opening hours and crane specifications. Though not considered here, the model can, for example, manage it when stacking and mixing are allowed at the same time.

In order to linearise the model, the waste level and time needs to be discretised. Rather large waste level and time units were proposed to reduce the model size. Herewith, the discretisation of the waste level led to a big loss in variation, e.g. in arriving waste and incineration speed. Also, the spread in travelling and handling times are almost cancelled out as the smaller, but significant, differences fall within a time unit.

The main obstacle regarding the implementation of the extended model was the size of the model. The size of the full model increases so fast over time that 15 minutes proved to be the maximal achievable scheduling period on a personal computer. Since the problem is the memory needed to set up the model, using an external server such as the NEOS Server[1] was not an option as most of them require a model as input, after which the optimisation can be run. Also limiting herein, is the use of Gurobi in setting up the model. This can be done more general such that only the optimisation requires Gurobi, enabling to build the model without a license.

As alternative, a rolling horizon approach is applied on the extended model. With this method a full (stacking) strategy period can be scheduled. A scheduling horizon of 7.5 minutes already required a time limit to keep the total running time considerable. With a time limit of 1000 seconds, it already took over five days to generate a schedule of 267 orders. So, when extending the scheduling horizon, e.g. to the current maximum of 15 minutes, most likely the time step needs to be adjusted to somewhat limit the total running time. The next iteration now started at the completion of the first scheduled order. By altering it to the completion of the second order, the time step will significantly lengthen and the number of iterations decrease. Herewith, instead of one order, two orders will be written away into the schedule per iteration. This has not been considered in this project.

Simulation Model

An important note on the simulation model is that during this research, the model was still under development. Hence, the model version used for the base model input differs from the version with which the results of the decision rules are obtained. The second version is more detailed and more inclusive, e.g. with regard to the waste level.

The decision rules derived from the optimisation models only consider one crane, while the simulation model considers two cranes in a bunker double the size. Because the cranes do have their own working areas in the model, the interaction between the cranes, and hence, the effects of not considering them together, are limited.

With the current implementation of the feeding rules, the only limit in the scheduling of (groups) of feeding orders is that a hopper is not allowed to be overloaded. A 1.5 meter margin is reasonable, however, it results in clusters of up to 24 feeding orders, which takes about 50 minutes to handle. This can be considered impractical, for example because in this model, in the hour before opening, mixing is no longer allowed, and only a very limited number of stacking orders can be carried out. Hence, a suggestion would be to limit the number of orders generated per hopper, to a number between 2 and 6, resulting in clusters of at most size 12. Of course this would depend on the number of hoppers in a crane working area, so, more general, the number of generated feeding orders per crane should be limited.

The location decision rule has only been implemented for mixing orders. Considering the substantial effects on the driving time and the number of mixing orders of this rule, also significant results can be expected when extending the rule to stacking and feeding orders. With no direct effect on the share of mixed waste, the location rule for stacking and feeding might result in only positive effects. For the destination of stacking orders, this can be done in the same manner the destinations of mixing orders are determined. For the origin of feeding orders, however, not only the previous destination, but also the hopper as its own destination should be taken into account.

The (combination of the) decision rules leads to substantial positive effects on the crane

[1] https://neos-server.org/

driving times and number of orders. The largest contributor is the (mixing) location rule. Compared to its effects on the total number of mixing orders and their average driving time, the effects of the feeding rule, and especially, of the validating rule are minimal. Most effects were expected. The odd one out is the effect on the share of waste that is mixed before it is fed to a hopper. With the location rule implemented, the mixed share decreased, which is an undesirable effect. This was the case for multiple versions, in which the ratio waste level - (x,y) distance varied in determining the locations. Combining the decision rules, this negative effect became stronger. At least, for the one implemented location rule version. A solid explanation has not established. Part of the problem is the large variation in amount of waste in the bunker, which directly affects the mixed share.

Waste Homogeneity
The importance of waste homogeneity for the waste-to-energy process is taken into account in several ways. In the optimisation model, the number of mixing orders is maximised. In studying the effects of the decision rules on the simulation model, a set of mixing KPIs is included.

Waste homogeneity can be quantified in several ways. For example, as the number of executed mixing orders. However, more mixing does not necessarily result in homogeneous waste, e.g. by picking up and dropping the same piece of waste over and over, the overall homogeneity is not increased. Hence, the mixing quality needs to be quantified. For example, by the share of waste that is mixed before it is fed. This homogeneity indicator is used in the reviewing of the effects of the decision rules on simulation. It is also considered in literature, as part of the distribution of the number of times a piece of waste is mixed. Here, the number of times waste pieces are mixed did not prove to be valuable information as it depends too much on the total number of waste pieces in the bunker, i.e. the amount of waste that is delivered, which varies substantially between simulation runs.

From the effects of the location decision rule, it is clear that the number of mixing orders in itself is not a proper indicator of the waste homogeneity. A 30% increase in number of mixing orders and at the same time a 5% decrease in mixed share reveals that the additional mixing orders only go to the mixing of the same waste pieces more often.

8.2 Main Conclusions

Rescheduling a schedule of waste crane orders to minimise driving times gives a good idea on where room for improvement lies. The clustering of feeding orders and minding order locations, origins and destinations, proved to affect the crane performance positively.

The waste crane scheduling problem can be formulated as a mixed integer program. For a linear model, the waste levels and time units need to be discretised. The model size increases very fast when lengthening the time period. An heuristic approach, such as the rolling horizon method, allows to schedule a larger period of time. Still, in order to build a schedule within reasonable time, each iteration requires a maximum running time, which leads to (very) limited optimisation.

Clustering feeding orders by generating them per group of hoppers, and ordering the orders within a cluster, results in small, but significant, positive effects on the crane driving times ($\sim-3.2\%$) and waste homogeneity ($\sim+4.5\%$). The implementation can be made more practical by limiting the feeding order cluster size.

Including the (x,y) distance in the determination of the origin and destination of mixing orders results in large positive effects on the mixing driving time (∼−20.0%) and number of mixing order (∼+29.3%). The increase in number of mixing orders mostly translates into mixing the same waste pieces more often, instead of mixing a larger share of the waste (∼−5.7%).

Validating orders are not necessary as they can be replaced by mixing orders. When mixing is not allowed, validating is still required. In this perspective, an investment in waste level measure equipment is most likely not worth it.

As indicator of waste homogeneity, the number of mixing orders in itself is not very good. Mixing orders can translate into mixing more waste pieces or mixing waste pieces more often, which do not necessarily go hand-in-hand. Waste homogeneity would be better indicated by the distribution in number of times waste pieces are mixed.

8.3 Recommendations

The most limiting factor in the optimisation of the base model is the rescheduling window. Its effect, e.g. on the origin and destination of mixing orders, could be investigated by enlarging it with small steps, to be sure not to loose too much on accuracy-time ratio.

For the extended model, the main problem is the model size, even with the built-in simplification. Hence, to obtain more significant results, more computational resources should be provided.

The location decision rule should be investigated further. For example, by trying more waste level - (x,y) distance ratios. Also, the way the locations are scored and hence, chosen, can be adjusted. For example, the (x,y,z) crane path can be included as a factor, next to or instead of the waste level and (x,y) distance factors.

The most obvious recommendation concerning simulation, is to increase the number of replications to base the results on. From the results of the simulation model, multiple deviations most probably follow from the limited number of replications. For example, the large variation in the amount of waste in the bunker significantly affects the share of waste that is mixed before it is fed to a hopper. Having said that, another possibility to decrease the variation in simulation runs, is to fix the amount of delivered waste, i.e., the truck arrivals and possibly the truck contents. In this way, the actual effects of the decision rules will be clearer as they can be tested in more similar settings and therefore, can be better compared to the base case and each other.

As supplement to the share of waste that is mixed, the distribution of the number of times waste pieces are mixed should be included as KPI for the waste homogeneity/mix quality. Herein, both the waste that has been fed during the simulation and the waste left in the bunker should be taken into account. The total number of waste pieces, indicating the overall waste level, should also be considered since that influences the distribution strongly.

In this thesis, it is shown that decision rules derived from optimisation models can significantly improve the performance of simulated waste handling cranes. It has also become clear that both the theoretical and the applied aspect of the automatic waste handling crane operations would benefit from further research. Though the waste-to-energy context is a very specific field of application, automation is advancing everywhere in the industry. The presented mathematical model describing the waste crane operations within the context of the waste-to-energy process can be taken as starting point for further scientific research on the improvement of waste crane performance. For the industry, a simulation model which takes the established operational rules into account could serve as a base.

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Appendix A

Gains and Gaps Base Model

In this appendix, the total driving time gain, optimality deviation, and initial and final integrality gaps of the base model instances are presented. Table A.1 displays the total driving time gains and the optimality deviations, and Table A.2 shows the initial and final integrality gaps. Optimally solved instances are indicated with [1] and instances without integer solution and hence output with [2].

Day	Stack+Feed			Mix+Feed			Mix/Stack+Feed		
	$b = 300$	$b = 600$	$b = 900$	$b = 300$	$b = 600$	$b = 900$	$b = 300$	$b = 600$	$b = 900$
1	2.90% (21.74%)	3.36% (8.77%)	3.58% (2.53%)	3.82% (13.76%)	4.23% (5.48%)	4.48% (0.00%)[1]	[2]	4.15% (3.48%)	4.34% (0.40%)
2	2.63% (9.61%)	2.85% (1.56%)	2.90% (0.13%)[1]	3.59% (18.43%)	4.22% (2.84%)	4.40% (0.03%)[1]	[2]	3.20% (5.02%)	3.37% (0.26%)
3	[2]	3.12% (6.71%)	3.17% (4.68%)	3.80% (17.66%)	4.47% (3.33%)	4.63% (0.03%)[1]	[2]	3.71% (1.08%)	3.75% (0.08%)[1]
4	[2]	3.01% (3.03%)	3.07% (0.21%)	5.96% (22.73%)	6.98% (9.99%)	7.63% (0.04%)[1]	[2]	3.72% (5.77%)	3.87% (0.07%)[1]
5	[2]	3.11% (5.96%)	3.22% (1.73%)	2.43% (21.69%)	2.97% (2.78%)	3.03% (0.05%)[1]	[2]	3.87% (2.30%)	3.96% (0.07%)[1]
6	[2]	3.19% (4.48%)	3.25% (2.61%)	3.57% (16.59%)	4.20% (1.27%)	4.26% (0.06%)[1]	[2]	3.92% (3.47%)	4.01% (2.30%)
7	[2]	2.75% (4.65%)	2.84% (1.64%)	3.81% (19.40%)	4.49% (3.80%)	4.64% (1.46%)	[2]	3.11% (2.00%)	3.16% (0.36%)
8	[2]	3.04% (3.41%)	3.12% (0.35%)	3.76% (18.84%)	4.59% (0.96%)	4.60% (0.00%)[1]	[2]	2.51% (5.34%)	2.60% (0.98%)
9	[2]	3.51% (6.15%)	3.69% (1.19%)	3.18% (8.96%)	3.69% (0.49%)	3.74% (0.07%)[1]	[2]	3.14% (2.34%)	3.18% (0.09%)[1]
10	2.63% (17.91%)	2.98% (4.82%)	3.08% (1.01%)	3.79% (10.34%)	4.23% (0.70%)	4.32% (0.05%)[1]	[2]	3.45% (4.82%)	3.58% (0.19%)
11	2.20% (33.28%)	2.96% (6.55%)	3.11% (1.84%)	3.32% (13.78%)	3.76% (1.68%)	3.83% (0.06%)[1]	3.19% (14.42%)	3.71% (0.25%)	3.73% (0.07%)[1]
12	2.85% (15.87%)	3.18% (3.76%)	3.27% (1.02%)	3.09% (30.35%)	3.95% (11.88%)	4.47% (0.00%)[1]	[2]	2.78% (1.84%)	2.82% (0.12%)[1]
13	[2]	3.32% (4.52%)	3.43% (1.59%)	4.44% (9.94%)	4.88% (1.25%)	4.99% (0.05%)[1]	[2]	3.24% (3.76%)	3.36% (0.09%)[1]
14	[2]	2.57% (1.70%)	2.60% (0.15%)[1]	[2]	2.67% (3.65%)	2.76% (0.11%)[1]	3.79% (3.26%)	3.93% (0.09%)[1]	3.95% (0.00%)[1]
15	3.06% (27.84%)	3.65% (12.51%)	3.89% (7.00%)	4.05% (12.99%)	4.50% (5.17%)	4.83% (0.05%)[1]	[2]	4.08% (2.15%)	4.15% (0.10%)
16	2.15% (11.00%)	2.37% (0.80%)	2.39% (0.16%)[1]	4.08% (29.94%)	5.28% (5.93%)	5.51% (1.66%)	[2]	3.11% (5.37%)	3.24% (2.47%)
17	3.02% (33.38%)	3.77% (11.99%)	3.95% (6.00%)	4.01% (25.24%)	4.96% (6.00%)	5.28% (0.05%)[1]	2.87% (23.34%)	3.46% (6.96%)	3.67% (0.90%)
18	[2]	2.37% (4.38%)	2.44% (0.51%)	4.05% (14.45%)	4.52% (2.87%)	4.67% (0.03%)[1]	[2]	1.99% (10.43%)	2.14% (1.50%)
19	3.09% (31.41%)	3.91% (10.63%)	4.12% (4.05%)	4.16% (24.28%)	5.31% (3.00%)	5.50% (1.03%)	3.45% (19.79%)	4.24% (1.57%)	4.27% (0.00%)[1]
20	[2]	2.28% (4.80%)	2.35% (1.55%)	3.89% (27.49%)	4.89% (5.63%)	5.17% (0.05%)[1]	[2]	2.42% (10.26%)	2.63% (0.18%)
mean	2.73%	3.07%	3.17%	3.87%	4.44%	4.64%	3.32%	3.39%	3.49%
median	2.85%	3.07%	3.15%	3.81%	4.48%	4.61%	3.32%	3.45%	3.62%

Table A.1: Total driving time gain (and optimality deviation) percentages of the base model, given per strategy period and buffer time b.

Day	Stack+Feed			Mix+Feed			Mix/Stack+Feed		
	$b = 300$	$b = 600$	$b = 900$	$b = 300$	$b = 600$	$b = 900$	$b = 300$	$b = 600$	$b = 900$
1	9.46% / 2.06%	9.61% / 0.84%	9.73% / 0.25%	16.2% / 2.23%	16.9% / 0.93%	17.2% / 0.00%[1]	[2]	14.8% / 0.51%	14.9% / 0.06%
2	7.27% / 0.70%	7.32% / 0.11%	7.37% / 0.01%[1]	14.7% / 2.71%	15.4% / 0.44%	15.7% / 0.00%[1]	[2]	12.5% / 0.63%	12.6% / 0.03%
3	[2]	8.49% / 0.57%	8.49% / 0.40%	16.0% / 2.83%	17.1% / 0.57%	17.4% / 0.00%[1]	[2]	13.3% / 0.14%	13.3% / 0.01%[1]
4	[2]	7.80% / 0.24%	7.83% / 0.02%	17.3% / 3.93%	17.6% / 1.76%	17.6% / 0.01%[1]	[2]	13.9% / 0.80%	14.0% / 0.01%[1]
5	[2]	8.21% / 0.49%	8.26% / 0.14%	15.6% / 3.38%	16.6% / 0.46%	16.8% / 0.01%[1]	[2]	13.8% / 0.32%	13.9% / 0.01%[1]
6	[2]	8.28% / 0.37%	8.33% / 0.22%	14.9% / 2.47%	16.3% / 0.21%	16.6% / 0.01%[1]	[2]	13.6% / 0.47%	13.8% / 0.32%
7	[2]	7.15% / 0.33%	7.34% / 0.12%	16.3% / 3.16%	16.7% / 0.63%	16.8% / 0.25%	[2]	10.9% / 0.22%	11.0% / 0.04%
8	[2]	8.12% / 0.28%	8.17% / 0.03%	17.4% / 3.28%	18.4% / 0.18%	18.6% / 0.00%[1]	[2]	8.53% / 0.46%	8.64% / 0.08%
9	[2]	9.39% / 0.58%	9.55% / 0.11%	12.4% / 1.11%	13.4% / 0.07%	13.5% / 0.01%[1]	[2]	11.2% / 0.26%	11.4% / 0.01%[1]
10	7.62% / 1.37%	7.63% / 0.37%	7.75% / 0.08%	14.5% / 1.50%	15.2% / 0.11%	15.6% / 0.01%[1]	[2]	11.7% / 0.56%	12.1% / 0.02%
11	7.48% / 2.49%	7.84% / 0.51%	8.00% / 0.15%	13.7% / 1.89%	14.3% / 0.24%	14.4% / 0.01%[1]	13.3% / 1.92%	13.6% / 0.03%	11.5% / 0.01%[1]
12	8.16% / 1.29%	8.18% / 0.31%	8.25% / 0.08%	15.5% / 4.70%	16.7% / 1.98%	16.8% / 0.00%[1]	[2]	8.64% / 0.16%	8.66% / 0.01%[1]
13	[2]	8.75% / 0.40%	8.93% / 0.13%	17.2% / 1.71%	17.8% / 0.22%	18.0% / 0.01%[1]	[2]	11.4% / 0.43%	11.5% / 0.01%[1]
14	[2]	6.59% / 0.11%	6.60% / 0.01%[1]	[2]	7.31% / 0.27%	7.31% / 0.01%[1]	10.0% / 0.33%	10.0% / 0.01%[1]	10.0% / 0.00%[1]
15	10.0% / 2.78%	10.3% / 1.29%	10.6% / 0.74%	16.7% / 2.17%	18.8% / 0.97%	19.8% / 0.01%[1]	[2]	15.0% / 0.32%	15.1% / 0.02%
16	6.30% / 0.69%	6.30% / 0.05%	6.30% / 0.01%[1]	18.4% / 5.51%	18.7% / 1.11%	18.7% / 0.31%	[2]	10.2% / 0.55%	10.3% / 0.25%
17	9.91% / 3.31%	10.2% / 1.22%	10.4% / 0.62%	18.8% / 4.74%	19.5% / 1.17%	19.8% / 0.01%[1]	13.1% / 3.06%	13.3% / 0.93%	13.4% / 0.12%
18	[2]	6.13% / 0.27%	6.13% / 0.03%	17.2% / 2.49%	18.5% / 0.53%	18.6% / 0.01%[1]	[2]	6.22% / 0.65%	6.24% / 0.09%
19	10.3% / 3.24%	10.7% / 1.14%	11.1% / 0.45%	18.4% / 4.47%	21.4% / 0.64%	22.3% / 0.23%	15.2% / 3.01%	15.7% / 0.25%	15.8% / 0.00%[1]
20	[2]	6.25% / 0.30%	6.25% / 0.10%	17.2% / 4.73%	17.7% / 1.00%	18.2% / 0.01%[1]	[2]	7.28% / 0.75%	7.30% / 0.01%

Table A.2: Initial and final integrality gaps of the base model, given per strategy period and buffer time b.

[1] solved to optimality
[2] no integer solution found

Appendix B

Optimised Schedules Base Model

In this appendix, the optimised schedules of three optimally solved base model instances are given. The three schedules correspond to the three different strategies. For each strategy, the instance with the largest gains under a buffer time of 900 seconds is displayed. For the stack+feed strategy, this is day 2, for mix+feed, day 4, and for mix/stack+feed, day 19.

Below an overview of the column headers and their explanation is given.

