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A SIMULATION TOOL FOR TRUCK LOADING AT FUEL FILLING PLANTS

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ABSTRACT

The various processes of truck loading at a fuel filling plant are interrelated which makes it complex to analyze and improve the performance of the filling plants. This paper describes these processes and presents a software tool developed in FlexSim for modelling the drivers' activities, analyzing different decision scenarios, and optimizing the filling processes at fuel terminals. The simulation model has been used to identify bottlenecks and evaluating opportunities for performance improvement. This paper reports the application of the model to a lubricant filling plant for analyzing and supporting decision making on the assignment of trucks to bays, and on the availability of the lubricants on the fuel arms at the lading bays.

1 INTRODUCTION

In this paper we apply a software tool that we have developed for simulation-based modelling and optimizing the processes of filling fuel trucks at a filling plant. Truck drivers arriving at the filling plant have to make many decisions concerning to which bay or sequence of bays they should drive their truck to for filling its compartments with the different fuels according to their bill of loading. At the bays they have to decide which fuel arms to use for this task. These are complex decision processes that the truck drivers face, without knowing exactly the consequences, though experienced drivers can find estimates of these. When the wrong decisions are taken, filling a truck would take too long causing also delays of the waiting trucks. In Section 2 we will describe these filling plant processes in more detail.

The aim of our work is to develop a software tool that is generic enough to model any filling plant, without much customization. Experienced users of this tool should be able to identify bottlenecks, analyze performance, and evaluate various scenarios to support decision making at the truck filling plants. For that reason, we have developed a comprehensive simulation-based model that is able to assess filling scenarios. Nowadays, simulation-based modelling and simulation-based optimization of real-life complex decision processes with uncertainty are well-established alternatives to numerical or analytical methods, in particular when these systems are hard to solve. This has led recently to a large number of publication in a variety of fields, for instance, logistics (Wang, Guan, Shao, and Ullah 2014), manufacturing (Melouk, Freeman, Miller, and Dunning 2013), routing (Bedogni, Bononi, Felice, D'Elia, Mock, Morandi, Rondelli, Cinotti, and Vergari 2016), transport (Romero, Moura, Ibeas, and Alonso 2015), supply chains (Grzybowska and Kovacs 2016), healthcare (Hamrock, Paige, Parks, Scheulen, and Levin 2013), scheduling (Legato, Mazza, and Trunfio 2010), aviation (Sridhar, Sheth, Ng, Morando, and Li 2016), design and construction (Ahn, Hislop-Lynch, and Caldwell 2015), quality control (Marelli, Coccola, Portillo, and Tymoschuk 2015), project management (Weber 2015), etc.

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We have built our simulation model in FlexSim (Beaverstock, Greenwood, Lavery, and Nordgren 2012), FlexSim is a commercial discrete-event simulation program, that has been ranked recently in the top 3 of most popular and used simulation tools (Dias, Vieira, Pereira, and Oliveira 2016). For our work we choose FlexSim for several reasons:

- ease of use with drag and drop technology,
- visualization in 3D,
- importing CAD-files directly to a model,
- the add-in OptQuest for experimenting and optimizing,
- exporting statistical reports.

We have applied our simulation tool to three test cases of real fuel filling plants. We have modelled and implemented in our tool the assignment rules that are mostly used by the drivers. The rules concern both trucks to loading bays, and fuel arms to truck compartments. By running the simulation program it was possible to compare the performances of various scenarios of assignment rules. Specifically, the simulation output identified bottlenecks in the throughputs of trucks; i.e., situations where trucks have long waiting times or long gate-to-gate times.

The purpose of this paper is to describe a case study in which we applied our simulation tool to a lubricant filling plant in Europe. This serves as a test for flexibility of our tool and model since lubricant filling plants are somewhat different from fuel filling plants. The organization of the paper is as follows. In Section 2 we describe the fuel filling process at the lubricant filling plant. In Section 3 we explain the elements of the simulation model. Section 4 describes the case study, our experiments, and the results.