Column Header	Explanation
nr	order number before rescheduling
type	order type
release	release date
starting	starting time after rescheduling
completion	completion time after rescheduling
travel	travelling time after rescheduling
start (sim)	starting time before rescheduling
end (sim)	completion time before rescheduling
origin	(x,y,z) start/pickup location
destination	(x,y,z) end/drop location

B.1 Stack+Feed

Nr	Type	Release	Starting	Completion	Travel	Start Sim	End Sim	Origin			Destination		
1	stacking	202935.0612	202935.0612	203007.8228	0	202971.6302	203044.4361	47.5	22.5	3.3	47.5	2.5	18.0
0	stacking	202807.3639	203048.0083	203119.3770	40.1855	202863.6482	202935.0612	47.5	22.5	4.6	32.5	2.5	18.0
4	stacking	203119.3770	203160.3125	203225.0384	40.9355	203315.455	203380.2233	32.5	22.5	3.9	32.5	12.5	18.1
6	stacking	203007.8228	203259.2238	203324.5925	34.1854	203545.3625	203610.7737	32.5	22.5	3.3	42.5	12.5	18.1
2	stacking	203044.4361	203356.9565	203420.5039	32.3640	203079.846	203143.4358	32.5	22.5	5.0	27.5	12.5	18.1
5	feeding	203280.7983	203447.7150	203527.9400	27.2111	203415.2127	203495.4419	22.5	17.5	21.1	8.5	-5.5	40.0
3	feeding	203137.1626	203566.0657	203646.8721	38.1257	203184.3443	203269.1935	7.5	17.5	21.1	35.5	-5.5	40.0
10	feeding	203970.8221	204006.4213	204086.7535	35.5992	204011.4128	204094.1973	17.5	2.5	21.0	32.5	-5.5	40.0
11	feeding	204113.6034	204152.2709	204232.6030	38.6675	204152.2058	204232.5422	7.5	7.5	21.0	11.5	-5.5	40.0
16	feeding	204808.9807	204844.5799	204924.9121	35.5992	204865.3043	204947.1565	12.5	12.5	21.0	35.5	-5.5	40.0
9	stacking	203324.5925	204972.6477	205042.0879	47.7356	203837.0526	203906.5323	42.5	22.5	3.2	37.5	7.5	18.3
7	stacking	203420.5039	205078.7376	205146.4635	36.6497	203638.4544	203706.2237	42.5	22.5	4.7	32.5	7.5	18.2
8	stacking	203225.0384	205183.6489	205251.1010	37.1854	203738.1326	203805.5383	42.5	22.5	4.1	27.5	17.5	18.2
12	stacking	205146.4635	205277.4450	205341.6352	26.3440	204468.9873	204533.2199	32.5	22.5	4.6	37.5	12.5	18.3
14	stacking	205042.0879	205373.9992	205433.8717	32.3640	204662.6698	204722.4450	37.5	22.5	5.2	42.5	17.5	18.5
15	stacking	205341.6352	205460.8586	205533.1916	26.9869	204746.6699	204819.0434	37.5	22.5	4.3	42.5	2.5	18.6

13	stacking	205251.1010	205575.0913	205644.3172	41.8997	204561.7870	204631.0563	32.5	22.5	3.6	27.5	7.5	18.5
19	feeding	205102.3575	205671.1874	205751.5196	26.8702	205208.9248	205289.2612	22.5	12.5	21.0	8.5	-5.5	40.0
21	feeding	205812.9042	205851.0300	205933.0364	38.1258	205874.9852	205960.8344	2.5	17.5	21.0	32.5	-5.5	40.0
17	stacking	205644.3172	205980.7720	206050.5336	47.7356	204993.8953	205063.7003	37.5	22.5	3.2	42.5	7.5	18.6
18	stacking	205433.8717	206087.5048	206157.7426	36.9712	205095.4728	205165.6619	27.5	22.5	4.7	47.5	12.5	18.6
23	stacking	206157.7426	206192.9518	206255.3958	35.2092	206100.5547	206162.9007	32.5	22.5	3.0	32.5	17.5	18.7
20	stacking	205533.1916	206283.3469	206354.7633	27.9511	205335.9772	205407.3491	27.5	22.5	3.6	47.5	17.5	18.6
24	stacking	206354.7633	206378.4287	206439.7561	23.6654	206192.8284	206254.2046	47.5	22.5	7.5	37.5	17.5	18.7
22	stacking	206050.5336	206466.9572	206531.8974	27.2011	206005.8231	206070.8058	32.5	22.5	4.3	32.5	12.5	18.7
25	stacking	206531.8974	206563.3566	206629.6897	31.4592	206281.5721	206347.9446	47.5	22.5	6.6	32.5	7.5	18.8
28	stacking	206439.7561	206667.3037	206739.9582	37.6140	206629.0202	206701.7189	47.5	22.5	4.3	37.5	2.5	18.9
27	stacking	206255.3958	206780.3579	206851.9409	40.3997	206520.8920	206592.5194	47.5	22.5	5.3	27.5	2.5	18.9
32	feeding	206926.7910	206953.0475	207033.9154	26.2565	207128.0111	207211.5486	22.5	2.5	20.5	8.5	-5.5	40.0
26	feeding	206262.1253	207072.0412	207152.3733	38.1258	206384.9987	206465.3351	17.5	17.5	21.0	11.5	-5.5	40.0
31	feeding	206828.2762	207188.1771	207268.8307	35.8038	207005.7146	207089.649	12.5	2.5	20.7	35.5	-5.5	40.0
29	stacking	206629.6897	207316.5663	207390.3994	47.7356	206738.9697	206812.8471	47.5	22.5	3.2	47.5	2.5	18.9
30	stacking	206851.9409	207432.0848	207501.3107	41.6854	206849.4842	206957.2028	37.5	22.5	4.1	47.5	7.5	19.0
35	stacking	207501.3107	207537.3175	207604.7220	36.0068	207476.7160	207544.1600	42.5	22.5	6.0	37.5	7.5	19.2
40	stacking	207604.7220	207641.6932	207706.2048	36.9712	208016.8174	208081.3714	27.5	22.5	5.3	37.5	12.5	19.3
43	stacking	207706.2048	207741.3545	207811.7590	35.1497	208315.1789	208385.6268	32.5	22.5	3.6	27.5	7.5	19.6
39	feeding	207758.6135	207831.9762	207913.0584	20.2172	207890.4240	207971.5104	22.5	7.5	20.3	11.5	-5.5	40.0
38	feeding	207657.3525	207949.1349	208030.2171	36.0765	207774.2580	207855.3444	12.5	7.5	20.3	32.5	-5.5	40.0
33	stacking	206739.9582	208077.9527	208144.5000	47.7356	207264.0374	207330.6271	37.5	22.5	3.2	42.5	12.5	19.1
34	stacking	207390.3994	208176.1140	208241.7447	31.6140	207381.1625	207446.7471	42.5	22.5	6.7	27.5	17.5	19.1
36	stacking	208144.5000	208265.8387	208327.7788	24.0940	207574.8644	207636.8470	27.5	22.5	7.6	27.5	12.5	19.2
37	stacking	208241.7447	208359.8214	208430.6545	32.0426	207664.6186	207735.4960	27.5	22.5	6.4	32.5	2.5	19.3
42	stacking	208430.6545	208473.6256	208544.2444	42.9711	208211.3845	208282.0427	27.5	22.5	3.3	42.5	7.5	19.5
41	stacking	208327.7788	208582.6084	208651.1319	38.3640	208110.3930	208178.8701	27.5	22.5	4.3	42.5	17.5	19.4
44	stacking	208651.1319	208679.1901	208745.0175	28.0582	208420.4117	208486.2879	47.5	22.5	4.2	37.5	17.5	19.6
49	stacking	208745.0175	208770.6115	208836.9922	25.5940	209059.8892	209126.2236	42.5	22.5	6.7	27.5	17.5	19.8
45	stacking	208544.2444	208868.7553	208941.9455	31.7631	208558.4691	208631.6997	37.5	22.5	4.6	42.5	2.5	19.7
50	stacking	208941.9455	208983.0952	209047.8512	41.1497	209158.0789	209222.8837	42.5	22.5	5.4	32.5	17.5	19.8
47	stacking	207811.7590	209076.3380	209142.4568	28.4868	208814.5092	208880.6704	37.5	22.5	4.2	47.5	12.5	19.7
51	stacking	209142.4568	209177.4993	209251.4395	35.0425	209252.4557	209326.4363	42.5	22.5	4.1	27.5	2.5	19.9
46	feeding	208577.3953	209281.0884	209362.2777	29.6489	208678.9242	208762.7023	7.5	2.5	20.2	8.5	-5.5	40.0
48	feeding	208832.2993	209398.4224	209479.6117	36.1447	208930.8976	209015.5368	7.5	12.5	20.2	35.5	-5.5	40.0
52	stacking	208836.9922	209527.3473	209598.5018	47.7356	209364.3689	209435.5668	42.5	22.5	3.2	47.5	7.5	19.9
56	stacking	209251.4395	209636.3301	209701.6988	37.8283	210010.2704	210075.6816	37.5	22.5	5.2	32.5	12.5	20.0
59	stacking	209701.6988	209737.2295	209807.6340	35.5307	210327.4465	210397.8943	47.5	22.5	4.1	32.5	7.5	20.1
53	feeding	209406.9638	209834.1308	209915.3201	26.4968	209479.5813	209560.7748	17.5	17.5	20.2	11.5	-5.5	40.0
54	feeding	209684.4704	209951.5330	210033.5394	36.2129	209719.6865	209805.4316	2.5	12.5	20.1	32.5	-5.5	40.0
61	feeding	210414.1493	210452.8167	210534.1131	38.6674	210544.8585	210626.1592	7.5	17.5	20.1	8.5	-5.5	40.0
57	stacking	209598.5018	210581.0987	210655.0389	46.9856	210105.1805	210179.1650	37.5	22.5	4.3	42.5	2.5	20.1
55	stacking	209047.8512	210695.8672	210767.7717	40.8283	209902.1844	209974.1332	37.5	22.5	6.1	37.5	2.5	20.0
62	feeding	210691.9622	210797.1907	210878.5943	29.4190	210730.6653	210814.7385	17.5	2.5	20.0	35.5	-5.5	40.0
60	stacking	210655.0389	210926.2617	210989.8843	47.6674	210431.6442	210495.1687	47.5	22.5	3.3	47.5	17.5	20.1
58	stacking	210767.7717	211017.8354	211091.0256	27.9511	210217.2567	210290.4912	47.5	22.5	5.0	47.5	2.5	20.1
64	stacking	211091.0256	211133.1396	211202.7940	42.1140	211245.9297	211315.6275	42.5	22.5	4.9	42.5	7.5	20.2
65	stacking	209807.6340	211242.3366	211309.4197	39.5426	211349.0365	211416.1620	42.5	22.5	3.9	37.5	12.5	20.3
67	stacking	210989.8843	211344.1408	211410.0453	34.7211	211577.4583	211643.4052	37.5	22.5	5.0	42.5	12.5	20.3
71	stacking	211309.4197	211576.6441	211645.8105	166.5988	212726.0213	212795.1415	42.5	22.5	4.7	27.5	12.5	20.4
66	feeding	211352.4093	211665.1819	211746.5855	19.3714	211450.5390	211531.9468	22.5	17.5	20.0	32.5	-5.5	40.0
68	stacking	211202.7940	211794.1847	211869.4106	47.5992	211674.7223	211749.9925	37.5	22.5	3.4	32.5	2.5	20.4
63	feeding	211076.9080	211895.5044	211976.9080	26.0938	211112.1922	211193.6000	17.5	12.5	20.0	11.5	-5.5	40.0
69	feeding	212085.8610	212122.2103	212203.7210	36.3493	212129.0170	212213.1165	2.5	2.5	19.9	8.5	-5.5	40.0
73	feeding	213024.2759	213060.6251	213142.1359	36.3492	213067.4297	213148.9446	12.5	12.5	19.9	32.5	-5.5	40.0
70	feeding	212366.9127	213178.4851	213259.9958	36.3492	212402.2651	212483.7801	17.5	7.5	19.9	35.5	-5.5	40.0
72	stacking	211410.0453	213307.5951	213371.4319	47.5993	212829.0195	212892.7583	42.5	22.5	3.4	42.5	17.5	20.4
79	stacking	212085.8610	213399.9188	213472.0851	28.4869	214998.1631	215070.2807	47.5	22.5	4.8	27.5	7.5	20.5
74	feeding	213100.4528	213498.0069	213579.5176	25.9218	213184.5470	213266.0620	12.5	17.5	19.9	11.5	-5.5	40.0
76	feeding	213945.2562	213981.6736	214063.2915	36.4174	213985.6767	214067.2988	7.5	7.5	19.8	8.5	-5.5	40.0
75	feeding	213693.7971	214099.7089	214183.5153	36.4174	213729.2177	213817.1108	2.5	7.5	19.8	35.5	-5.5	40.0
82	stacking	213472.0851	214230.7055	214300.8361	47.1902	215350.0503	215420.1328	32.5	22.5	4.0	47.5	12.5	20.6
85	stacking	214300.8361	214336.9501	214408.3189	36.1140	215680.1204	215751.5325	42.5	22.5	4.0	32.5	7.5	20.9
78	feeding	214789.9876	214818.3450	214900.0701	28.3574	214858.6206	214943.0152	12.5	2.5	19.7	11.5	-5.5	40.0
77	feeding	214698.5464	214938.1958	215020.2022	38.1257	214733.9670	214819.7130	2.5	17.5	19.8	32.5	-5.5	40.0
80	stacking	212600.6520	215067.9378	215139.7352	47.7356	215107.6126	215179.4533	47.5	22.5	3.2	37.5	7.5	20.5
81	stacking	212701.1980	215178.7420	215249.0393	39.0068	215212.5214	215315.9369	32.5	22.5	4.7	47.5	7.5	20.6
83	stacking	215139.7352	215287.4033	215360.9150	38.3640	215455.5330	215529.0889	27.5	22.5	5.4	27.5	2.5	20.8
86	feeding	215713.1452	215731.7802	215813.6124	18.6350	215781.8079	215866.0924	22.5	2.5	19.6	35.5	-5.5	40.0

88	stacking	215360.9150	215860.6661	215930.9040	47.0537	216259.9556	216330.1452	47.5	22.5	4.2	32.5	12.5	20.9
84	stacking	215249.0393	215966.9108	216041.6010	36.0068	215566.8169	215641.5514	27.5	22.5	4.4	37.5	2.5	20.9
87	feeding	215797.9277	216066.8556	216148.6878	25.2546	215901.6493	215983.4857	22.5	12.5	19.6	8.5	-5.5	40.0
91	feeding	216560.6335	216597.3918	216679.5454	36.7583	216615.1359	216701.3731	7.5	2.5	19.3	32.5	-5.5	40.0
89	stacking	216041.6010	216727.2810	216791.8678	47.7356	216363.7505	216428.2393	47.5	22.5	3.2	47.5	17.5	20.9
92	stacking	215930.9040	216820.4618	216883.0129	28.5940	216746.7482	216809.2014	42.5	22.5	5.2	37.5	17.5	21.0
90	stacking	214408.3189	216910.5355	216983.2971	27.5226	216494.7078	216567.5099	37.5	22.5	6.3	47.5	2.5	21.0
94	stacking	216791.8678	217026.6968	217096.7203	43.3997	216981.5627	217051.5380	42.5	22.5	4.6	27.5	17.5	21.1
95	stacking	216983.2971	217125.6358	217188.4012	28.9155	217076.7402	217139.4053	32.5	22.5	5.1	32.5	17.5	21.1
97	stacking	217096.7203	217219.2452	217291.7925	30.8440	217271.9118	217344.5025	32.5	22.5	3.3	47.5	7.5	21.3
101	stacking	217291.7925	217331.1208	217401.8467	39.3283	217711.1212	217781.8866	37.5	22.5	5.2	37.5	7.5	21.5
93	feeding	216796.7747	217428.8309	217511.0917	26.9842	216844.6789	216929.5285	17.5	2.5	19.2	11.5	-5.5	40.0
96	stacking	216883.0129	217558.2136	217629.7967	47.1219	217165.7894	217237.4119	32.5	22.5	4.1	42.5	7.5	21.2
98	stacking	217188.4012	217669.1250	217735.9937	39.3283	217379.5844	217446.4956	27.5	22.5	5.1	37.5	12.5	21.3
102	stacking	217735.9937	217771.1434	217833.8017	35.1497	217815.2728	217877.8331	42.5	22.5	5.6	42.5	17.5	21.5
106	stacking	217833.8017	217864.0028	217939.7644	30.2011	218250.7002	218326.5062	37.5	22.5	4.3	27.5	2.5	21.8
107	validating	217939.7644	217939.7644	217963.6934	0	0	218350.4965	27.5	2.5	17.5	27.5	2.5	21.8
99	feeding	217406.9482	217980.4001	218062.6608	16.7067	217478.4609	217560.7259	22.5	7.5	19.2	35.5	-5.5	40.0
105	stacking	217401.8467	218110.3282	218182.3874	47.6674	218147.0312	218219.0422	42.5	22.5	3.3	27.5	12.5	21.7
104	feeding	217956.1998	218209.0194	218291.2802	26.6320	218010.0957	218092.3606	7.5	12.5	19.2	8.5	-5.5	40.0
100	stacking	217629.7967	218338.6067	218412.8088	47.3265	217607.0556	217681.2092	27.5	22.5	3.8	47.5	17.5	21.4
103	stacking	218412.8088	218443.1170	218507.4896	30.3082	217905.4592	217969.7315	42.5	22.5	4.1	37.5	17.5	21.6
109	stacking	218507.4896	218537.7979	218602.1704	30.3083	218508.6204	218572.8949	32.5	22.5	4.3	27.5	17.5	21.8
110	validating	218602.1704	218602.1704	218626.0994	0	0	218596.8853	27.5	17.5	17.5	27.5	17.5	21.8
111	stacking	218182.3874	218657.4791	218734.2050	31.3797	218623.6557	218700.4220	32.5	22.5	3.5	32.5	2.5	21.9
108	feeding	218236.6500	218760.4036	218842.6643	26.1986	218381.3667	218463.6316	12.5	12.5	19.2	32.5	-5.5	40.0
112	feeding	218635.8499	218881.3318	218963.5925	38.6675	218736.9933	218819.2582	7.5	17.5	19.2	11.5	-5.5	40.0
113	stacking	217939.7644	219010.3054	219085.7456	46.7129	218874.2243	218949.7088	47.5	22.5	4.7	42.5	2.5	21.9
114	validating	219085.7456	219085.7456	219108.9866	0	0	218972.9016	42.5	2.5	18.0	42.5	2.5	21.9
119	feeding	219232.3170	219260.8861	219343.3611	28.5691	219262.4291	219344.9083	17.5	7.5	19.0	35.5	-5.5	40.0
115	stacking	218602.1704	219390.8922	219463.8681	47.5311	219011.9933	219085.0126	47.5	22.5	3.5	32.5	7.5	21.9
116	validating	219463.8681	219463.8681	219487.6282	0	0	219108.8055	32.5	7.5	17.7	32.5	7.5	21.9
123	feeding	219905.0412	219927.6103	220010.0854	22.5691	219941.0073	220023.4865	17.5	17.5	19.0	32.5	-5.5	40.0
121	stacking	219463.8681	220057.4119	220126.3164	47.3265	219489.7422	219558.6891	37.5	22.5	3.8	47.5	12.5	21.9
117	stacking	218734.2050	220162.0018	220228.8705	35.6854	219142.1463	219209.0575	37.5	22.5	5.7	32.5	12.5	21.9
118	validating	220228.8705	220228.8705	220252.4598	0	0	219232.6517	32.5	12.5	17.8	32.5	12.5	21.9
122	feeding	219464.9844	220278.0289	220360.5039	25.5691	219600.4601	219682.9393	12.5	17.5	19.0	8.5	-5.5	40.0
120	stacking	219085.7456	220407.2168	220475.1570	46.7129	219390.6243	219458.6070	37.5	22.5	4.7	42.5	12.5	21.9
126	stacking	220228.8705	220511.3781	220582.6397	36.2211	220903.0188	220974.3238	47.5	22.5	5.2	42.5	7.5	22.0
127	validating	220582.6397	220582.6397	220605.3413	0	0	220996.9038	42.5	7.5	18.4	42.5	7.5	22.0
130	stacking	220126.3164	220645.3124	220716.5740	39.9711	221171.4903	221242.7953	27.5	22.5	5.3	27.5	7.5	22.1
124	feeding	220135.1189	220738.4976	220821.0797	21.9236	220171.1531	220253.7395	12.5	7.5	18.9	11.5	-5.5	40.0
128	stacking	220475.1570	220868.4744	220945.2003	47.3947	221032.6764	221109.4466	47.5	22.5	3.7	47.5	2.5	22.1
129	validating	220945.2003	220945.2003	220968.9604	0	0	221133.2395	47.5	2.5	17.9	47.5	2.5	22.1
125	feeding	220739.0231	220996.8840	221079.4661	27.9236	220775.0573	220857.6437	22.5	17.5	18.9	35.5	-5.5	40.0
131	stacking	220582.6397	221126.3154	221200.5175	46.8493	221277.5906	221351.7439	27.5	22.5	4.5	47.5	7.5	22.1
132	validating	221200.5175	221200.5175	221224.1067	0	0	221375.3382	47.5	7.5	18.0	47.5	7.5	22.1
135	stacking	220945.2003	221264.2921	221328.0218	40.1854	221664.1983	221727.8300	32.5	22.5	5.2	32.5	17.5	22.1
139	stacking	221328.0218	221358.1158	221422.3812	30.0940	222001.6445	222065.8119	37.5	22.5	5.0	37.5	17.5	22.4
140	validating	221422.3812	221422.3812	221446.1413	0	0	222089.6048	37.5	17.5	18.2	37.5	17.5	22.4
136	stacking	220716.5740	221477.4139	221553.9255	31.2726	221754.8277	221831.3797	32.5	22.5	4.2	37.5	2.5	22.4
134	feeding	221402.3750	221579.2776	221661.9669	25.3521	221537.1297	221619.8232	17.5	12.5	18.8	32.5	-5.5	40.0
141	stacking	221553.9255	221709.0889	221785.9219	47.1220	222116.6252	222193.4987	37.5	22.5	4.1	27.5	2.5	22.6
133	feeding	221311.7384	221814.4883	221897.1776	28.5664	221418.3338	221501.0273	2.5	12.5	18.8	8.5	-5.5	40.0
137	stacking	221200.5175	221944.7768	222018.3956	47.5992	221870.1305	221943.7926	32.5	22.5	3.4	37.5	7.5	22.4
138	validating	222018.3956	222018.3956	222041.6366	0	0	221966.9855	37.5	7.5	18.5	37.5	7.5	22.4
143	feeding	222220.7279	222252.1871	222334.9835	31.4592	222345.9027	222431.2271	7.5	7.5	18.7	35.5	-5.5	40.0
146	stacking	221422.3812	222381.9691	222447.1988	46.9856	222599.2397	222664.3714	27.5	22.5	4.3	27.5	17.5	22.6
144	stacking	222018.3956	222477.5071	222545.5544	30.3083	222476.5341	222544.6238	27.5	22.5	5.3	37.5	12.5	22.6
145	validating	222545.5544	222545.5544	222569.1437	0	0	222568.2181	37.5	12.5	18.5	37.5	12.5	22.6
150	stacking	222545.5544	222607.9362	222681.8764	38.7925	223038.2015	223112.1850	42.5	22.5	3.5	32.5	7.5	22.8
149	feeding	222811.4055	222843.2933	222926.0898	31.8878	222855.3430	222938.1437	2.5	17.5	18.7	8.5	-5.5	40.0
142	feeding	222146.0854	222963.2572	223046.0536	37.1674	222224.3469	222309.7322	2.5	2.5	18.7	11.5	-5.5	40.0
147	stacking	221785.9219	223093.8574	223170.2024	47.8038	222692.7100	222769.0079	27.5	22.5	3.1	47.5	17.5	22.7
148	validating	223170.2024	223170.2024	223192.1484	0	0	222790.7473	47.5	17.5	19.5	47.5	17.5	22.7
152	stacking	222447.1988	223222.2423	223290.1825	30.0939	223362.2569	223430.2395	47.5	22.5	5.6	42.5	12.5	22.8
153	validating	223290.1825	223290.1825	223313.4236	0	0	223453.4324	42.5	12.5	18.9	42.5	12.5	22.8
154	stacking	223170.2024	223351.4661	223426.6325	38.0425	223486.2722	223561.3883	47.5	22.5	4.4	27.5	7.5	22.9
155	validating	223426.6325	223426.6325	223450.0487	0	0	223584.7826	27.5	7.5	18.9	27.5	7.5	22.9

157	feeding	223647.1919	223663.6788	223746.6895	16.4869	223719.5429	223805.1424	22.5	2.5	18.5	11.5	-5.5	40.0
156	stacking	222681.8764	223794.3569	223867.7019	47.6674	223623.9327	223697.2295	47.5	22.5	3.3	32.5	12.5	22.9
151	feeding	223203.6712	223893.8040	223976.7076	26.1021	223231.7986	223317.1545	12.5	2.5	18.6	32.5	-5.5	40.0
158	stacking	223290.1825	224023.6932	224100.7405	46.9856	223854.6312	223931.7228	37.5	22.5	4.3	32.5	2.5	23.0
159	validating	224100.7405	224100.7405	224123.8041	0	0	223954.7130	32.5	2.5	19.2	32.5	2.5	23.0
166	feeding	224478.7446	224508.1682	224591.2860	29.4236	224599.6040	224682.7261	7.5	12.5	18.4	8.5	-5.5	40.0
160	feeding	223891.4459	224628.5898	224712.3962	37.3038	223988.8597	224077.606	2.5	7.5	18.5	35.5	-5.5	40.0
164	stacking	224100.7405	224760.0637	224838.2896	47.6675	224367.5653	224445.8316	32.5	22.5	3.3	42.5	2.5	23.1
167	feeding	224732.9592	224864.8202	224947.9381	26.5306	224769.3343	224852.4564	22.5	12.5	18.4	32.5	-5.5	40.0
161	stacking	223426.6325	224995.8101	225074.2503	47.8720	224124.4811	224202.9656	37.5	22.5	3.0	47.5	2.5	23.0
162	stacking	223867.7019	225119.9000	225189.0488	45.6497	224242.8755	224312.0731	32.5	22.5	4.5	42.5	17.5	23.0
163	validating	225189.0488	225189.0488	225212.2898	0	0	224335.2660	42.5	17.5	19.1	42.5	17.5	23.0
165	stacking	225074.2503	225243.8838	225317.0740	31.5940	224485.5597	224558.7933	47.5	22.5	4.5	47.5	7.5	23.1
168	stacking	225189.0488	225356.4023	225423.1639	39.3283	225294.4705	225361.2745	42.5	22.5	7.0	47.5	12.5	23.1
169	validating	225423.1639	225423.1639	225446.4049	0	0	225384.4674	47.5	12.5	19.2	47.5	12.5	23.1
171	stacking	224838.2896	225483.2689	225551.1320	36.864	225562.6428	225630.5548	42.5	22.5	5.8	32.5	17.5	23.1
172	validating	225551.1320	225551.1320	225574.0158	0	0	225653.3406	32.5	17.5	19.4	32.5	17.5	23.1
174	stacking	225317.0740	225605.6098	225682.5500	31.594	225807.7567	225884.7412	37.5	22.5	4.6	37.5	2.5	23.2
175	validating	225682.5500	225682.5500	225706.8110	0	0	225909.1228	37.5	2.5	18.7	37.5	2.5	23.2
170	feeding	225323.5826	225739.5559	225822.7809	32.7449	225425.3629	225511.1768	7.5	2.5	18.3	11.5	-5.5	40.0
176	stacking	225423.1639	225869.9711	225940.1613	47.1902	225947.8389	226018.0715	37.5	22.5	4	27.5	12.5	23.3
177	validating	225940.1613	225940.1613	225963.4023	0	0	226041.2644	27.5	12.5	19.4	27.5	12.5	23.3
178	feeding	226005.3937	226022.6306	226105.9627	17.2369	226059.6688	226143.0052	22.5	7.5	18.2	8.5	-5.5	40.0
180	stacking	225682.5500	226153.2893	226227.6580	47.3266	226301.5136	226375.9219	47.5	22.5	3.8	42.5	7.5	23.5
181	stacking	225940.1613	226268.0577	226339.7479	40.3997	226460.3677	226532.1013	42.5	22.5	6.4	37.5	7.5	23.6
173	feeding	225586.2990	226366.9214	226450.1465	27.1735	225678.7432	225761.9725	17.5	7.5	18.3	35.5	-5.5	40.0
179	stacking	225551.1320	226496.7911	226565.9400	46.6446	226200.1531	226269.3507	47.5	22.5	4.8	37.5	17.5	23.3
183	stacking	226565.9400	226598.2840	226668.6884	32.3440	226695.5042	226765.9512	32.5	22.5	4.1	37.5	12.5	23.6
188	stacking	226668.6884	226705.1239	226775.7902	36.4355	227552.7454	227623.3621	42.5	22.5	6.7	27.5	17.5	23.8
184	stacking	226227.6580	226809.0985	226880.0387	33.3083	226798.0637	226869.0463	32.5	22.5	3.7	32.5	12.5	23.7
187	stacking	226339.7479	226914.9741	226988.7000	34.9354	227440.2699	227514.0401	42.5	22.5	8.2	37.5	2.5	23.8
182	feeding	226429.0614	227022.1950	227105.5271	33.4950	226566.2403	226650.3791	7.5	17.5	18.2	32.5	-5.5	40.0
189	stacking	226880.0387	227151.6264	227228.3523	46.0993	227657.3083	227734.0746	42.5	22.5	5.6	47.5	2.5	24.0
186	feeding	227277.0923	227307.8016	227391.1337	30.7093	227313.6038	227396.9402	22.5	17.5	18.2	35.5	-5.5	40.0
193	stacking	227228.3523	227438.6648	227527.9740	47.5311	228134.2925	228223.5509	2.5	22.5	3.5	42.5	12.5	24.0
190	stacking	226988.7000	227566.7666	227640.4925	38.7926	227772.8936	227846.6629	42.5	22.5	4.9	27.5	7.5	24.0
185	feeding	227013.0400	227665.2017	227748.5339	24.7092	227041.0123	227124.3487	12.5	17.5	18.2	11.5	-5.5	40.0
191	stacking	226775.7902	227795.4513	227880.7963	46.9174	227887.5666	227972.8610	2.5	22.5	4.4	37.5	12.5	24.0
195	stacking	227640.4925	227922.6484	228000.2314	41.8521	228400.9678	228478.5952	17.5	22.5	5.0	27.5	2.5	24.2
192	feeding	227857.4805	228025.3692	228108.9157	25.1378	228004.2076	228087.7582	12.5	12.5	18.0	8.5	-5.5	40.0
194	feeding	228126.0321	228163.7450	228247.3986	37.7129	228264.7197	228355.4563	2.5	2.5	17.9	32.5	-5.5	40.0
196	stacking	227880.7963	228294.5887	228374.5766	47.1901	228518.4141	228598.3543	17.5	22.5	4.0	42.5	17.5	24.2
201	stacking	228374.5766	228404.1348	228471.3551	29.5582	229109.8660	229177.1351	47.5	22.5	7.6	37.5	17.5	24.3
198	stacking	227527.9740	228503.1633	228580.2107	31.8082	228765.4311	228842.5227	42.5	22.5	5.6	32.5	2.5	24.3
199	feeding	228808.8832	228837.3424	228921.1032	28.4592	228871.2359	228958.9520	12.5	2.5	17.8	35.5	-5.5	40.0
205	stacking	228471.3551	228968.5660	229040.4705	47.4628	229560.3632	229632.3101	17.5	22.5	3.6	27.5	12.5	24.5
197	feeding	228542.7250	229063.0193	229146.6729	22.5488	228629.6709	228713.3287	17.5	17.5	17.9	11.5	-5.5	40.0
200	stacking	228000.2314	229192.4995	229267.4515	45.8266	229003.7816	229078.6852	27.5	22.5	6.0	47.5	12.5	24.3
203	stacking	229267.4515	229306.3513	229384.1486	38.8998	229317.8489	229395.6906	47.5	22.5	5.1	42.5	2.5	24.5
202	stacking	228580.2107	229429.5840	229502.3456	45.4354	229208.5934	229281.3946	47.5	22.5	6.2	32.5	7.5	24.4
204	feeding	229379.1311	229527.9120	229611.6727	25.5664	229427.5475	229513.8971	17.5	2.5	17.8	8.5	-5.5	40.0
207	feeding	229655.4971	229693.3463	229777.2142	37.8492	229775.7481	229864.4938	2.5	12.5	17.7	32.5	-5.5	40.0
206	stacking	229502.3456	229824.9498	229900.1162	47.7356	229664.4579	229739.5778	17.5	22.5	3.2	32.5	17.5	24.5
208	stacking	229384.1486	229927.6388	229993.0075	27.5226	229905.7326	229971.1438	32.5	22.5	9.8	32.5	12.5	24.6
211	stacking	229993.0075	230030.8358	230107.4546	37.8283	230203.5845	230280.2437	32.5	22.5	6.4	47.5	2.5	24.7
209	stacking	229040.4705	230150.4257	230216.7888	42.9711	230001.5290	230067.9432	32.5	22.5	8.7	42.5	17.5	24.6
213	stacking	230216.7888	230247.2042	230319.2158	30.4154	230448.1853	230520.2403	37.5	22.5	7.2	37.5	7.5	24.7
210	stacking	229900.1162	230359.2941	230429.5319	40.0783	230098.6970	230168.8884	32.5	22.5	7.9	47.5	17.5	24.6
215	stacking	230429.5319	230464.8307	230538.0209	35.2988	230695.4480	230768.6816	37.5	22.5	6.1	42.5	7.5	24.7
216	stacking	230107.4546	230578.9564	230651.1823	40.9355	230804.7269	230876.9962	47.5	22.5	7.1	47.5	7.5	24.8
217	stacking	230319.2158	230693.6177	230771.0936	42.4354	230912.7460	230990.2662	47.5	22.5	5.8	32.5	2.5	24.9
212	feeding	230230.7978	230797.3028	230881.1707	26.2092	230315.8017	230399.6738	17.5	12.5	17.7	11.5	-5.5	40.0
214	feeding	230516.2000	230919.2965	231003.1643	38.1258	230559.2977	230650.6866	2.5	17.5	17.7	35.5	-5.5	40.0
220	stacking	230651.1823	231050.4227	231122.4343	47.2584	231283.5397	231355.5937	47.5	22.5	3.9	37.5	12.5	24.9
218	stacking	230538.0209	231161.3340	231237.2504	38.8997	231030.6534	231106.5210	47.5	22.5	5.7	27.5	12.5	24.9
224	stacking	231237.2504	231277.5429	231356.6260	40.2925	231760.5779	231839.7052	27.5	22.5	4.4	32.5	2.5	25.0
219	feeding	231075.6119	231389.1566	231473.2388	32.5306	231137.8572	231224.5282	7.5	2.5	17.5	8.5	-5.5	40.0
223	feeding	231574.2853	231612.2709	231696.3531	37.9856	231630.5709	231714.6573	2.5	7.5	17.5	11.5	-5.5	40.0
222	stacking	230771.0936	231744.2251	231823.0343	47.8720	231517.4749	231596.2354	47.5	22.5	3.0	27.5	17.5	24.9
226	stacking	231823.0343	231855.3783	231929.4256	32.3440	231990.0456	232064.1363	32.5	22.5	5.7	27.5	7.5	25.1

221	feeding	231353.5643	231949.3410	232033.4232	19.9154	231383.9288	231470.5998	22.5	2.5	17.5	32.5	-5.5	40.0
225	stacking	231122.4343	232081.0906	232156.6856	47.6674	231882.0469	231957.5921	27.5	22.5	3.3	42.5	12.5	25.0
228	stacking	232156.6856	232195.0496	232272.4183	38.3604	232221.4201	232298.8332	37.5	22.5	6.3	37.5	2.5	25.3
229	feeding	232184.5586	232308.2704	232392.3526	35.8521	232335.1884	232424.3638	7.5	7.5	17.5	35.5	-5.5	40.0
232	stacking	232272.4183	232439.9518	232520.5349	47.5992	232693.1402	232773.7676	37.5	22.5	3.4	47.5	2.5	25.4
230	stacking	231929.4256	232567.6846	232638.2262	47.1497	232469.5344	232540.1258	37.5	22.5	5.5	27.5	17.5	25.3
227	stacking	231356.6260	232672.6059	232752.1176	34.3797	232101.9316	232181.4875	32.5	22.5	4.2	27.5	2.5	25.2
233	feeding	232757.5511	232784.2961	232868.3783	26.7450	232813.4403	232897.5267	12.5	7.5	17.5	8.5	-5.5	40.0
234	stacking	232638.2262	232915.9093	232988.7010	47.5310	232947.8109	233020.6537	32.5	22.5	3.5	42.5	17.5	25.4
231	stacking	232752.1176	233022.5450	233101.6280	33.8440	232572.2205	232651.3440	37.5	22.5	4.8	42.5	2.5	25.4
238	feeding	233417.1465	233456.2129	233540.4022	39.0664	233458.7034	233542.8970	7.5	12.5	17.4	11.5	-5.5	40.0
236	stacking	232520.5349	233587.7287	233660.7046	47.3265	233162.2121	233235.2304	42.5	22.5	3.8	32.5	12.5	25.7
239	stacking	232988.7010	233701.2710	233772.6698	40.5664	233607.0363	233678.4840	47.5	22.5	5.1	37.5	17.5	25.7
235	stacking	233101.6280	233806.6209	233881.8468	33.9511	233049.3559	233124.6213	42.5	22.5	5.0	32.5	7.5	25.5
237	feeding	233184.5261	233905.8957	233989.9778	24.0489	233259.6892	233343.7756	22.5	12.5	17.5	32.5	-5.5	40.0
240	stacking	233881.8468	234037.1680	234113.7867	47.1902	233711.8969	233788.5552	47.5	22.5	4.0	37.5	7.5	25.8
244	stacking	234113.7867	234158.6864	234236.9600	44.8997	234385.4668	234463.6919	27.5	22.5	4.5	47.5	12.5	25.9
241	stacking	233660.7046	234277.7882	234349.6927	40.8282	234033.3913	234105.3382	37.5	22.5	4.9	37.5	12.5	25.8
243	stacking	233772.6698	234389.0210	234467.1398	39.3283	234265.1666	234343.3297	27.5	22.5	6.2	27.5	2.5	25.9
242	feeding	234032.8816	234491.8314	234576.1279	24.6916	234136.1727	234220.4733	17.5	7.5	17.3	35.5	-5.5	40.0
249	stacking	234236.9600	234623.8635	234705.4108	47.7356	234881.6221	234963.2137	32.5	22.5	3.2	37.5	2.5	26.1
245	feeding	234419.7240	234739.3343	234823.6308	33.9235	234503.5902	234587.8909	12.5	17.5	17.3	8.5	-5.5	40.0
246	stacking	234349.6927	234871.3664	234941.4175	47.7356	234636.1296	234706.0828	27.5	22.5	3.2	27.5	17.5	26.0
247	validating	234941.4175	234941.4175	234965.6785	0	0	234730.4644	27.5	17.5	21.5	27.5	17.5	26.0
248	stacking	234467.1398	235000.7011	235081.0698	35.0226	234759.3030	234839.7122	32.5	22.5	4.3	32.5	2.5	26.1
254	feeding	235246.8654	235284.0032	235368.5139	37.1378	235476.6131	235563.7934	2.5	2.5	17.1	11.5	-5.5	40.0
253	feeding	235215.7428	235406.7041	235491.1077	38.1902	235339.2887	235427.9327	7.5	17.5	17.2	32.5	-5.5	40.0
251	stacking	235081.0698	235538.7751	235615.5486	47.6674	235119.0258	235195.7528	47.5	22.5	3.3	32.5	17.5	26.1
252	stacking	234705.4108	235648.4283	235718.8629	32.8797	235225.1983	235295.6848	37.5	22.5	6.4	47.5	17.5	26.1
250	stacking	234941.4175	235753.7783	235830.1827	34.9154	235004.2372	235080.6851	47.5	22.5	4.5	47.5	7.5	26.1
255	stacking	235830.1827	235874.3325	235953.5226	44.1498	235614.7140	235693.9485	37.5	22.5	5.5	47.5	2.5	26.2
256	validating	235953.5226	235953.5226	235976.7637	0	0	235717.1414	47.5	2.5	22.3	47.5	2.5	26.2
262	feeding	236253.3792	236287.6241	236372.1349	34.2449	236313.2911	236397.8061	22.5	17.5	17.1	8.5	-5.5	40.0
261	feeding	236048.3955	236410.3932	236494.9039	38.2583	236188.2885	236276.0296	12.5	12.5	17.1	35.5	-5.5	40.0
258	stacking	235718.8629	236542.5032	236612.7686	47.5993	235866.0782	235936.2456	37.5	22.5	3.4	42.5	17.5	26.4
259	stacking	235953.5226	236648.0054	236724.8385	35.2368	235966.6900	236043.5625	42.5	22.5	4.5	42.5	7.5	26.5
257	stacking	235615.5486	236770.7025	236843.8927	45.8640	235758.6194	235831.8520	37.5	22.5	4.3	42.5	12.5	26.4
260	stacking	236843.8927	236886.8638	236964.9826	42.9711	236082.1078	236160.2699	42.5	22.5	3.4	27.5	7.5	26.6
263	feeding	236878.4104	236987.0408	237071.6587	22.0582	236915.7401	237000.3622	22.5	7.5	17.0	32.5	-5.5	40.0
264	feeding	237111.5161	237150.1835	237234.9085	38.6674	237157.3328	237244.7274	7.5	2.5	16.9	11.5	-5.5	40.0

B.2 Mix+Feed

Nr	Type	Release	Starting	Completion	Travel	Start Sim	End Sim	Origin			Destination		
0	feeding	410498.6441	410498.6441	410584.1191	0.0000	410536.5192	410621.9984	2.5	17.5	16.2	11.5	-5.5	40.0
1	feeding	410520.8941	410623.0592	410708.6414	38.9402	410663.3606	410758.4697	7.5	2.5	16.1	35.5	-5.5	40.0
3	mixing	410889.4158	410923.9241	411006.5854	34.5083	410925.5312	411035.3801	32.5	2.5	22.6	42.5	22.5	7.3
7	mixing	411006.5854	411042.1147	411112.6370	35.5293	411453.9763	411547.5361	47.5	17.5	22.5	47.5	22.5	7.9
4	mixing	411035.3801	411205.1521	411280.2063	41.7441	411059.0631	411159.2623	37.5	12.5	22.6	32.5	22.5	7.4
2	mixing	410758.4697	411315.9401	411391.2387	35.7338	410791.7767	410889.4158	27.5	17.5	22.9	37.5	22.5	7.3
5	mixing	411391.2387	411433.3918	411513.7436	42.1532	411190.6247	411294.8567	47.5	12.5	22.6	27.5	22.5	7.9
8	feeding	411513.7436	411548.2050	411633.7872	34.4614	411593.4503	411679.0366	17.5	17.5	16.1	32.5	-5.5	40.0
9	mixing	411280.2063	411668.4319	411749.7004	34.6447	411716.1034	411821.2343	37.5	2.5	22.4	37.5	22.5	8.4
6	feeding	411163.3377	411789.8384	411875.4205	40.1380	411321.5602	411407.1466	17.5	12.5	16.1	8.5	-5.5	40.0
10	mixing	411513.7436	411910.4880	411987.7921	35.0674	411853.6028	411956.4865	27.5	7.5	22.4	32.5	22.5	8.6
12	feeding	411994.7400	412035.2568	412120.9461	40.5168	412127.0359	412212.7294	12.5	7.5	16.0	11.5	-5.5	40.0
11	mixing	411112.6370	412157.2135	412234.4106	36.2674	411983.9204	412086.5898	32.5	7.5	22.4	42.5	22.5	8.7
14	mixing	411749.7004	412886.6134	412962.7866	34.5065	412415.1676	412513.0775	42.5	17.5	22.4	27.5	22.5	8.8
13	feeding	412191.2731	413005.5838	413091.2731	42.7971	412250.7409	412345.2360	2.5	12.5	16.0	35.5	-5.5	40.0
15	mixing	411987.7921	413126.0541	413202.8226	34.7811	412544.3073	412645.7982	42.5	7.5	22.2	47.5	22.5	8.9
20	feeding	413165.9579	413352.2154	413438.0118	43.9941	413209.3629	413297.8290	22.5	2.5	15.9	8.5	-5.5	40.0
18	mixing	413202.8226	413473.0792	413552.6334	35.0674	412939.8437	413043.4783	27.5	2.5	22.0	32.5	22.5	9.6
23	mixing	413552.6334	413586.1172	413653.3181	33.4838	413579.5852	413665.4736	27.5	17.5	21.8	32.5	22.5	10.3
26	mixing	413653.3181	413692.8122	413763.1521	39.4941	413944.4773	414034.9207	42.5	12.5	21.7	42.5	22.5	10.9
27	validating	413763.1521	413763.1521	413786.0359	0	0	414081.0797	42.5	22.5	7.2	42.5	22.5	10.9
19	feeding	413014.4628	413828.6663	413914.4628	42.6304	413079.4791	413167.8644	17.5	2.5	15.9	32.5	-5.5	40.0
17	mixing	412962.7866	413949.3120	414025.3305	34.8492	412805.4840	412904.5105	47.5	7.5	22.1	42.5	22.5	9.5
16	mixing	412234.4106	414065.8776	414138.2532	40.5471	412678.5713	412774.7041	27.5	12.5	22.2	37.5	22.5	9.5
21	mixing	414138.2532	414171.9416	414246.6148	33.6884	413335.7496	413430.9864	32.5	17.5	22.0	47.5	22.5	9.8
22	mixing	414025.3305	414290.2680	414365.2150	43.6532	413461.7623	413559.9317	37.5	7.5	21.8	27.5	22.5	10.2
28	feeding	414022.6005	414406.9894	414492.7858	41.7744	414132.2656	414226.2671	2.5	7.5	15.9	35.5	-5.5	40.0
24	mixing	414246.6148	414527.9078	414606.3906	35.1220	413702.7012	413804.1930	47.5	2.5	21.7	42.5	22.5	10.3
30	mixing	414606.3906	414645.8846	414721.6293	39.4941	414410.5322	414505.8714	47.5	12.5	21.7	27.5	22.5	11.3
29	feeding	414166.6557	414763.9188	414849.8224	42.2895	414276.8339	414365.4070	2.5	2.5	15.8	11.5	-5.5	40.0
34	mixing	414721.6293	414886.0899	414959.1083	36.2674	414824.9412	414918.6106	32.5	7.5	21.6	37.5	22.5	11.8
35	validating	414959.1083	414959.1083	414982.1719	0	0	414964.0684	37.5	22.5	8.0	37.5	22.5	11.8
36	feeding	414879.5287	415020.3706	415106.2741	38.1986	414995.9773	415081.8851	22.5	7.5	15.8	32.5	-5.5	40.0
32	mixing	413763.1521	415141.4643	415218.4471	35.1902	414652.6811	414751.1729	42.5	2.5	21.6	32.5	22.5	11.6
33	validating	415218.4471	415218.4471	415241.6881	0	0	414797.5073	32.5	22.5	7.7	32.5	22.5	11.6
25	mixing	414365.2150	415280.2958	415350.7429	38.6077	413827.8759	413920.7944	32.5	12.5	21.7	37.5	22.5	10.8
31	mixing	415350.7429	415383.3403	415453.0674	32.5974	414529.3765	414618.1542	37.5	17.5	21.7	47.5	22.5	11.3
38	mixing	415453.0674	415485.1876	415559.6465	32.1202	415252.9523	415344.1132	47.5	17.5	21.5	27.5	22.5	12.3
39	validating	415559.6465	415559.6465	415583.7425	0	0	415389.0450	27.5	22.5	7.9	27.5	22.5	12.3
37	feeding	415008.7673	415612.6887	415698.5923	27.5520	415120.0330	415205.9408	22.5	17.5	15.8	8.5	-5.5	40.0
43	mixing	415559.6465	415733.9870	415809.3626	35.3947	415703.4461	415798.4022	27.5	2.5	21.3	32.5	22.5	12.8
44	feeding	415676.6313	415849.1597	415935.2776	39.7971	415833.5502	415919.6722	7.5	12.5	15.6	11.5	-5.5	40.0
40	mixing	415218.4471	415970.6041	416042.8726	35.3265	415420.9168	415513.7291	27.5	7.5	21.4	42.5	22.5	12.3
41	mixing	414959.1083	416080.7985	416149.1026	37.9259	415537.4120	415624.7591	37.5	12.5	21.4	47.5	22.5	12.5
42	validating	416149.1026	416149.1026	416171.9864	0	0	415668.1129	47.5	22.5	8.8	47.5	22.5	12.5
47	mixing	416149.1026	416213.4578	416284.7620	41.4714	416209.0421	416298.9616	42.5	7.5	21.3	37.5	22.5	13.1
48	mixing	415809.3626	416325.8242	416396.9141	41.0623	416330.5437	416420.0346	47.5	7.5	21.3	42.5	22.5	13.3
52	mixing	416396.9141	416427.3298	416496.3244	30.4156	416838.7660	416921.9990	42.5	17.5	21.0	27.5	22.5	14.1
45	feeding	415715.3531	416529.2352	416615.3531	32.9108	415957.9565	416045.9168	12.5	17.5	15.6	35.5	-5.5	40.0
50	mixing	416284.7620	416650.8841	416724.8669	35.5311	416582.6008	416674.1284	47.5	2.5	21.1	47.5	22.5	13.9
55	mixing	416724.8669	416754.7371	416820.0713	29.8702	417191.7996	417271.4689	47.5	17.5	20.8	37.5	22.5	14.5
51	feeding	416559.0985	416988.0594	417074.3915	30.6625	416717.8273	416804.1636	17.5	7.5	15.4	32.5	-5.5	40.0
46	mixing	416042.8726	417109.7862	417184.9476	35.3947	416083.7335	416178.2623	37.5	2.5	21.3	27.5	22.5	13.0
53	feeding	416874.5128	417218.4720	417304.8041	33.5244	416957.2777	417043.6141	12.5	12.5	15.4	8.5	-5.5	40.0

49	mixing	417184.9476	417342.8715	417417.3900	38.0674	416455.0194	416546.9741	32.5	2.5	21.2	32.5	22.5	13.5
54	mixing	417417.3900	417454.1568	417520.2110	36.7668	417078.5347	417162.0259	27.5	12.5	20.9	32.5	22.5	14.1
56	mixing	416496.3244	417560.1824	417629.2366	39.9714	417302.6989	417388.4397	37.5	7.5	20.7	42.5	22.5	14.6
57	mixing	417520.2110	417665.1170	417729.9926	35.8804	417415.9226	417497.0554	32.5	12.5	20.7	27.5	22.5	15.0
60	feeding	417729.9926	417759.6415	417846.0808	29.6489	417798.8148	417885.2583	7.5	17.5	15.3	11.5	-5.5	40.0
61	mixing	417629.2366	417881.9528	417954.1141	35.8720	417923.5523	418012.4025	27.5	2.5	20.6	47.5	22.5	15.1
58	mixing	416820.0713	417989.6536	418057.3626	35.5395	417540.0326	417621.6586	47.5	12.5	20.7	32.5	22.5	15.0
63	mixing	418057.3626	418086.2782	418153.1300	28.9156	418155.4049	418235.9607	27.5	17.5	20.5	42.5	22.5	15.6
65	mixing	417954.1141	418185.3414	418245.3636	32.2114	418398.7336	418471.6288	32.5	17.5	20.5	27.5	22.5	15.7
59	feeding	417571.6484	418277.4574	418363.8967	32.0938	417661.2891	417754.8260	2.5	17.5	15.3	35.5	-5.5	40.0
62	mixing	417729.9926	418399.7687	418471.8229	35.8720	418043.5873	418131.9005	32.5	2.5	20.6	37.5	22.5	15.2
64	feeding	418233.2915	418505.5752	418592.1217	33.7523	418275.6550	418364.7903	12.5	2.5	15.2	32.5	-5.5	40.0
69	mixing	418153.1300	418628.1300	418698.6842	36.0083	418773.6370	418858.9515	42.5	2.5	20.4	47.5	22.5	16.4
73	mixing	418698.6842	418733.0646	418795.3688	34.3804	419146.1717	419222.1617	42.5	12.5	20.3	42.5	22.5	17.0
74	validating	418795.3688	418795.3688	418819.1289	0	0	419256.9246	42.5	22.5	12.8	42.5	22.5	17.0
66	mixing	418471.8229	418846.6809	418906.1675	27.5520	418500.6711	418572.4917	37.5	17.5	20.5	32.5	22.5	16.2
67	validating	418906.1675	418906.1675	418929.7567	0	0	418607.6054	32.5	22.5	12.1	32.5	22.5	16.2
68	feeding	418549.6575	418955.1448	419041.6912	25.3881	418639.6560	418726.2067	22.5	12.5	15.2	8.5	-5.5	40.0
70	mixing	418245.3636	419077.6995	419144.2894	36.0083	418891.7247	418971.8941	27.5	7.5	20.4	27.5	22.5	16.6
71	validating	419144.2894	419144.2894	419167.3530	0	0	419006.4817	27.5	22.5	12.8	27.5	22.5	16.6
75	feeding	419254.5299	419276.6611	419363.2075	22.1312	419293.3453	419379.8959	17.5	17.5	15.2	35.5	-5.5	40.0
77	mixing	419144.2894	419399.3522	419468.8350	36.1447	419555.9956	419638.8458	37.5	2.5	20.2	32.5	22.5	17.2
76	feeding	419369.6847	420183.0311	420269.6847	33.2889	419426.7711	419513.4289	2.5	12.5	15.1	11.5	-5.5	40.0
72	mixing	418906.1675	420305.9522	420372.4349	36.2674	419038.0639	419118.3405	32.5	7.5	20.3	37.5	22.5	16.6
78	mixing	420372.4349	420399.9869	420457.8663	27.5520	419665.6961	419737.2256	42.5	17.5	20.1	47.5	22.5	17.3
79	mixing	418795.3688	420484.9410	420546.0967	27.0747	419756.8767	419827.2188	47.5	17.5	20.1	37.5	22.5	17.7
80	validating	420546.0967	420546.0967	420569.5129	0	0	419859.3518	37.5	22.5	13.7	37.5	22.5	17.7
82	feeding	419934.4346	420644.4980	420731.1516	26.4290	419996.9756	420083.6334	17.5	12.5	15.1	32.5	-5.5	40.0
81	mixing	419468.8350	420767.4327	420834.2845	36.2811	419891.4825	419969.2948	47.5	7.5	20.0	27.5	22.5	17.9
85	feeding	420201.4248	420862.8536	420949.6143	28.5691	420335.4190	420422.1840	2.5	7.5	15.0	8.5	-5.5	40.0
83	mixing	420457.8663	420985.8954	421049.7472	36.2811	420118.9176	420193.4701	27.5	12.5	20.0	42.5	22.5	17.9
84	mixing	420546.0967	421082.9003	421143.2760	33.1532	420217.1531	420289.9287	32.5	12.5	20.0	42.5	22.5	18.5
86	mixing	420834.2845	421176.0200	421236.3957	32.7441	420463.2182	420534.3866	37.5	12.5	20.0	47.5	22.5	18.5
87	validating	421236.3957	421236.3957	421260.1558	0	0	420565.4677	47.5	22.5	14.3	47.5	22.5	18.5
89	mixing	421143.2760	421296.5817	421360.2787	36.4259	420708.3773	420783.4039	42.5	7.5	19.9	27.5	22.5	18.8
90	feeding	420775.2526	421386.4284	421473.1892	26.1497	420814.9446	420904.8753	7.5	7.5	15.0	35.5	-5.5	40.0
88	mixing	421049.7472	421509.5384	421577.1997	36.3492	420601.0945	420680.9434	47.5	2.5	19.9	32.5	22.5	18.6
94	feeding	421211.5473	421606.9923	421693.8602	29.7926	421251.1496	421340.6063	7.5	2.5	14.9	11.5	-5.5	40.0
91	mixing	421236.3957	421733.1276	421796.6104	39.2674	420940.3640	421014.9633	37.5	7.5	19.7	37.5	22.5	18.8
92	mixing	421577.1997	421816.8979	421878.7140	20.2875	421037.9627	421108.1224	32.5	17.5	19.6	47.5	22.5	19.4
95	mixing	421796.6104	421905.0441	421963.5983	26.3302	421385.7315	421454.5278	47.5	12.5	19.5	42.5	22.5	19.7
96	mixing	421878.7140	421983.1352	422041.3980	19.5369	421477.7552	421542.8662	37.5	17.5	19.5	27.5	22.5	19.8
102	feeding	422041.3980	422072.5835	422159.5585	31.1854	422106.6180	422196.1818	2.5	2.5	14.8	8.5	-5.5	40.0
99	mixing	422041.3980	422196.3168	422261.2137	36.7583	421766.6340	421839.9849	27.5	2.5	19.3	27.5	22.5	20.5
100	feeding	421773.9836	422278.9863	422365.8541	17.7726	421863.1609	421950.0329	22.5	17.5	14.9	32.5	-5.5	40.0
93	mixing	421360.2787	422402.4761	422468.5303	36.6220	421139.3033	421215.9294	42.5	2.5	19.5	32.5	22.5	19.7
97	mixing	422468.5303	422494.5409	422552.6604	26.0106	421570.6935	421637.8348	27.5	12.5	19.4	37.5	22.5	20.0
98	mixing	421963.5983	422578.4155	422636.0651	25.7551	421665.6661	421731.3009	42.5	12.5	19.4	47.5	22.5	20.4
103	mixing	422636.0651	422665.0058	422725.4513	28.9407	422234.2615	422301.0874	32.5	7.5	19.2	32.5	22.5	20.9
110	feeding	422722.7233	422754.1725	422841.2546	28.7211	422842.8601	422929.9465	12.5	7.5	14.7	11.5	-5.5	40.0
109	feeding	422610.8717	422881.1493	422968.2315	39.8947	422713.0412	422802.7122	22.5	2.5	14.7	35.5	-5.5	40.0
101	mixing	422552.6604	423005.0580	423069.5479	36.8265	421988.2815	422061.5367	32.5	2.5	19.2	42.5	22.5	20.7
105	mixing	423069.5479	423098.0578	423157.4466	28.5099	422428.5825	422494.0559	47.5	7.5	19.1	47.5	22.5	21.4
104	mixing	422261.2137	423185.0142	423245.3040	27.5676	422332.6696	422401.1487	27.5	7.5	19.1	37.5	22.5	20.9
106	mixing	422725.4513	423269.8253	423324.7531	24.5213	422521.0848	422581.3166	37.5	12.5	19.1	27.5	22.5	21.7
107	validating	423324.7531	423324.7531	423348.5132	0	0	422605.8922	27.5	22.5	17.5	27.5	22.5	21.7
108	mixing	423245.3040	423365.2198	423419.9634	16.7066	422625.5456	422678.4080	27.5	17.5	19.1	37.5	22.5	21.7
113	mixing	423324.7531	423446.4720	423503.1622	26.5086	423072.9777	423129.7113	42.5	7.5	18.9	47.5	22.5	22.1
111	mixing	423157.4466	423518.2562	423567.0931	15.0940	422975.1625	423023.9021	47.5	17.5	19.0	42.5	22.5	22.0
112	validating	423567.0931	423567.0931	423589.9769	0	0	423046.6879	42.5	22.5	18.3	42.5	22.5	22.0
118	mixing	423503.1622	423619.2337	423676.5668	29.2569	423366.5561	423423.9325	47.5	2.5	18.8	42.5	17.5	22.6
114	mixing	423419.9634	423683.3593	423736.2224	6.7926	423148.0825	423200.9975	42.5	17.5	18.9	32.5	22.5	22.2
115	validating	423736.2224	423736.2224	423759.1062	0	0	423223.7833	32.5	22.5	18.5	32.5	22.5	22.2
121	feeding	423562.0895	423788.6369	423875.7191	29.5307	423652.3037	423739.3901	12.5	17.5	14.7	8.5	-5.5	40.0
120	feeding	423469.4132	423915.6138	424002.6959	39.8947	423526.3195	423613.4059	22.5	7.5	14.7	32.5	-5.5	40.0
116	mixing	423567.0931	424039.7952	424100.5568	37.0992	423253.1417	423313.9476	37.5	2.5	18.8	37.5	22.5	22.3
117	validating	424100.5568	424100.5568	424123.9730	0	0	423337.3419	37.5	22.5	18.3	37.5	22.5	22.3
122	mixing	424100.5568	424139.4955	424193.0015	15.5226	423780.2425	423833.7995	37.5	17.5	18.8	47.5	17.5	22.7
119	mixing	423736.2224	424215.6750	424269.2581	22.6735	423445.0163	423498.6378	32.5	12.5	18.8	27.5	22.5	22.6
123	mixing	423676.5668	424285.3163	424343.0780	16.0583	423857.8352	423915.6402	32.5	17.5	18.6	37.5	2.5	22.8
124	mixing	424269.2581	424350.1920	424407.5250	7.1140	423927.8373	423985.2137	37.5	2.5	18.8	32.5	17.5	22.6

127	mixing	424407.5250	424414.5319	424472.0792	7.0069	424136.8923	424194.4830	32.5	17.5	18.7	37.5	2.5	22.7
126	mixing	424343.0780	424479.1932	424536.7405	7.1140	424067.1045	424124.6952	37.5	2.5	18.7	32.5	17.5	22.7
125	mixing	424193.0015	424543.8545	424601.4018	7.1140	423997.3166	424054.9073	32.5	17.5	18.7	37.5	2.5	22.7
128	mixing	424601.4018	424627.8730	424685.6346	26.4711	424219.2751	424277.0801	42.5	17.5	18.6	47.5	2.5	22.8
129	mixing	424536.7405	424693.0700	424750.1293	7.4354	424289.5519	424346.5614	47.5	2.5	18.5	32.5	12.5	22.9
132	mixing	424472.0792	424757.0290	424812.8025	6.8997	424628.1980	424683.9276	32.5	12.5	19.1	47.5	2.5	22.3
133	mixing	424685.6346	425008.5707	425062.7966	19.5488	424705.0083	424759.2819	37.5	7.5	18.5	42.5	17.5	22.9
130	feeding	424307.5629	425096.1844	425183.3737	33.3878	424374.2618	424464.0400	17.5	2.5	14.6	35.5	-5.5	40.0
131	feeding	424410.8765	425223.4730	425310.8765	40.0992	424504.6424	424592.0502	12.5	12.5	14.4	11.5	-5.5	40.0
137	feeding	424968.4674	425350.9758	425438.3794	40.0992	425011.9154	425102.8003	2.5	17.5	14.4	32.5	-5.5	40.0
143	feeding	425430.1501	425478.4786	425565.8822	40.0992	425515.7143	425603.1221	7.5	17.5	14.4	8.5	-5.5	40.0
136	mixing	425062.7966	425603.9496	425658.0684	38.0674	424923.9171	424978.0783	32.5	2.5	18.6	27.5	12.5	22.9
134	mixing	424750.1293	425665.6110	425719.9440	7.5426	424783.0852	424837.4659	27.5	12.5	18.5	32.5	2.5	23.0
135	mixing	424812.8025	425726.9509	425779.9982	7.0069	424849.5688	424902.6586	32.5	2.5	19.1	27.5	12.5	22.4
138	mixing	425719.9440	425786.3622	425839.4095	6.3640	425138.6981	425191.7879	27.5	12.5	19.1	32.5	2.5	22.4
139	mixing	425779.9982	426055.5673	426106.0113	7.0069	425203.8908	425254.2368	32.5	2.5	18.5	32.5	7.5	23.0
140	mixing	425658.0684	426113.2324	426162.8193	7.2211	425266.5268	425316.0132	32.5	7.5	18.9	32.5	2.5	22.6
144	mixing	426162.8193	426184.9571	426243.6235	22.1378	425688.3627	425746.9806	47.5	12.5	19.2	27.5	12.5	22.3
142	mixing	426106.0113	426250.4160	426310.3681	6.7926	425412.7314	425472.6347	27.5	12.5	18.6	47.5	12.5	22.9
141	mixing	425839.4095	426317.9107	426378.0771	7.5426	425340.0529	425400.1705	47.5	12.5	18.5	27.5	12.5	23.0
145	mixing	426378.0771	426394.6711	426445.1150	16.5940	425764.4604	425814.8052	27.5	17.5	18.5	32.5	17.5	23.0
149	mixing	426445.1150	426452.0147	426500.9587	6.8997	426086.9764	426135.8200	32.5	17.5	19.2	27.5	17.5	22.3
148	mixing	426243.6235	426507.7513	426557.9810	6.7926	426024.9355	426075.0662	27.5	17.5	18.6	32.5	17.5	22.9
146	mixing	426310.3681	426565.3093	426615.3247	7.3283	425827.2770	425877.1920	32.5	17.5	18.7	27.5	17.5	22.8
147	feeding	425827.2057	426639.8021	426727.2057	24.4774	425901.2889	425988.6967	17.5	17.5	14.4	35.5	-5.5	40.0
150	feeding	426097.8309	426767.4413	426855.0592	40.2356	426160.3871	426248.0092	17.5	7.5	14.2	11.5	-5.5	40.0
157	feeding	426654.2174	426895.2948	426982.9126	40.2356	426754.6192	426842.2413	7.5	12.5	14.2	32.5	-5.5	40.0
159	feeding	426934.3547	427023.1483	427110.7661	40.2356	426967.4128	427055.0349	22.5	12.5	14.2	8.5	-5.5	40.0
151	mixing	426615.3247	427152.6419	427212.8083	41.8758	426284.3161	426344.4380	27.5	22.5	18.5	47.5	22.5	23.0
152	validating	427212.8083	427212.8083	427236.3975	0	0	426368.0322	47.5	22.5	18.9	47.5	22.5	23.0
153	mixing	426557.9810	427243.6186	427302.9279	7.2211	426380.3222	426439.5826	47.5	22.5	18.9	27.5	22.5	22.6
156	mixing	427302.9279	427318.9861	427380.7120	16.0583	426604.6559	426712.0851	32.5	22.5	18.6	47.5	2.5	23.0
155	mixing	427212.8083	427387.9332	427449.0162	7.2211	426531.2386	426592.3660	47.5	2.5	18.9	32.5	22.5	22.7
154	mixing	426500.9587	427456.3445	427518.2847	7.3283	426456.8726	426518.8571	32.5	22.5	18.5	47.5	2.5	23.1
158	mixing	427518.2847	427525.6130	427586.6960	7.3283	426881.6944	426942.8230	47.5	2.5	18.9	32.5	22.5	22.7
162	mixing	427586.6960	427593.5957	427654.6788	6.8997	427240.2459	427301.3733	32.5	22.5	18.9	47.5	2.5	22.7
161	mixing	427380.7120	427661.6856	427722.9829	7.0069	427166.8014	427228.1430	47.5	2.5	18.8	32.5	22.5	22.8
160	mixing	427449.0162	427730.2041	427791.7157	7.2211	427092.9555	427154.5114	32.5	22.5	18.7	47.5	2.5	22.9
163	mixing	427791.7157	427799.0440	427860.5556	7.3283	427313.5704	427375.1263	47.5	2.5	18.7	32.5	22.5	22.9
166	mixing	427860.5556	427867.8839	427929.3955	7.3283	427533.3770	427594.9329	32.5	22.5	18.7	47.5	2.5	22.9
165	mixing	427654.6788	427936.4024	427997.2711	7.0069	427460.3610	427521.2741	47.5	2.5	19.0	32.5	22.5	22.6
164	mixing	427722.9829	428004.0637	428065.1467	6.7926	427387.3235	427448.4508	32.5	22.5	18.9	47.5	2.5	22.7
167	mixing	428065.1467	428071.7250	428132.1652	6.5783	427606.8431	427667.3276	47.5	2.5	19.2	32.5	22.5	22.4
170	feeding	427776.4951	428159.5530	428247.2780	27.3878	427834.9169	427922.6461	17.5	12.5	14.1	11.5	-5.5	40.0
171	feeding	427832.4478	428287.6500	428375.4822	40.3720	427965.4401	428061.2969	2.5	2.5	14.0	35.5	-5.5	40.0
168	mixing	427997.2711	428412.8541	428463.5124	37.3720	427696.0278	427746.5881	32.5	2.5	18.4	32.5	7.5	23.1
169	mixing	427929.3955	428470.5193	428519.4632	7.0069	427758.6910	427807.5346	32.5	7.5	19.2	32.5	2.5	22.3
174	mixing	428519.4632	428525.8272	428575.1998	6.3640	428234.8539	428284.1261	32.5	2.5	19.0	37.5	2.5	22.5
172	mixing	428132.1652	428582.4209	428633.0792	7.2211	428101.0909	428151.6512	37.5	2.5	18.4	32.5	2.5	23.1
173	mixing	428463.5124	428639.4432	428691.9315	6.3640	428163.1565	428215.2028	32.5	2.5	19.8	37.5	2.5	21.7
175	mixing	428633.0792	428707.2398	428757.8981	15.3083	428301.4161	428351.9741	32.5	7.5	18.4	37.5	7.5	23.1
176	mixing	428691.9315	428765.3335	428815.1346	7.4354	428364.4459	428414.1467	37.5	7.5	18.8	32.5	7.5	22.7
179	mixing	428815.1346	428822.1415	428871.9426	7.0069	428551.4559	428601.1568	32.5	7.5	18.8	37.5	7.5	22.7
178	mixing	428757.8981	428879.2709	428929.7149	7.3283	428488.7307	428539.0744	37.5	7.5	18.5	32.5	7.5	23.0
177	mixing	428575.1998	428937.1503	428987.1657	7.4354	428426.3438	428476.2589	32.5	7.5	18.7	37.5	7.5	22.8
180	mixing	428987.1657	428993.8511	429042.7951	6.6854	428612.8679	428661.7116	37.5	7.5	19.2	32.5	7.5	22.3
185	mixing	429042.7951	429049.6948	429100.1388	6.8997	429077.7592	429128.3309	32.5	7.5	18.5	37.5	7.5	23.0
182	mixing	428871.9426	429107.2528	429156.6253	7.1140	428736.2597	428785.5319	37.5	7.5	19.0	32.5	7.5	22.5
181	mixing	428929.7149	429163.7393	429214.1833	7.1140	428673.7189	428724.0626	32.5	7.5	18.5	37.5	7.5	23.0
186	mixing	429214.1833	429221.0830	429270.0270	6.8997	429140.3382	429189.1845	37.5	7.5	19.2	32.5	7.5	22.3
183	feeding	428783.5311	429303.4144	429391.2465	33.3878	428818.8690	428909.1565	7.5	2.5	14.0	8.5	-5.5	40.0
184	feeding	428837.1435	429431.6182	429519.4504	40.3720	428951.9505	429042.4523	12.5	2.5	14.0	32.5	-5.5	40.0
191	feeding	429455.2010	429561.1178	429648.9500	41.6674	429503.7024	429591.5388	2.5	12.5	14.0	11.5	-5.5	40.0
192	feeding	429512.7786	429689.3899	429777.3292	40.4401	429630.9821	429718.9256	22.5	17.5	13.9	35.5	-5.5	40.0
187	mixing	429156.6253	429814.6867	429865.3450	37.3719	429213.2798	429263.8389	47.5	7.5	18.4	42.5	7.5	23.1
188	mixing	429100.1388	429872.4431	429921.6013	7.1140	429276.0360	429325.0940	42.5	7.5	19.1	47.5	7.5	22.4
189	mixing	429270.0270	429937.6391	429992.0022	16.0583	429342.2911	429396.7061	42.5	12.5	18.4	32.5	17.5	23.1
190	mixing	429865.3450	429999.0066	430051.6554	7.0069	429408.8090	429461.5075	32.5	17.5	19.2	42.5	12.5	22.3
193	mixing	429921.6013	430074.3516	430132.7561	22.6735	429755.3008	429813.7486	27.5	17.5	18.4	27.5	2.5	23.2
194	mixing	429992.0022	430140.4058	430198.1674	7.6497	429826.3974	429884.2024	27.5	2.5	18.7	27.5	17.5	22.9
196	mixing	430132.7561	430206.1237	430264.0996	7.4354	429977.5322	430035.5515	27.5	17.5	18.6	27.5	2.5	23.0

197	mixing	430198.1674	430270.9993	430327.6895	6.8997	430047.5588	430104.2923	27.5	2.5	19.2	27.5	17.5	22.4
195	mixing	430051.6554	430333.7321	430391.7650	6.0426	429895.9136	429952.2186	27.5	17.5	19.4	27.5	2.5	22.2
198	mixing	430391.7650	430398.7718	430449.6444	7.0069	430129.0845	430179.8581	27.5	2.5	18.3	32.5	2.5	23.2
201	mixing	430449.6444	430456.5441	430507.2879	6.8997	430316.2755	430364.6906	32.5	2.5	19.4	27.5	2.5	22.1
200	mixing	430327.6895	430514.1876	430565.0601	6.8997	430253.4960	430304.2682	27.5	2.5	18.3	32.5	2.5	23.2
199	mixing	430264.0996	430572.2813	430621.4395	7.2211	430192.1481	430241.2060	32.5	2.5	19.1	27.5	2.5	22.4
205	feeding	430621.4395	430642.4264	430730.4728	20.9868	430658.8639	430749.3657	22.5	2.5	13.8	8.5	-5.5	40.0
202	feeding	430334.6877	430770.9811	430859.0276	40.5083	430389.2193	430479.8546	17.5	2.5	13.8	32.5	-5.5	40.0
206	mixing	430507.2879	430896.4677	430947.3403	37.4402	430793.7278	430844.5031	37.5	2.5	18.3	32.5	7.5	23.2
204	mixing	430565.0601	430954.4543	431003.3983	7.1140	430582.6892	430631.5328	32.5	7.5	19.2	37.5	2.5	22.3
203	mixing	430621.4395	431010.5123	431061.3848	7.1140	430519.7167	430570.4921	37.5	2.5	18.3	32.5	7.5	23.2
207	mixing	431061.3848	431068.9274	431118.7285	7.5426	430857.0640	430906.7648	32.5	7.5	18.8	37.5	2.5	22.7
209	mixing	430947.3403	431125.4140	431174.5722	6.6854	430986.8906	431035.9485	37.5	2.5	19.1	42.5	2.5	22.4
208	mixing	431003.3983	431181.7934	431232.6659	7.2211	430923.8257	430974.6007	42.5	2.5	18.3	37.5	2.5	23.2
211	mixing	431232.6659	431239.7799	431288.7239	7.1140	431110.8066	431159.6502	37.5	2.5	19.2	42.5	2.5	22.3
210	mixing	431118.7285	431295.7308	431346.3890	7.0069	431048.1457	431098.7036	42.5	2.5	18.4	37.5	2.5	23.1
212	mixing	431174.5722	431354.2530	431404.9113	7.8640	431177.0032	431227.5611	37.5	2.5	18.4	42.5	2.5	23.1
214	mixing	431346.3890	431412.3467	431462.1478	7.4354	431402.1665	431451.8699	42.5	2.5	18.8	37.5	2.5	22.7
215	mixing	431288.7239	431469.0476	431518.6344	6.8997	431463.8772	431513.3637	37.5	2.5	18.9	42.5	2.5	22.6
216	mixing	431404.9113	431541.7251	431599.3201	23.1021	431537.0780	431594.6247	27.5	7.5	18.3	42.5	7.5	23.2
217	mixing	431462.1478	431665.9831	431722.2923	7.4354	431607.0965	431663.3576	42.5	7.5	18.9	27.5	7.5	22.6
219	mixing	431518.6344	431729.2991	431786.0369	7.0069	431818.3696	431875.0634	27.5	7.5	18.7	42.5	7.5	22.8
222	mixing	431786.0369	431792.7223	431848.3887	6.6854	432023.2077	432078.8259	42.5	7.5	19.2	27.5	7.5	22.3
221	mixing	431722.2923	431855.3955	431912.7762	7.0069	431953.7723	432011.1048	27.5	7.5	18.4	42.5	7.5	23.1
220	mixing	431599.3201	431919.5574	431977.0236	6.7926	431886.6725	431941.8622	42.5	7.5	19.4	27.5	7.5	22.1
213	feeding	431198.4546	432010.4081	432098.4546	33.3878	431269.9346	431362.6453	2.5	7.5	13.8	35.5	-5.5	40.0
218	feeding	431629.1729	432138.9629	432227.0094	40.5083	431694.1483	431782.1990	7.5	7.5	13.8	11.5	-5.5	40.0
225	feeding	432197.7827	432267.5859	432355.7395	40.5765	432246.7000	432334.8578	12.5	7.5	13.7	32.5	-5.5	40.0
223	mixing	431977.0236	432457.3189	432511.8963	37.4401	432096.0231	432150.6523	32.5	7.5	18.3	42.5	12.5	23.2
227	mixing	432511.8963	432519.6532	432573.5877	7.7569	432436.9256	432490.9098	42.5	12.5	18.6	32.5	7.5	22.9
226	mixing	431848.3887	432581.1189	432635.2677	7.5426	432370.1648	432424.3647	32.5	7.5	18.5	42.5	12.5	23.0
224	mixing	431912.7762	432642.3703	432695.4477	7.1140	432163.0339	432216.1610	42.5	12.5	19.0	32.5	7.5	22.5
228	mixing	432695.4477	432702.4546	432756.3891	7.0069	432503.3816	432557.3659	32.5	7.5	18.6	42.5	12.5	22.9
232	mixing	432756.3891	432764.0388	432818.4019	7.6497	432849.8318	432904.2438	42.5	12.5	18.4	32.5	7.5	23.1
230	mixing	432573.5877	432825.9445	432879.6648	7.5426	432633.7861	432687.5561	32.5	7.5	18.7	42.5	12.5	22.8
229	mixing	432635.2677	432886.3388	432938.9876	6.6854	432569.2761	432621.9747	42.5	12.5	19.2	32.5	7.5	22.3
233	mixing	432938.9876	432945.7802	432999.7147	6.7926	432916.8926	432970.8769	32.5	7.5	18.6	42.5	12.5	22.9
237	mixing	432999.7147	433006.6145	433059.4776	6.8997	433258.0880	433311.0008	42.5	12.5	19.1	32.5	7.5	22.4
236	mixing	432818.4019	433066.6987	433121.2761	7.2211	433191.1724	433245.7980	32.5	7.5	18.3	42.5	12.5	23.2
234	mixing	432879.6648	433128.5704	433181.6477	7.3283	432982.9798	433036.1069	42.5	12.5	19.0	32.5	7.5	22.5
238	mixing	433181.6477	433188.7617	433242.9106	7.1140	433323.1037	433377.3023	32.5	7.5	18.5	42.5	12.5	23.0
242	mixing	433242.9106	433250.1317	433303.4234	7.2211	433679.4669	433732.8074	42.5	12.5	18.9	32.5	7.5	22.6
240	mixing	433059.4776	433310.5147	433364.4492	7.1140	433455.1308	433509.1151	32.5	7.5	18.6	42.5	12.5	22.9
239	mixing	433121.2761	433371.5290	433424.8207	7.1140	433389.5923	433442.9337	42.5	12.5	18.9	32.5	7.5	22.6
231	feeding	432637.9792	433449.8257	433537.9792	25.0131	432717.7989	432805.9567	22.5	7.5	13.7	8.5	-5.5	40.0
235	feeding	433034.9815	433578.6237	433666.8844	40.6447	433066.4641	433154.7291	12.5	17.5	13.6	35.5	-5.5	40.0
241	feeding	433482.8578	433707.5973	433795.9652	40.7129	433549.0606	433637.4327	7.5	17.5	13.5	11.5	-5.5	40.0
248	feeding	434045.9770	434086.7580	434175.2330	40.7811	434135.3016	434227.3690	2.5	17.5	13.4	32.5	-5.5	40.0
251	feeding	434329.4821	434370.3313	434458.9135	40.8492	434414.8869	434503.4733	12.5	12.5	13.3	8.5	-5.5	40.0
245	mixing	433303.4234	434496.9612	434551.5386	38.0674	433876.9941	433931.6212	32.5	7.5	18.3	42.5	12.5	23.2
244	mixing	433364.4492	434559.0698	434612.5758	7.5426	433810.8775	433864.4332	42.5	12.5	18.8	32.5	7.5	22.7
243	mixing	433424.8207	434645.5710	434699.2912	7.1140	433744.9104	433798.6804	32.5	7.5	18.7	42.5	12.5	22.8
246	mixing	434699.2912	434705.7624	434760.2110	6.4711	433943.6285	433995.8985	42.5	12.5	19.4	32.5	7.5	22.1
249	mixing	434551.5386	434767.1134	434819.7622	6.9024	434262.1987	434314.8986	32.5	7.5	19.2	42.5	12.5	22.3
247	mixing	434612.5758	434826.7802	434881.1433	7.0069	434043.4889	434097.9002	42.5	12.5	18.4	32.5	7.5	23.1
252	mixing	434881.1433	434887.9359	434938.6797	6.7926	434541.4166	434590.0597	32.5	7.5	19.4	37.5	7.5	22.1
250	mixing	434760.2110	434945.5681	434996.4406	6.8997	434332.0957	434383.0983	37.5	7.5	18.3	32.5	7.5	23.2
253	mixing	434819.7622	435004.4004	435055.0587	7.9711	434607.6920	434658.2499	32.5	7.5	18.4	37.5	7.5	23.1
257	mixing	435055.0587	435062.0656	435111.0096	7.0069	434937.0557	434985.9017	37.5	7.5	19.2	32.5	7.5	22.3
255	mixing	434938.6797	435118.1236	435168.9961	7.1140	434730.5824	434781.3547	32.5	7.5	18.3	37.5	7.5	23.2
254	mixing	434996.4406	435175.8845	435226.6282	6.8997	434670.1600	434718.5752	37.5	7.5	19.4	32.5	7.5	22.1
261	feeding	435183.9617	435260.6574	435349.3467	34.0307	435252.5177	435343.7958	7.5	2.5	13.2	11.5	-5.5	40.0
256	feeding	434726.1158	435390.1946	435478.7767	40.8492	434812.6397	434901.2261	17.5	17.5	13.3	35.5	-5.5	40.0
258	mixing	435226.6282	435516.1970	435574.7086	37.4401	435009.8413	435068.3975	47.5	7.5	18.3	47.5	22.5	23.2
262	mixing	435574.7086	435581.9297	435638.7271	7.2211	435388.9437	435445.7844	47.5	22.5	19.1	47.5	7.5	22.4
260	mixing	435111.0096	435645.9467	435704.4583	7.2212	435150.6104	435209.1654	47.5	7.5	18.3	47.5	22.5	23.2
259	mixing	435168.9961	435711.8937	435769.1196	7.4354	435080.8693	435138.1386	47.5	22.5	18.9	47.5	7.5	22.6
263	mixing	435769.1196	435776.1265	435833.7809	7.0069	435457.6945	435515.3924	47.5	7.5	18.7	47.5	22.5	22.8
266	mixing	435833.7809	435840.6806	435897.6923	6.8997	435666.9753	435724.0303	47.5	22.5	19.0	47.5	7.5	22.5
265	mixing	435638.7271	435904.5920	435962.2464	6.8997	435597.2702	435654.9680	47.5	7.5	18.7	47.5	22.5	22.8
264	mixing	435704.4583	435969.3604	436026.8006	7.1140	435527.5895	435585.0730	47.5	22.5	18.8	47.5	7.5	22.7

267	mixing	436026.8006	436034.1289	436092.2120	7.3283	435736.2274	435794.3538	47.5	7.5	18.5	47.5	22.5	23.0
271	mixing	436092.2120	436099.6474	436157.3019	7.4354	436099.6430	436157.3408	47.5	22.5	18.7	47.5	7.5	22.8
269	mixing	435897.6923	436164.4159	436221.8560	7.1140	435874.6987	435932.1823	47.5	7.5	18.8	47.5	22.5	22.7
268	mixing	435962.2464	436228.4343	436285.0174	6.5783	435806.3611	435862.9875	47.5	22.5	19.2	47.5	7.5	22.3
272	mixing	436285.0174	436291.3814	436348.3930	6.3640	436169.3481	436226.4031	47.5	7.5	19.0	47.5	22.5	22.5
274	mixing	436221.8560	436355.3998	436413.2686	7.0069	436399.2116	436457.1237	47.5	22.5	18.6	47.5	7.5	22.9
276	mixing	436348.3930	436420.9183	436479.2156	7.6497	436550.9210	436609.2617	47.5	7.5	18.4	47.5	22.5	23.1
277	mixing	436413.2686	436485.9011	436544.8388	6.6854	436621.0732	436677.0553	47.5	22.5	19.5	47.5	7.5	22.0
275	mixing	436157.3019	436551.7412	436608.5386	6.9024	436469.1310	436525.9717	47.5	7.5	19.1	47.5	22.5	22.4
270	feeding	435904.5737	436648.8907	436737.5800	40.3521	435972.1942	436063.4724	12.5	2.5	13.2	32.5	-5.5	40.0
273	feeding	436181.4157	436778.4974	436867.1867	40.9174	436263.5293	436352.2228	17.5	7.5	13.2	8.5	-5.5	40.0
280	feeding	436867.1867	436908.3087	436997.3194	41.1220	436920.8657	437012.5460	2.5	2.5	12.9	11.5	-5.5	40.0
279	feeding	436732.3444	437038.2368	437126.9261	40.9174	436781.3781	436870.0717	22.5	12.5	13.2	35.5	-5.5	40.0
281	mixing	436479.2156	437163.9572	437217.5402	37.0311	437051.9991	437105.6258	27.5	2.5	18.9	32.5	12.5	22.7
278	mixing	436608.5386	437225.0828	437279.9516	7.5426	436701.4594	436756.3667	32.5	12.5	18.3	27.5	2.5	23.3
283	mixing	437279.9516	437286.6370	437342.4769	6.6854	437184.9094	437236.8013	27.5	2.5	19.7	32.5	12.5	21.9
282	mixing	436544.8388	437349.1623	437404.0311	6.6854	437118.1867	437173.0979	32.5	12.5	18.3	27.5	2.5	23.3
285	mixing	437404.0311	437411.2522	437464.1924	7.2211	437315.8139	437368.7965	27.5	2.5	19.2	32.5	12.5	22.4
284	mixing	437217.5402	437471.4135	437526.2823	7.2211	437248.6128	437303.5239	32.5	12.5	18.3	27.5	2.5	23.3
286	mixing	437342.4769	437534.2534	437588.6936	7.9711	437390.1507	437444.6333	27.5	2.5	18.5	32.5	12.5	23.1
287	mixing	437526.2823	437595.9148	437649.2835	7.2211	437456.9233	437510.3345	32.5	12.5	19.0	27.5	2.5	22.6
288	mixing	437464.1924	437656.6118	437711.2663	7.3283	437522.7160	437577.4129	27.5	2.5	18.4	32.5	12.5	23.2
290	mixing	437588.6936	437718.3803	437771.3205	7.1140	437729.8159	437782.7985	32.5	12.5	19.2	27.5	2.5	22.4
293	mixing	437711.2663	437777.4702	437830.1961	6.1497	438005.6376	438058.4060	27.5	2.5	19.3	32.5	12.5	22.3
292	mixing	437649.2835	437837.3101	437892.1788	7.1140	437938.5293	437993.4405	32.5	12.5	18.3	27.5	2.5	23.3
294	mixing	437771.3205	437900.2571	437954.9116	8.0783	438079.7601	438134.4570	27.5	2.5	18.4	32.5	12.5	23.2
295	mixing	437892.1788	437962.2399	438015.6086	7.3283	438146.8386	438200.2497	32.5	12.5	19.0	27.5	2.5	22.6
299	mixing	438015.6086	438022.2941	438075.6628	6.6854	438488.4819	438541.8931	27.5	2.5	19.0	32.5	12.5	22.6
291	feeding	437699.4120	438101.5331	438190.5438	25.8703	437811.5711	437900.5860	22.5	17.5	12.9	8.5	-5.5	40.0
289	feeding	437569.0981	438231.6658	438320.6765	41.1220	437605.9712	437694.9862	17.5	12.5	12.9	32.5	-5.5	40.0
296	mixing	437830.1961	438357.9121	438412.1380	37.2356	438212.4469	438266.7152	27.5	2.5	18.6	32.5	12.5	23.0
298	mixing	437954.9116	438419.3592	438472.9422	7.2211	438422.9463	438476.5718	32.5	12.5	18.9	27.5	2.5	22.7
301	mixing	438472.9422	438479.5205	438532.4607	6.5783	438619.9603	438672.9429	27.5	2.5	19.2	32.5	12.5	22.4
300	mixing	438412.1380	438539.2532	438593.2649	6.7926	438553.9960	438608.0501	32.5	12.5	18.7	27.5	2.5	22.9
302	mixing	438075.6628	438600.9146	438655.5690	7.6497	438694.1413	438748.8382	27.5	2.5	18.4	32.5	12.5	23.2
306	mixing	438655.5690	438663.2188	438717.2304	7.6497	439039.9779	439094.0320	32.5	12.5	18.7	27.5	2.5	22.9
305	mixing	438532.4607	438724.4515	438778.2488	7.2211	438973.8482	439027.6879	27.5	2.5	18.8	32.5	12.5	22.8
304	mixing	438593.2649	438785.2557	438838.8387	7.0069	438908.1198	438961.7452	32.5	12.5	18.9	27.5	2.5	22.7
297	feeding	438225.7881	438864.9233	438954.0412	26.0845	438295.2054	438386.9121	17.5	2.5	12.8	35.5	-5.5	40.0
303	feeding	438695.5282	438995.2313	439084.3492	41.1902	438782.9635	438872.0856	7.5	12.5	12.8	11.5	-5.5	40.0
307	feeding	439060.7106	439125.6075	439214.8325	41.2583	439128.2781	439220.5589	2.5	12.5	12.7	32.5	-5.5	40.0

B.3 Mix/Stack+Feed

Nr	Type	Release	Starting	Completion	Travel	Start Sim	End Sim	Origin			Destination		
2	mixing	1735417.9960	1735417.9960	1735469.0820	0.0000	1735440.1510	1735491.1410	7.5	22.5	17.1	2.5	17.5	22.2
1	mixing	1735330.1710	1735486.3190	1735544.1290	17.2368	1735360.2350	1735417.9960	2.5	22.5	17.1	17.5	12.5	22.2
0	mixing	1735239.1040	1735567.8140	1735629.4330	23.6854	1735268.5070	1735330.1710	17.5	22.5	17.2	2.5	2.5	21.5
3	mixing	1735629.4330	1735659.9750	1735711.0620	30.5426	1735512.8680	1735563.8570	12.5	22.5	17.1	7.5	17.5	22.2
8	mixing	1735711.0620	1735729.4780	1735789.4890	18.4154	1736042.4710	1736102.5260	2.5	22.5	16.0	2.5	7.5	22.3
5	mixing	1735544.1290	1735818.2100	1735881.8650	28.7211	1735725.4140	1735789.1130	7.5	22.5	16.1	12.5	2.5	22.3
6	mixing	1735469.0820	1735914.3360	1735977.9900	32.4711	1735819.8670	1735883.5660	12.5	22.5	16.1	17.5	2.5	22.3
7	feeding	1735822.9420	1736004.6920	1736082.9890	26.7018	1735916.1590	1735994.4590	27.5	12.5	22.9	35.5	-5.5	40.0
4	feeding	1735528.7210	1736117.2920	1736195.6990	34.3038	1735605.2970	1735687.4710	32.5	7.5	22.9	8.5	-5.5	40.0
11	mixing	1735789.4890	1736237.5750	1736298.6580	41.8758	1736305.1910	1736366.3170	12.5	22.5	15.0	17.5	7.5	22.3
10	mixing	1735977.9900	1736328.3430	1736389.2120	29.6854	1736217.0060	1736277.9180	2.5	22.5	15.2	12.5	7.5	22.3
9	mixing	1735881.8650	1736418.4690	1736478.9090	29.2569	1736129.3870	1736189.8700	17.5	22.5	15.6	7.5	7.5	22.3
12	mixing	1736478.9090	1736508.9160	1736569.1890	30.0069	1736394.1580	1736454.3820	17.5	22.5	14.9	2.5	12.5	22.3
14	mixing	1736389.2120	1736595.5530	1736653.1010	26.3640	1736617.8230	1736675.4130	7.5	22.5	14.8	7.5	12.5	22.3
16	mixing	1736298.6580	1736680.1070	1736738.2980	27.0069	1736845.2860	1736903.5190	2.5	22.5	14.2	12.5	12.5	22.3
17	mixing	1736569.1890	1736765.4120	1736819.8200	27.1140	1736927.6540	1736981.9640	17.5	22.5	14.1	12.5	17.5	22.3
19	mixing	1736738.2980	1736840.9140	1736907.9970	21.0940	1737082.2300	1737149.3530	7.5	22.5	13.6	7.5	2.5	23.0
13	feeding	1736373.6510	1736940.2560	1737018.7210	32.2593	1736498.6090	1736578.9930	32.5	17.5	22.8	11.5	-5.5	40.0
15	feeding	1736662.7060	1737057.9880	1737136.4990	39.2674	1736719.5320	1736798.0470	37.5	12.5	22.7	32.5	-5.5	40.0
22	mixing	1736907.9970	1737178.3750	1737242.8860	41.8758	1737376.8330	1737441.3880	7.5	22.5	12.6	2.5	7.5	23.1
20	mixing	1736819.8200	1737275.5720	1737339.3340	32.6854	1737182.0810	1737245.8860	2.5	22.5	13.2	7.5	7.5	23.0
18	mixing	1736653.1010	1737371.2690	1737425.9990	31.9354	1737002.5530	1737057.1820	12.5	22.5	13.8	17.5	17.5	22.3
21	mixing	1737425.9990	1737447.7360	1737515.5690	21.7368	1737275.5000	1737343.3770	17.5	22.5	13.0	2.5	2.5	23.1
26	mixing	1737515.5690	1737553.1830	1737617.4200	37.6140	1737808.4110	1737872.6000	17.5	22.5	12.1	2.5	17.5	23.2
27	mixing	1737242.8860	1737641.1930	1737698.8150	23.7726	1737895.4990	1737953.0220	2.5	22.5	12.0	7.5	17.5	23.2
25	mixing	1737339.3340	1737722.1590	1737783.1350	23.3440	1737719.1030	1737780.1220	12.5	22.5	12.4	2.5	12.5	23.1
28	mixing	1737783.1350	1737813.5710	1737879.1540	30.4354	1737975.5880	1738041.2110	12.5	22.5	11.8	12.5	7.5	23.3
23	feeding	1737391.7930	1737904.9870	1737983.6050	25.8331	1737481.5400	1737562.7540	27.5	2.5	22.6	8.5	-5.5	40.0
30	mixing	1737698.8150	1738026.0220	1738091.5460	42.4174	1738161.2540	1738226.7310	2.5	22.5	11.0	17.5	12.5	23.3
31	mixing	1737879.1540	1738123.1600	1738193.5640	31.6140	1738254.4800	1738324.9290	12.5	22.5	10.9	17.5	2.5	23.4
24	feeding	1737495.4050	1738212.5840	1738291.2020	19.0200	1737596.2650	1737674.8870	22.5	7.5	22.6	35.5	-5.5	40.0
29	mixing	1737617.4200	1738333.2100	1738395.2580	42.0083	1738071.4830	1738133.5730	7.5	22.5	11.6	12.5	12.5	23.3
32	mixing	1738395.2580	1738426.9790	1738486.1010	31.7211	1738360.0660	1738419.0900	17.5	22.5	10.8	12.5	17.5	23.4
36	mixing	1738193.5640	1738512.5530	1738576.8500	26.4511	1738785.7260	1738850.0660	12.5	22.5	9.7	7.5	12.5	23.5
35	mixing	1738091.5460	1738609.4280	1738676.9400	32.5783	1738685.9660	1738753.5210	7.5	22.5	10.2	17.5	7.5	23.5
34	feeding	1738409.2230	1738695.6750	1738774.5070	18.7350	1738565.1640	1738644.0000	22.5	12.5	22.4	11.5	-5.5	40.0
39	mixing	1738576.8500	1738818.1520	1738883.0150	43.6447	1739082.5680	1739147.4830	7.5	22.5	9.2	17.5	17.5	23.7
38	mixing	1738676.9400	1738909.8940	1738977.3470	26.8797	1738986.4850	1739053.8870	17.5	22.5	9.6	2.5	12.5	23.7
37	mixing	1738486.1010	1739010.7820	1739082.7940	33.4354	1738878.5870	1738950.6430	2.5	22.5	9.6	12.5	2.5	23.6
33	feeding	1738346.7070	1739108.2510	1739186.9760	25.4574	1738452.7870	1738531.5160	27.5	7.5	22.5	32.5	-5.5	40.0
40	mixing	1739082.7940	1739230.8930	1739304.1910	43.9174	1739172.4350	1739245.7730	17.5	22.5	8.8	2.5	2.5	24.0
44	mixing	1738883.0150	1739346.7330	1739416.8160	42.5426	1739633.0340	1739703.1610	12.5	22.5	8.4	2.5	7.5	24.1
45	mixing	1739304.1910	1739455.9300	1739526.3350	39.1140	1739736.5470	1739806.9950	7.5	22.5	8.2	7.5	7.5	24.2
43	mixing	1738977.3470	1739565.2350	1739638.8530	38.8997	1739522.1890	1739595.8520	2.5	22.5	8.5	7.5	2.5	24.0
41	feeding	1739175.4090	1739669.7800	1739748.6120	30.9266	1739287.5480	1739366.3840	32.5	12.5	22.4	35.5	-5.5	40.0
46	mixing	1739638.8530	1739793.0750	1739863.6940	44.4629	1739840.5860	1739911.2480	17.5	22.5	8.0	12.5	7.5	24.2
42	feeding	1739241.9250	1739888.3820	1739967.2140	24.6879	1739400.0320	1739479.0640	27.5	17.5	22.4	8.5	-5.5	40.0
47	mixing	1739416.8160	1740012.1540	1740075.8840	44.9402	1739945.3160	1740009.1750	12.5	22.5	7.3	7.5	17.5	24.2
51	mixing	1739863.6940	1740105.9780	1740174.1320	30.0940	1740396.2130	1740464.4100	7.5	22.5	7.1	2.5	12.5	24.5
54	mixing	1740174.1320	1740212.2820	1740277.8330	38.1497	1740712.9680	1740778.4210	12.5	22.5	6.0	12.5	17.5	24.6
52	mixing	1740075.8840	1740308.5700	1740379.7720	30.7368	1740498.1990	1740569.3530	17.5	22.5	6.9	2.5	17.5	24.5
48	mixing	1739526.3350	1740410.0800	1740481.8770	30.3083	1740036.0320	1740107.8680	2.5	22.5	7.2	17.5	7.5	24.5
50	feeding	1740173.7280	1740498.9710	1740578.1240	17.0931	1740265.5600	1740347.3830	22.5	2.5	22.1	32.5	-5.5	40.0
49	feeding	1740064.3930	1740612.9050	1740692.5120	34.7811	1740142.4470	1740228.2890	37.5	2.5	22.2	11.5	-5.5	40.0

53	mixing	1740481.8770	1740738.3380	1740815.2780	45.8265	1740596.7590	1740673.7400	2.5	22.5	6.0	17.5	2.5	24.6
59	feeding	1741176.3840	1741199.5820	1741278.9500	23.1986	1741249.4600	1741328.8320	32.5	7.5	21.9	35.5	-5.5	40.0
58	mixing	1740277.8330	1741325.3220	1741395.7270	46.3720	1741148.7820	1741219.2290	17.5	22.5	5.2	17.5	12.5	24.7
55	feeding	1740737.6820	1741412.4330	1741491.5870	16.7066	1740806.6260	1740885.7840	22.5	17.5	22.1	8.5	-5.5	40.0
56	mixing	1740379.7720	1741537.4820	1741614.6360	45.8947	1740930.6820	1741007.8810	7.5	22.5	5.9	12.5	2.5	24.7
61	feeding	1741408.1050	1741637.5610	1741716.9290	22.9253	1741471.5340	1741550.9060	27.5	12.5	21.9	11.5	-5.5	40.0
63	mixing	1741395.7270	1741763.7100	1741834.8650	46.7811	1741714.8570	1741786.0540	7.5	22.5	4.6	7.5	12.5	24.8
60	mixing	1741614.6360	1741874.4070	1741941.1370	39.5426	1741377.5940	1741444.2250	12.5	22.5	5.0	17.5	17.5	24.7
57	mixing	1740815.2780	1741973.0520	1742042.7070	31.9154	1741047.2450	1741116.9420	17.5	22.5	5.9	12.5	12.5	24.7
62	mixing	1742042.7070	1742082.3570	1742160.7970	39.6497	1741596.5530	1741675.0380	2.5	22.5	4.8	2.5	2.5	24.8
68	feeding	1742006.2250	1742195.3660	1742274.7340	34.5691	1742095.3590	1742174.7310	37.5	17.5	21.9	32.5	-5.5	40.0
64	mixing	1741941.1370	1742321.7190	1742397.3740	46.9856	1741818.8250	1741894.5230	2.5	22.5	4.3	2.5	7.5	25.2
65	validating	1742397.3740	1742397.3740	1742421.1340	0.0000	0.0000	1741918.3160	2.5	7.5	21.0	2.5	7.5	25.2
66	mixing	1742160.7970	1742465.8190	1742545.5450	44.6854	1741954.9980	1742034.7680	17.5	22.5	4.1	2.5	2.5	25.3
67	validating	1742545.5450	1742545.5450	1742569.4740	0.0000	0.0000	1742058.7580	2.5	2.5	21.0	2.5	2.5	25.3
70	feeding	1742243.3160	1742603.7190	1742685.1260	34.2449	1742336.4590	1742421.8410	37.5	7.5	21.8	8.5	-5.5	40.0
69	mixing	1741834.8650	1742732.5890	1742812.8500	47.4629	1742222.6970	1742303.0030	12.5	22.5	3.6	7.5	2.5	25.3
75	feeding	1742835.7010	1742864.0530	1742943.6350	28.3521	1742882.3030	1742964.4740	32.5	2.5	21.7	35.5	-5.5	40.0
72	mixing	1742545.5450	1742991.2350	1743067.9600	47.5992	1742583.0150	1742659.7840	2.5	22.5	3.4	12.5	7.5	25.3
76	mixing	1743067.9600	1743083.6970	1743137.3870	15.7368	1743004.9170	1743058.6510	7.5	7.5	21.6	7.5	17.5	25.5
73	mixing	1742812.8500	1743176.6510	1743249.8410	39.2631	1742697.0790	1742770.3120	17.5	22.5	3.3	12.5	12.5	25.4
79	feeding	1743085.2800	1743278.3000	1743357.9060	28.4592	1743183.2600	1743266.7600	37.5	12.5	21.7	11.5	-5.5	40.0
71	mixing	1742397.3740	1743405.4370	1743482.0560	47.5311	1742468.3750	1742545.0370	7.5	22.5	3.5	7.5	7.5	25.3
74	mixing	1743482.0560	1743497.7930	1743555.2330	15.7368	1742791.5720	1742849.0550	7.5	2.5	21.6	2.5	17.5	25.5
77	mixing	1743249.8410	1743562.5620	1743616.4960	7.3283	1743075.7830	1743129.7670	2.5	17.5	21.3	12.5	17.5	25.6
78	validating	1743616.4960	1743616.4960	1743639.9120	0.0000	0.0000	1743153.1610	12.5	17.5	21.6	12.5	17.5	25.6
80	mixing	1743555.2330	1743647.0260	1743700.3180	7.1140	1743300.9530	1743354.2950	12.5	17.5	21.6	2.5	17.5	25.3
81	mixing	1743137.3870	1743707.0030	1743760.0810	6.6854	1743366.1060	1743419.2340	2.5	17.5	21.7	12.5	17.5	25.2
82	mixing	1743616.4960	1743782.6950	1743833.1390	22.6140	1743440.4320	1743490.7790	12.5	7.5	21.2	17.5	7.5	25.7
83	validating	1743833.1390	1743833.1390	1743857.4000	0.0000	0.0000	1743515.1600	17.5	7.5	21.2	17.5	7.5	25.7
84	mixing	1743700.3180	1743865.0490	1743915.4930	7.6497	1743527.8090	1743578.1530	17.5	7.5	21.2	12.5	7.5	25.7
85	mixing	1743760.0810	1743922.0720	1743973.3700	6.5783	1743589.8640	1743638.0630	12.5	7.5	22.2	17.5	7.5	24.7
88	feeding	1743680.8780	1743988.4640	1744068.1540	15.0940	1743761.6140	1743841.3070	22.5	7.5	21.6	32.5	-5.5	40.0
90	feeding	1743926.3800	1744106.2790	1744185.9690	38.1258	1743964.2570	1744046.4990	32.5	17.5	21.6	8.5	-5.5	40.0
96	feeding	1744369.9900	1744405.2480	1744485.0450	35.2583	1744420.7150	1744500.5150	27.5	7.5	21.5	35.5	-5.5	40.0
91	mixing	1743973.3700	1744522.5120	1744576.4470	37.4674	1744080.8960	1744134.8810	12.5	12.5	21.3	2.5	12.5	25.6
89	mixing	1743915.4930	1744583.9890	1744638.1380	7.5426	1743883.0230	1743937.2210	2.5	12.5	21.2	12.5	12.5	25.7
86	mixing	1743833.1390	1744645.7880	1744699.9360	7.6497	1743655.9960	1743710.1970	12.5	12.5	21.2	2.5	12.5	25.7
87	validating	1744699.9360	1744699.9360	1744724.1970	0.0000	0.0000	1743734.5780	2.5	12.5	21.2	2.5	12.5	25.7
92	mixing	1744699.9360	1744731.0970	1744783.7460	6.8997	1744146.7910	1744199.4900	2.5	12.5	21.9	12.5	12.5	25.0
93	mixing	1744638.1380	1744799.6970	1744850.3550	15.9511	1744216.8430	1744267.6310	12.5	7.5	21.1	7.5	2.5	25.8
94	mixing	1744576.4470	1744857.1480	1744907.8920	6.7926	1744279.5410	1744327.9590	7.5	2.5	22.1	12.5	7.5	24.8
98	mixing	1744907.8920	1744914.6840	1744965.3430	6.7926	1744604.1790	1744654.7370	12.5	7.5	21.1	7.5	2.5	25.8
95	mixing	1744783.7460	1744973.0990	1745023.5430	7.7569	1744345.7400	1744396.0830	7.5	2.5	21.2	12.5	7.5	25.7
97	mixing	1744850.3550	1745030.4430	1745079.3870	6.8997	1744537.7540	1744586.8260	12.5	7.5	21.9	7.5	2.5	25.0
99	mixing	1745023.5430	1745086.2870	1745136.7310	6.8997	1744667.4720	1744717.8160	7.5	2.5	21.2	12.5	7.5	25.7
100	mixing	1745079.3870	1745143.7380	1745192.8960	7.0069	1744729.9190	1744778.9770	12.5	7.5	21.8	7.5	2.5	25.1
104	mixing	1745192.8960	1745199.2600	1745248.4180	6.3640	1745048.2660	1745097.3240	7.5	2.5	21.8	12.5	7.5	25.1
103	mixing	1745136.7310	1745255.3180	1745305.5480	6.8997	1744986.1290	1745036.2580	12.5	7.5	21.3	7.5	2.5	25.6
102	mixing	1744965.3430	1745312.8760	1745362.8910	7.3283	1744923.8290	1744973.7480	7.5	2.5	21.4	12.5	7.5	25.5
101	feeding	1744764.0080	1745385.6720	1745465.4680	22.7807	1744806.2800	1744886.0810	27.5	17.5	21.5	11.5	-5.5	40.0
108	feeding	1745218.5800	1745500.7950	1745580.6980	35.3265	1745283.3990	1745365.8920	27.5	2.5	21.4	32.5	-5.5	40.0
105	mixing	1745362.8910	1745616.3660	1745670.9130	35.6674	1745114.5210	1745169.1110	12.5	12.5	21.1	17.5	2.5	25.8
106	validating	1745670.9130	1745670.9130	1745694.6730	0.0000	0.0000	1745192.9040	17.5	2.5	21.6	17.5	2.5	25.8
110	mixing	1745670.9130	1745702.4300	1745756.7630	7.7569	1745467.1430	1745521.5190	17.5	2.5	21.2	12.5	12.5	25.7
109	mixing	1745248.4180	1745763.9840	1745817.4600	7.2211	1745401.3350	1745454.8530	12.5	12.5	21.6	17.5	2.5	25.3
107	mixing	1745305.5480	1745824.2530	1745877.7290	6.7926	1745205.2860	1745258.8040	17.5	2.5	21.6	12.5	12.5	25.3
111	mixing	1745877.7290	1745883.9860	1745938.6180	6.2569	1745533.3300	1745585.7770	12.5	12.5	22.1	17.5	2.5	24.8
113	mixing	1745756.7630	1745945.5210	1745998.3540	6.9024	1745673.8810	1745726.7570	17.5	2.5	21.9	12.5	12.5	25.0
112	mixing	1745817.4600	1746005.3610	1746059.9080	7.0069	1745607.1890	1745661.7780	12.5	12.5	21.1	17.5	2.5	25.8
116	mixing	1746059.9080	1746075.8590	1746131.4180	15.9511	1745954.1560	1746009.6690	17.5	7.5	21.9	2.5	2.5	24.9
114	mixing	1745938.6180	1746138.4250	1746195.9130	7.0069	1745747.9550	1745805.3960	2.5	2.5	21.0	17.5	7.5	25.8
118	feeding	1746057.9210	1746212.5070	1746292.5180	16.5940	1746105.0590	1746185.0740	22.5	12.5	21.3	35.5	-5.5	40.0
115	feeding	1745770.4500	1746327.8440	1746409.2510	35.3265	1745832.9550	1745920.1670	37.5	2.5	21.4	8.5	-5.5	40.0
117	mixing	1745998.3540	1746444.8500	1746495.6150	35.5992	1746027.0220	1746077.9170	2.5	7.5	21.0	2.5	12.5	25.8
119	mixing	1746195.9130	1746502.9440	1746552.4230	7.3283	1746228.5180	1746277.8990	2.5	12.5	21.6	2.5	7.5	25.2
122	mixing	1746552.4230	1746559.7520	1746610.5170	7.3283	1746413.8910	1746464.5560	2.5	7.5	21.0	2.5	12.5	25.8
121	mixing	1746495.6150	1746617.6310	1746666.6820	7.1140	1746352.7430	1746401.6940	2.5	12.5	21.8	2.5	7.5	25.0
120	mixing	1746131.4180	1746673.6890	1746724.2400	7.0069	1746290.1890	1746340.6400	2.5	7.5	21.1	2.5	12.5	25.7
123	mixing	1746724.2400	1746731.0330	1746781.4270	6.7926	1746476.5630	1746525.0860	2.5	12.5	22.0	2.5	7.5	24.8
125	mixing	1746610.5170	1746787.7910	1746837.4850	6.3640	1746605.7000	1746655.2940	2.5	7.5	21.5	7.5	7.5	25.3

124	mixing	1746666.6820	1746844.9200	1746895.6850	7.4354	1746542.5630	1746593.2290	7.5	7.5	21.0	2.5	7.5	25.8
127	mixing	1746895.6850	1746902.7990	1746951.8510	7.1140	1746730.6280	1746779.5790	2.5	7.5	21.8	7.5	7.5	25.0
126	mixing	1746781.4270	1746958.9650	1747009.7300	7.1140	1746667.7660	1746718.4310	7.5	7.5	21.0	2.5	7.5	25.8
128	mixing	1746837.4850	1747017.7010	1747068.4670	7.9711	1746796.7760	1746847.4410	2.5	7.5	21.0	7.5	7.5	25.8
131	mixing	1747009.7300	1747075.7950	1747125.2740	7.3283	1747106.3860	1747155.9930	7.5	7.5	21.6	2.5	7.5	25.2
132	mixing	1746951.8510	1747132.3880	1747182.7250	7.1140	1747168.1910	1747218.4300	2.5	7.5	21.2	7.5	7.5	25.6
133	mixing	1747068.4670	1747189.7320	1747238.9980	7.0069	1747230.5330	1747279.6980	7.5	7.5	21.7	2.5	7.5	25.1
129	feeding	1746786.7560	1747264.5640	1747344.5750	25.5664	1746871.5900	1746951.6050	22.5	17.5	21.3	11.5	-5.5	40.0
130	feeding	1746875.6240	1747380.8420	1747460.9600	36.2674	1746987.8210	1747067.9430	32.5	12.5	21.2	32.5	-5.5	40.0
135	mixing	1747182.7250	1747496.2870	1747552.9170	35.3265	1747366.9870	1747423.5690	17.5	12.5	21.4	2.5	12.5	25.4
134	mixing	1747125.2740	1747560.4600	1747617.9480	7.5426	1747296.9880	1747354.4260	2.5	12.5	21.0	17.5	12.5	25.8
137	mixing	1747617.9480	1747625.0620	1747680.8350	7.1140	1747503.7510	1747559.4770	17.5	12.5	21.8	2.5	12.5	25.0
136	mixing	1747238.9980	1747687.4130	1747743.8300	6.5783	1747435.6720	1747492.0400	2.5	12.5	21.5	17.5	12.5	25.3
142	feeding	1747895.1610	1747918.3700	1747998.8100	23.2092	1747936.1020	1748016.5460	32.5	7.5	20.9	35.5	-5.5	40.0
139	feeding	1747625.4600	1748034.4770	1748114.9160	35.6674	1747663.7520	1747746.7800	22.5	2.5	20.9	8.5	-5.5	40.0
138	mixing	1747552.9170	1748150.5160	1748204.9860	35.5992	1747580.4970	1747635.0170	12.5	12.5	21.0	2.5	12.5	25.8
140	mixing	1747743.8300	1748211.5640	1748267.2200	6.5783	1747780.4970	1747832.2110	2.5	12.5	22.3	12.5	12.5	24.5
143	mixing	1748204.9860	1748274.7520	1748327.5080	7.5319	1748053.8520	1748106.6600	12.5	12.5	21.8	2.5	12.5	25.0
141	mixing	1747680.8350	1748334.5150	1748388.7700	7.0069	1747853.8940	1747908.2000	2.5	12.5	21.1	12.5	12.5	25.7
145	mixing	1748388.7700	1748395.8840	1748448.8550	7.1140	1748184.8610	1748237.8810	12.5	12.5	21.7	2.5	12.5	25.1
144	mixing	1748267.2200	1748455.8620	1748509.9030	7.0069	1748118.6670	1748172.7580	2.5	12.5	21.2	12.5	12.5	25.6
147	mixing	1748509.9030	1748517.2320	1748570.8450	7.3283	1748315.2440	1748368.9070	12.5	12.5	21.4	2.5	12.5	25.4
146	mixing	1748327.5080	1748577.8520	1748631.2500	7.0069	1748249.6930	1748303.1410	2.5	12.5	21.5	12.5	12.5	25.3
149	mixing	1748631.2500	1748637.8290	1748690.5850	6.5783	1748446.5780	1748499.3840	12.5	12.5	21.8	2.5	12.5	25.0
148	mixing	1748448.8550	1748697.2700	1748750.8830	6.6854	1748381.1040	1748434.7670	2.5	12.5	21.4	12.5	12.5	25.4
153	mixing	1748750.8830	1748757.6760	1748810.6460	6.7926	1748850.2840	1748903.3040	12.5	12.5	21.7	2.5	12.5	25.1
152	mixing	1748570.8450	1748817.7600	1748872.0160	7.1140	1748783.7820	1748838.0860	2.5	12.5	21.1	12.5	12.5	25.7
155	mixing	1748872.0160	1748878.7010	1748933.4450	6.6854	1748981.6180	1749033.7810	12.5	12.5	22.1	2.5	12.5	24.7
154	mixing	1748690.5850	1748940.1300	1748994.3860	6.6854	1748915.5010	1748969.8060	2.5	12.5	21.1	12.5	12.5	25.7
156	mixing	1748810.6460	1749002.2500	1749056.7210	7.8640	1749055.0150	1749109.5350	12.5	12.5	21.0	2.5	12.5	25.8
157	mixing	1748994.3860	1749063.8350	1749116.5910	7.1140	1749121.7320	1749174.5380	2.5	12.5	21.8	12.5	12.5	25.0
150	feeding	1748462.7660	1749145.4780	1749225.9180	28.8878	1748535.6670	1748619.3740	37.5	17.5	20.9	11.5	-5.5	40.0
151	feeding	1748555.6180	1749262.1850	1749342.7320	36.2674	1748659.0310	1748742.2470	32.5	2.5	20.8	32.5	-5.5	40.0
158	mixing	1748933.4450	1749378.3310	1749435.9260	35.5992	1749191.7350	1749249.2800	17.5	12.5	21.0	2.5	2.5	25.9
159	mixing	1749056.7210	1749443.4680	1749499.9920	7.5426	1749261.8410	1749318.3170	2.5	2.5	21.5	17.5	12.5	25.4
163	mixing	1749499.9920	1749507.3200	1749564.4860	7.3283	1749599.3180	1749656.4400	17.5	12.5	21.2	2.5	2.5	25.7
161	mixing	1749435.9260	1749571.8150	1749628.3380	7.3283	1749400.5930	1749457.0680	2.5	2.5	21.5	17.5	12.5	25.4
166	mixing	1749628.3380	1749635.3450	1749691.8690	7.0069	1749873.8590	1749930.3350	17.5	12.5	21.5	2.5	2.5	25.4
167	mixing	1749564.4860	1749699.1970	1749756.3630	7.3283	1749942.7160	1749999.8340	2.5	2.5	21.2	17.5	12.5	25.7
170	mixing	1749756.3630	1749763.4770	1749819.5720	7.1140	1750149.5570	1750205.6030	17.5	12.5	21.7	2.5	2.5	25.2
169	mixing	1749691.8690	1749826.1510	1749882.2450	6.5783	1750081.7990	1750137.8450	2.5	2.5	21.7	17.5	12.5	25.2
164	feeding	1749640.1560	1749902.4370	1749982.9840	20.1917	1749686.6730	1749767.2240	27.5	12.5	20.8	8.5	-5.5	40.0
162	feeding	1749396.0580	1750024.0510	1750104.5970	41.0674	1749484.3010	1749564.8520	37.5	7.5	20.8	35.5	-5.5	40.0
160	mixing	1749116.5910	1750140.1290	1750197.5090	35.5311	1749330.7880	1749388.1210	17.5	12.5	21.1	2.5	2.5	25.8
165	mixing	1750197.5090	1750205.0520	1750261.7900	7.5426	1749804.9720	1749861.6620	2.5	2.5	21.4	17.5	12.5	25.5
168	mixing	1750261.7900	1750269.2250	1750326.3910	7.4354	1750012.4830	1750069.6010	17.5	12.5	21.2	2.5	2.5	25.7
171	mixing	1750326.3910	1750334.0410	1750391.2070	7.6497	1750217.8000	1750274.9190	2.5	2.5	21.2	17.5	12.5	25.7
173	mixing	1749882.2450	1750398.5360	1750455.0590	7.3283	1750407.6610	1750464.1400	17.5	12.5	21.5	2.5	2.5	25.4
174	mixing	1749819.5720	1750462.3880	1750519.5540	7.3283	1750476.5220	1750533.6400	2.5	2.5	21.2	17.5	12.5	25.7
175	mixing	1750391.2070	1750526.5610	1750582.4410	7.0069	1750545.7430	1750601.5750	17.5	12.5	21.8	2.5	2.5	25.1
176	mixing	1750455.0590	1750589.3410	1750646.2930	6.8997	1750613.5830	1750670.4860	2.5	2.5	21.3	17.5	12.5	25.6
178	mixing	1750519.5540	1750653.1930	1750709.0740	6.8997	1750817.5620	1750873.3950	17.5	12.5	21.8	2.5	2.5	25.1
181	mixing	1750709.0740	1750715.9730	1750772.9250	6.8997	1751022.9630	1751079.8660	2.5	2.5	21.3	17.5	12.5	25.6
180	mixing	1750646.2930	1750779.9320	1750836.0270	7.0069	1750954.8130	1751010.8600	17.5	12.5	21.7	2.5	2.5	25.2
179	mixing	1750582.4410	1750843.1410	1750900.3080	7.1140	1750885.4980	1750942.6160	2.5	2.5	21.2	17.5	12.5	25.7
172	feeding	1750238.2470	1750917.4370	1750998.0910	17.1297	1750292.7410	1750373.3990	22.5	7.5	20.7	32.5	-5.5	40.0
177	feeding	1750637.8720	1751033.8950	1751114.5480	35.8038	1750698.7240	1750783.5050	37.5	12.5	20.7	11.5	-5.5	40.0
182	feeding	1751072.0520	1751150.4200	1751231.1810	35.8720	1751101.7650	1751182.5300	27.5	7.5	20.6	35.5	-5.5	40.0
183	mixing	1750900.3080	1751266.3710	1751322.6800	35.1902	1751216.9730	1751273.2380	17.5	12.5	21.6	2.5	2.5	25.3
184	mixing	1750836.0270	1751330.0090	1751387.3890	7.3283	1751285.6200	1751342.9520	2.5	2.5	21.1	17.5	12.5	25.8
185	mixing	1750772.9250	1751394.2890	1751450.9490	6.8997	1751354.9600	1751410.3640	17.5	12.5	22.0	2.5	2.5	24.9
189	mixing	1751450.9490	1751473.1940	1751530.8490	22.2449	1751723.6030	1751781.3000	17.5	2.5	21.4	7.5	17.5	25.5
186	mixing	1751322.6800	1751538.4980	1751597.0100	7.6497	1751435.4690	1751494.0240	7.5	17.5	21.0	17.5	2.5	25.9
188	mixing	1751387.3890	1751603.8030	1751662.7400	6.7926	1751641.8620	1751697.8450	17.5	2.5	22.2	7.5	17.5	24.7
191	mixing	1751597.0100	1751669.1040	1751726.7590	6.3640	1751928.7590	1751986.4570	7.5	17.5	21.4	17.5	2.5	25.5
192	mixing	1751662.7400	1751734.0870	1751791.9560	7.3283	1751998.8380	1752056.7500	17.5	2.5	21.3	7.5	17.5	25.6
193	mixing	1751530.8490	1751799.0700	1751856.2960	7.1140	1752068.9480	1752126.2170	7.5	17.5	21.6	17.5	2.5	25.3
187	feeding	1751480.8920	1751883.4100	1751964.1700	27.1140	1751520.5910	1751604.6590	32.5	17.5	20.6	8.5	-5.5	40.0
190	feeding	1751740.4710	1752002.2960	1752083.2710	38.1258	1751809.2000	1751890.1790	27.5	17.5	20.4	32.5	-5.5	40.0
194	mixing	1751726.7590	1752121.3970	1752178.9920	38.1258	1752150.9410	1752208.4890	17.5	17.5	21.0	2.5	7.5	25.9

195	mixing	1751791.9560	1752186.2130	1752242.0940	7.2211	1752220.7790	1752276.6120	2.5	7.5	21.8	17.5	17.5	25.1
196	mixing	1751856.2960	1752248.6720	1752304.9810	6.5783	1752288.3230	1752344.5840	17.5	17.5	21.6	2.5	7.5	25.3
200	mixing	1752304.9810	1752312.2020	1752362.6460	7.2211	1752619.2370	1752669.5810	2.5	7.5	21.2	7.5	12.5	25.7
199	mixing	1752242.0940	1752370.1890	1752420.4190	7.5426	1752556.5470	1752606.6770	7.5	12.5	21.3	2.5	7.5	25.6
198	mixing	1752178.9920	1752428.1750	1752479.0480	7.7569	1752493.0360	1752543.8120	2.5	7.5	21.0	7.5	12.5	25.9
201	mixing	1752479.0480	1752486.8050	1752537.0350	7.7569	1752682.1420	1752732.2710	7.5	12.5	21.3	2.5	7.5	25.6
202	mixing	1752420.4190	1752544.1490	1752593.7350	7.1140	1752744.4690	1752793.9550	2.5	7.5	21.6	7.5	12.5	25.3
207	mixing	1752593.7350	1752601.0640	1752651.7220	7.3283	1753209.8590	1753260.6450	7.5	12.5	21.1	2.5	7.5	25.8
205	mixing	1752537.0350	1752659.0500	1752708.6370	7.3283	1753002.6890	1753052.1790	2.5	7.5	21.6	7.5	12.5	25.3
204	mixing	1752362.6460	1752715.6440	1752765.6590	7.0069	1752940.4430	1752990.5870	7.5	12.5	21.4	2.5	7.5	25.5
197	feeding	1752331.3040	1752795.7260	1752876.8080	30.0664	1752374.8990	1752458.4340	27.5	2.5	20.3	11.5	-5.5	40.0
203	feeding	1752733.6690	1752912.8840	1752993.9670	36.0765	1752819.0270	1752900.1140	22.5	12.5	20.3	35.5	-5.5	40.0
206	feeding	1753004.5100	1753040.6540	1753122.0610	36.1447	1753085.8310	1753175.3250	37.5	2.5	20.2	8.5	-5.5	40.0

Appendix C

Output Rolling Horizon

This appendix shows the schedule for the stacking period as generated with the rolling horizon approach explained in Section 6.2.3. Besides the orders and their characteristics, also the truck arrivals and drop zone location assignment are incorporated.

Order Type	Starting Time	Completion Time	Travel Time	Handling Time	x_from	y_from	z_from	x_to	y_to	z_to
3720	22.5									
feeding	3828	3900	24	72	32.5	12.5	24	10	-5.5	40
4356	2.5									
feeding	4344	4416	36	72	32.5	2.5	24	34	-5.5	40
stacking	4548	4620	36	72	22.5	22.5	5	22.5	17.5	11
stacking	4656	4728	36	72	22.5	22.5	4	12.5	12.5	11
4740	7.5									
stacking	4764	4836	36	72	22.5	22.5	3	22.5	12.5	11
feeding	4860	4932	24	72	27.5	7.5	24	10	-5.5	40
feeding	5172	5244	36	72	42.5	12.5	24	34	-5.5	40
5244	37.5									
5328	47.5									
stacking	5292	5364	36	72	2.5	22.5	4	7.5	17.5	11
stacking	5388	5460	24	72	2.5	22.5	3	2.5	17.5	10
stacking	5484	5556	24	72	7.5	22.5	4	12.5	17.5	10
stacking	5580	5652	24	72	7.5	22.5	3	17.5	12.5	11
feeding	5688	5772	36	84	27.5	12.5	23	10	-5.5	40
5940	7.5									
feeding	6012	6084	36	72	37.5	2.5	24	34	-5.5	40
stacking	6132	6216	48	84	37.5	22.5	4	7.5	17.5	12
stacking	6276	6360	60	84	37.5	22.5	3	22.5	2.5	10
stacking	6408	6492	48	84	47.5	22.5	4	22.5	2.5	11
feeding	6528	6612	36	84	27.5	2.5	23	10	-5.5	40
stacking	6660	6732	48	72	7.5	22.5	4	2.5	17.5	11
6792	17.5									
6816	22.5									
stacking	6768	6840	36	72	7.5	22.5	3	2.5	12.5	11
feeding	6876	6948	36	72	47.5	7.5	24	34	-5.5	40
stacking	6984	7068	36	84	47.5	22.5	3	22.5	7.5	11
feeding	7296	7380	24	84	27.5	17.5	24	10	-5.5	40
stacking	7428	7500	36	72	17.5	22.5	4	17.5	17.5	11
stacking	7536	7608	36	72	17.5	22.5	3	7.5	12.5	11
stacking	7716	7788	48	72	22.5	22.5	5	12.5	12.5	12
7884	32.5									
feeding	7836	7908	48	72	37.5	12.5	24	34	-5.5	40
7980	2.5									
stacking	7956	8028	48	72	22.5	22.5	4	22.5	12.5	12
stacking	8052	8124	24	72	22.5	22.5	3	17.5	17.5	12
8148	27.5									
feeding	8160	8244	36	84	27.5	12.5	22	10	-5.5	40
8484	7.5									
feeding	8484	8556	36	72	47.5	12.5	24	34	-5.5	40

order type	starting time	completion time	travel time	handling time	x_from	y_from	z_from	x_to	y_to	z_to
stacking	8640	8712	36	72	32.5	22.5	5	22.5	17.5	12
stacking	8760	8832	48	72	32.5	22.5	4	22.5	17.5	13
stacking	8856	8940	24	84	32.5	22.5	3	22.5	2.5	12
feeding	9084	9168	36	84	32.5	7.5	23	10	-5.5	40
stacking	9204	9276	36	72	27.5	22.5	5	12.5	17.5	11
9276	2.5									
stacking	9300	9372	24	72	27.5	22.5	4	22.5	17.5	14
feeding	9408	9492	36	84	27.5	7.5	23	34	-5.5	40
stacking	9540	9612	48	72	7.5	22.5	5	17.5	17.5	13
9684	12.5									
stacking	9660	9732	48	72	7.5	22.5	4	7.5	17.5	13
stacking	9768	9840	36	72	7.5	22.5	3	7.5	17.5	14
feeding	9888	9972	48	84	27.5	12.5	21	10	-5.5	40
stacking	10020	10104	48	84	27.5	22.5	3	7.5	7.5	11
stacking	10152	10224	48	72	2.5	22.5	7	2.5	7.5	11
feeding	10272	10356	48	84	32.5	7.5	22	34	-5.5	40
10368	17.5									
stacking	10404	10476	48	72	2.5	22.5	6	2.5	12.5	12
10512	47.5									
stacking	10512	10584	36	72	2.5	22.5	5	12.5	17.5	12
10596	42.5									
stacking	10620	10692	24	72	12.5	22.5	5	22.5	12.5	13
feeding	10728	10812	36	84	32.5	7.5	21	10	-5.5	40
stacking	10848	10920	36	72	2.5	22.5	4	2.5	17.5	12
10956	2.5									
feeding	10944	11016	24	72	42.5	2.5	24	34	-5.5	40
stacking	11052	11124	36	72	12.5	22.5	4	17.5	17.5	14
stacking	11160	11232	36	72	12.5	22.5	3	12.5	17.5	13
stacking	11292	11376	60	84	42.5	22.5	4	17.5	12.5	12
11496	22.5									
stacking	11496	11568	48	72	17.5	22.5	4	7.5	12.5	12
11676	12.5									
feeding	11616	11700	48	84	27.5	12.5	20	10	-5.5	40
stacking	11748	11820	48	72	2.5	22.5	5	2.5	17.5	13
stacking	11856	11940	36	84	2.5	22.5	4	12.5	12.5	13
11976	2.5									
feeding	11976	12060	36	84	27.5	2.5	22	34	-5.5	40
stacking	12108	12192	48	84	17.5	22.5	3	12.5	2.5	10
12216	7.5									
12324	42.5									
stacking	12252	12336	36	84	42.5	22.5	3	22.5	2.5	13
stacking	12360	12444	24	84	47.5	22.5	4	22.5	12.5	14
feeding	12468	12552	24	84	42.5	7.5	23	10	-5.5	40
stacking	12600	12684	48	84	22.5	22.5	4	7.5	12.5	13
12744	22.5									
stacking	12732	12816	48	84	22.5	22.5	3	17.5	12.5	13
12840	37.5									
feeding	12852	12924	36	72	47.5	2.5	24	34	-5.5	40
stacking	12972	13044	36	72	2.5	22.5	5	2.5	12.5	13
stacking	13080	13164	36	84	12.5	22.5	4	12.5	2.5	11
stacking	13200	13284	36	84	12.5	22.5	3	22.5	7.5	12
feeding	13332	13416	36	84	32.5	12.5	23	10	-5.5	40
stacking	13464	13548	36	84	7.5	22.5	4	12.5	2.5	12
stacking	13584	13668	36	84	2.5	22.5	4	22.5	7.5	13
13692	2.5									
feeding	13704	13788	36	84	32.5	7.5	20	34	-5.5	40
stacking	13836	13920	48	84	7.5	22.5	3	2.5	12.5	14
13956	42.5									
stacking	13956	14040	36	84	22.5	22.5	4	12.5	12.5	14
stacking	14076	14160	36	84	37.5	22.5	5	12.5	2.5	13
14268	47.5									
feeding	14196	14280	36	84	37.5	17.5	24	10	-5.5	40
stacking	14316	14400	36	84	37.5	22.5	4	17.5	7.5	11
stacking	14436	14520	36	84	37.5	22.5	3	17.5	12.5	14
feeding	14556	14640	36	84	37.5	7.5	23	34	-5.5	40
stacking	14676	14760	36	84	22.5	22.5	3	17.5	7.5	12
stacking	14796	14880	36	84	2.5	22.5	5	17.5	7.5	13
stacking	14916	15000	36	84	47.5	22.5	6	22.5	7.5	14
feeding	15024	15108	24	84	27.5	2.5	21	10	-5.5	40

order type	starting time	completion time	travel time	handling time	x_from	y_from	z_from	x_to	y_to	z_to
stacking	15156	15240	36	84	2.5	22.5	4	7.5	2.5	11
stacking	15276	15360	36	84	42.5	22.5	6	17.5	7.5	14
feeding	15396	15480	36	84	32.5	12.5	22	34	-5.5	40
15552	7.5									
stacking	15528	15612	36	84	47.5	22.5	5	12.5	7.5	11
stacking	15660	15744	36	84	42.5	22.5	5	12.5	7.5	12
feeding	15780	15864	36	84	27.5	12.5	19	10	-5.5	40
15912	47.5									
15960	32.5									
stacking	15912	15996	36	84	42.5	22.5	4	12.5	7.5	13
stacking	16044	16128	48	84	2.5	22.5	3	2.5	7.5	12
16200	42.5									
stacking	16164	16248	36	84	42.5	22.5	3	17.5	2.5	10
16332	2.5									
feeding	16284	16368	36	84	27.5	12.5	18	34	-5.5	40
feeding	16404	16488	36	84	27.5	2.5	20	10	-5.5	40
stacking	16572	16656	36	84	7.5	22.5	4	2.5	7.5	13
16692	17.5									
16716	27.5									
16728	7.5									
stacking	16704	16788	36	84	7.5	22.5	3	2.5	2.5	11
stacking	16824	16908	36	84	47.5	22.5	6	17.5	2.5	11
17004	47.5									
stacking	16944	17028	36	84	32.5	22.5	4	17.5	2.5	12
feeding	17064	17148	36	84	32.5	7.5	19	34	-5.5	40
stacking	17184	17268	36	84	32.5	22.5	3	17.5	2.5	13
stacking	17364	17448	36	84	27.5	22.5	4	7.5	7.5	12
feeding	17484	17568	36	84	27.5	17.5	23	10	-5.5	40
stacking	17604	17688	36	84	27.5	22.5	3	12.5	7.5	14
stacking	17724	17808	36	84	2.5	22.5	4	7.5	12.5	14
stacking	17844	17928	36	84	2.5	22.5	3	7.5	2.5	12
feeding	17964	18048	36	84	27.5	12.5	17	34	-5.5	40
stacking	18084	18168	36	84	17.5	22.5	5	2.5	2.5	12
stacking	18204	18288	36	84	17.5	22.5	4	7.5	7.5	13
feeding	18324	18408	36	84	27.5	2.5	19	10	-5.5	40
18516	2.5									
stacking	18444	18528	36	84	17.5	22.5	3	2.5	7.5	14
18624	7.5									
stacking	18576	18660	36	84	7.5	22.5	3	7.5	2.5	13
stacking	18696	18792	36	96	42.5	22.5	3	7.5	7.5	14
feeding	18828	18912	36	84	27.5	12.5	16	34	-5.5	40
stacking	18948	19044	36	96	47.5	22.5	7	2.5	2.5	13
stacking	19080	19176	36	96	47.5	22.5	6	7.5	2.5	14
19248	12.5									
feeding	19212	19296	36	84	32.5	12.5	21	10	-5.5	40
stacking	19332	19416	36	84	7.5	22.5	4	2.5	2.5	14
19464	17.5									
feeding	19452	19536	36	84	47.5	2.5	23	34	-5.5	40
validating	19572	19584	36	12	7.5	17.5	15	7.5	17.5	15
stacking	19620	19692	36	72	7.5	22.5	3	7.5	17.5	15
stacking	19728	19800	36	72	2.5	22.5	4	7.5	17.5	16
stacking	19836	19920	36	84	2.5	22.5	3	7.5	17.5	17
feeding	19956	20040	36	84	32.5	12.5	20	10	-5.5	40
validating	20076	20088	36	12	17.5	17.5	15	17.5	17.5	15
stacking	20124	20196	36	72	12.5	22.5	4	17.5	17.5	15
stacking	20232	20316	36	84	12.5	22.5	3	7.5	17.5	18
20340	27.5									
stacking	20352	20448	36	96	47.5	22.5	5	17.5	17.5	16
feeding	20484	20568	36	84	27.5	7.5	22	34	-5.5	40
20652	2.5									
stacking	20604	20688	36	84	17.5	22.5	4	17.5	17.5	17
stacking	20724	20808	36	84	17.5	22.5	3	17.5	17.5	18
feeding	20844	20928	36	84	27.5	7.5	21	10	-5.5	40
21072	47.5									
validating	21168	21180	36	12	22.5	17.5	15	22.5	17.5	15
21252	22.5									
stacking	21204	21276	24	72	27.5	22.5	4	22.5	17.5	15
feeding	21300	21384	24	84	32.5	17.5	24	34	-5.5	40
stacking	21432	21516	36	84	2.5	22.5	4	22.5	17.5	16

order type	starting time	completion time	travel time	handling time	x_from	y_from	z_from	x_to	y_to	z_to
21588	32.5									
21612	2.5									
stacking	21540	21624	24	84	2.5	22.5	3	22.5	17.5	17
21720	37.5									
stacking	21648	21732	24	84	27.5	22.5	3	22.5	17.5	18
feeding	21756	21840	24	84	27.5	17.5	22	10	-5.5	40
validating	21876	21888	36	12	22.5	7.5	15	22.5	7.5	15
21912	12.5									
feeding	21912	21996	24	84	27.5	2.5	18	34	-5.5	40
stacking	22056	22140	36	84	47.5	22.5	6	22.5	7.5	15
stacking	22164	22248	24	84	47.5	22.5	5	22.5	7.5	16
22308	7.5									
stacking	22272	22356	24	84	22.5	22.5	4	22.5	7.5	17
stacking	22380	22464	24	84	22.5	22.5	3	22.5	7.5	18
validating	22488	22500	24	12	22.5	17.5	19	22.5	17.5	19
feeding	22524	22608	24	84	27.5	17.5	21	10	-5.5	40
stacking	22644	22728	36	84	37.5	22.5	4	22.5	17.5	19
stacking	22752	22836	24	84	37.5	22.5	3	22.5	17.5	20
stacking	22860	22944	24	84	12.5	22.5	4	22.5	17.5	21
feeding	22968	23052	24	84	27.5	17.5	20	34	-5.5	40
stacking	23088	23172	36	84	32.5	22.5	4	22.5	17.5	22
feeding	23196	23280	24	84	27.5	17.5	19	10	-5.5	40
validating	23724	23736	36	12	22.5	12.5	15	22.5	12.5	15
feeding	23760	23844	24	84	27.5	17.5	18	34	-5.5	40
23856	12.5									
23916	32.5									
stacking	23880	23964	36	84	2.5	22.5	4	22.5	12.5	15
stacking	23988	24072	24	84	2.5	22.5	3	22.5	12.5	16
24108	47.5									
stacking	24096	24180	24	84	7.5	22.5	4	22.5	12.5	17
feeding	24204	24288	24	84	27.5	7.5	20	10	-5.5	40
24348	17.5									
stacking	24324	24408	36	84	7.5	22.5	3	22.5	12.5	18
validating	24432	24444	24	12	2.5	12.5	15	2.5	12.5	15
feeding	24480	24564	36	84	27.5	2.5	17	34	-5.5	40
stacking	24600	24684	36	84	12.5	22.5	5	2.5	12.5	15
stacking	24720	24804	36	84	12.5	22.5	4	2.5	12.5	16
stacking	24840	24924	36	84	12.5	22.5	3	2.5	12.5	17
feeding	24960	25044	36	84	32.5	12.5	19	10	-5.5	40
validating	25080	25092	36	12	22.5	12.5	19	22.5	12.5	19
25176	32.5									
stacking	25116	25200	24	84	17.5	22.5	4	22.5	12.5	19
stacking	25224	25332	24	108	47.5	22.5	6	2.5	12.5	18
stacking	25368	25452	36	84	17.5	22.5	3	22.5	12.5	20
feeding	25476	25560	24	84	27.5	17.5	17	34	-5.5	40
25644	7.5									
stacking	25596	25692	36	96	47.5	22.5	5	22.5	12.5	21
25752	2.5									
stacking	25716	25812	24	96	47.5	22.5	4	22.5	12.5	22
feeding	25836	25920	24	84	32.5	7.5	18	10	-5.5	40
26064	47.5									
26148	12.5									
validating	26160	26172	36	12	7.5	7.5	15	7.5	7.5	15
feeding	26208	26292	36	84	32.5	7.5	17	34	-5.5	40
stacking	26376	26460	36	84	32.5	22.5	7	7.5	7.5	15
stacking	26496	26580	36	84	2.5	22.5	4	7.5	7.5	16
stacking	26616	26700	36	84	32.5	22.5	6	7.5	7.5	17
feeding	26736	26820	36	84	37.5	7.5	22	10	-5.5	40
26880	22.5									
stacking	26856	26940	36	84	12.5	22.5	4	7.5	7.5	18
feeding	26976	27060	36	84	32.5	7.5	16	34	-5.5	40
27360	47.5									
feeding	27504	27588	36	84	37.5	2.5	23	10	-5.5	40
27792	37.5									
validating	27828	27840	36	12	22.5	7.5	19	22.5	7.5	19
stacking	27864	27948	24	84	22.5	22.5	5	22.5	7.5	19
28044	27.5									
feeding	27972	28056	24	84	37.5	2.5	22	34	-5.5	40
28092	17.5									

order type	starting time	completion time	travel time	handling time	x_from	y_from	z_from	x_to	y_to	z_to
stacking	28092	28176	36	84	32.5	22.5	5	22.5	7.5	20
stacking	28200	28296	24	96	47.5	22.5	8	22.5	7.5	21
feeding	28392	28476	24	84	27.5	2.5	16	10	-5.5	40
stacking	28512	28608	36	96	7.5	22.5	4	22.5	7.5	22
feeding	28632	28716	24	84	32.5	17.5	23	34	-5.5	40
28860	47.5									
28872	42.5									
feeding	29160	29244	36	84	32.5	7.5	15	10	-5.5	40
29328	37.5									
29400	32.5									
feeding	29484	29568	36	84	37.5	17.5	23	34	-5.5	40
29784	12.5									
feeding	30012	30096	36	84	32.5	12.5	18	10	-5.5	40
validating	30132	30144	36	12	2.5	12.5	19	2.5	12.5	19
stacking	30180	30264	36	84	7.5	22.5	3	2.5	12.5	19
stacking	30300	30384	36	84	2.5	22.5	3	2.5	12.5	20
stacking	30420	30504	36	84	17.5	22.5	4	2.5	12.5	21
feeding	30540	30624	36	84	42.5	7.5	22	34	-5.5	40
stacking	30804	30888	36	84	12.5	22.5	5	2.5	12.5	22
feeding	30924	31008	36	84	47.5	7.5	23	10	-5.5	40
31032	47.5									
31296	12.5									
feeding	31248	31332	36	84	27.5	12.5	15	34	-5.5	40
validating	31368	31380	36	12	12.5	12.5	15	12.5	12.5	15
stacking	31416	31500	36	84	37.5	22.5	7	12.5	12.5	15
stacking	31536	31620	36	84	17.5	22.5	3	12.5	12.5	16
stacking	31656	31740	36	84	37.5	22.5	6	12.5	12.5	17
31752	17.5									
feeding	31776	31860	36	84	42.5	12.5	23	10	-5.5	40
validating	31896	31908	36	12	17.5	17.5	19	17.5	17.5	19
feeding	31944	32028	36	84	27.5	2.5	15	34	-5.5	40
stacking	32064	32136	36	72	12.5	22.5	7	17.5	17.5	19
stacking	32172	32256	36	84	22.5	22.5	4	12.5	12.5	18
32544	2.5									
feeding	32496	32580	36	84	37.5	2.5	21	10	-5.5	40
32736	42.5									
32784	7.5									
feeding	32820	32904	36	84	32.5	12.5	17	34	-5.5	40
stacking	32940	33024	36	84	47.5	22.5	13	17.5	17.5	20
stacking	33060	33144	36	84	17.5	22.5	5	17.5	17.5	21
stacking	33180	33264	36	84	27.5	22.5	4	17.5	17.5	22
33360	32.5									
feeding	33300	33384	36	84	42.5	17.5	24	10	-5.5	40
33624	12.5									
validating	33624	33636	36	12	17.5	12.5	15	17.5	12.5	15
feeding	33672	33756	36	84	27.5	7.5	19	34	-5.5	40
33804	42.5									
stacking	33792	33876	36	84	47.5	22.5	12	17.5	12.5	15
stacking	33912	33996	36	84	27.5	22.5	3	17.5	12.5	16
34032	27.5									
stacking	34032	34116	36	84	17.5	22.5	4	17.5	12.5	17
stacking	34152	34236	36	84	32.5	22.5	8	17.5	12.5	18
feeding	34272	34356	36	84	42.5	7.5	21	10	-5.5	40
34368	17.5									
34512	7.5									
34584	22.5									
validating	34596	34608	36	12	7.5	17.5	19	7.5	17.5	19
stacking	34644	34716	36	72	12.5	22.5	8	7.5	17.5	19
34764	37.5									
feeding	34752	34836	36	84	32.5	17.5	22	34	-5.5	40
stacking	34872	34956	36	84	12.5	22.5	7	7.5	17.5	20
stacking	34992	35076	36	84	2.5	22.5	4	7.5	17.5	21
35076	42.5									
35160	12.5									
feeding	35112	35196	36	84	47.5	7.5	22	10	-5.5	40
validating	35232	35244	36	12	7.5	12.5	15	7.5	12.5	15
stacking	35280	35352	36	72	7.5	22.5	7	7.5	12.5	15
stacking	35388	35472	36	84	22.5	22.5	6	7.5	12.5	16
35472	17.5									

order type	starting time	completion time	travel time	handling time	x_from	y_from	z_from	x_to	y_to	z_to
feeding	35508	35592	36	84	27.5	7.5	18	34	-5.5	40
stacking	35628	35712	36	84	2.5	22.5	3	7.5	17.5	22
35772	2.5									
stacking	35748	35832	36	84	22.5	22.5	5	7.5	12.5	17
stacking	35868	35952	36	84	7.5	22.5	6	7.5	12.5	18
feeding	35988	36072	36	84	32.5	17.5	21	10	-5.5	40
validating	36108	36120	36	12	12.5	7.5	15	12.5	7.5	15
stacking	36180	36264	48	84	42.5	22.5	11	12.5	7.5	15
stacking	36300	36384	36	84	22.5	22.5	4	12.5	7.5	16
feeding	36420	36504	36	84	32.5	17.5	20	34	-5.5	40
stacking	36540	36624	36	84	27.5	22.5	4	12.5	7.5	17
stacking	36660	36744	36	84	7.5	22.5	5	12.5	7.5	18
feeding	36780	36864	36	84	37.5	2.5	20	10	-5.5	40
validating	36900	36912	36	12	7.5	12.5	19	7.5	12.5	19
stacking	36948	37032	36	84	12.5	22.5	8	7.5	12.5	19
stacking	37068	37152	36	84	22.5	22.5	3	7.5	12.5	20
feeding	37188	37272	36	84	32.5	2.5	23	34	-5.5	40
stacking	37308	37392	36	84	7.5	22.5	4	7.5	12.5	21
stacking	37428	37512	36	84	17.5	22.5	9	7.5	12.5	22
feeding	37548	37632	36	84	37.5	2.5	19	10	-5.5	40
validating	37668	37680	36	12	12.5	12.5	19	12.5	12.5	19
stacking	37716	37800	36	84	32.5	22.5	7	12.5	12.5	19
stacking	37836	37920	36	84	12.5	22.5	7	12.5	12.5	20
stacking	37956	38040	36	84	17.5	22.5	8	12.5	12.5	21
feeding	38076	38160	36	84	37.5	12.5	23	34	-5.5	40
validating	38196	38208	36	12	7.5	7.5	19	7.5	7.5	19
stacking	38244	38328	36	84	2.5	22.5	5	7.5	7.5	19
stacking	38364	38448	36	84	2.5	22.5	4	7.5	7.5	20
feeding	38484	38568	36	84	47.5	2.5	22	10	-5.5	40
stacking	38604	38688	36	84	12.5	22.5	6	12.5	12.5	22
stacking	38724	38808	36	84	17.5	22.5	7	7.5	7.5	21
feeding	38844	38928	36	84	47.5	12.5	23	34	-5.5	40
validating	38964	38976	36	12	2.5	7.5	15	2.5	7.5	15
stacking	39012	39096	36	84	32.5	22.5	6	2.5	7.5	15
stacking	39132	39216	36	84	12.5	22.5	5	2.5	7.5	16
stacking	39252	39336	36	84	17.5	22.5	6	7.5	7.5	22
feeding	39372	39456	36	84	47.5	17.5	23	10	-5.5	40
stacking	39492	39576	36	84	7.5	22.5	3	2.5	7.5	17