2 FUEL FILLING PROCESSES

One of the processes oil companies are dealing with is the process of filling fuel trucks at the filling plant. Typically, fuel trucks have several compartments for loading different fuel types. The filling plant consists of a number of parallel loading bays where each bay offers different combinations of fuel types. A truck arriving at the plant might require many different fuel types, and thus the driver has to choose which bay to enter, or stand in line in case the bay is occupied. The time to fill all compartments can take up to 30 minutes, so choosing the right bay can make a significant difference.

In some cases, the fuels required by a truck are not offered at a single loading bay, so it needs to visit multiple bays to complete its order. We call this splitloading. Sometimes there is a long queue at a loading bay, and then trucks choose to do a splitload even when the bay offers all the required fuels. Finally, decisions have to take into account the design of the loading bay concerning orientation and flexibility of the fuel arms. Some bays may have so-called swing arms that are connected to two loading bays. Normal arms are connected to a single loading bay.

This leads to our focus on the questions how to model these processes in a simulation project and implement various assignment rules of trucks to loading bays with the objective of minimizing the truck loading process time. The loading process time is defined as the time taken from entering the loading bay queue to leaving the loading bay once all the compartments of the truck have been filled.

3 SIMULATION MODEL

In order to build a generic software tool for fuel truck filling, we must construct fixed resources that can be found at filling plants, as well as manage the ways in which these fixed resources connect and communicate with each other. Below, we discuss the processes at a filling plant and the types of structures that are typically encountered there.

3.1 The Processes

The processes in a typical fuel filling plant are truck arrivals, access control, inspection, bay assignment, loading, and collecting bill of loading, as depicted in Figure 1.

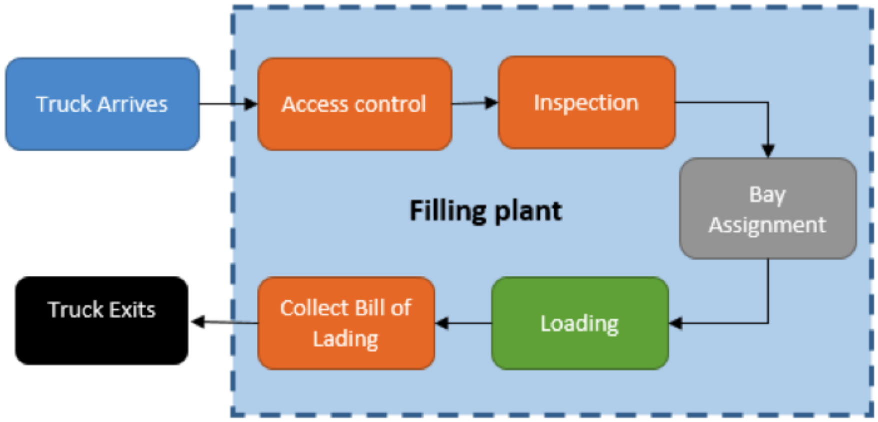

Figure 1: Flowchart of the processes in a typical filling plant.

3.2 Truck Arrivals

The truck arrivals are modeled in FlexSim by a customized source fixed resource. The source has the function that it creates "flowitems" and sends them into the model. We customize the source by modifying the inter-arrival time of the flowitem to ensure trucks enter the model in a similar fashion as they do in real life. Secondly, we attach individual characteristics of the trucks to the flowitems.

3.3 Bay Assignment

The bay assignment process concerns the assignment of the trucks to the loading bays. In simulation terms, its main function is to send the flowitem onwards over the right path to the best suited loading bay. To model this process in FlexSim we have chosen to use a processor fixed resource with the specific bay assignment functionality embedded in a "sendTo" command. When you run the sendTo command, it returns a number, and then releases the flowitem over the path connected to the out-port of that number. The problem of returning the out-port leading to the optimal loading bay is a rather complicated one, as the choice of bay is not straightforward and depends on a number of factors.

3.4 Loading

A loading bay is simply a parking place for the truck, where a number of consecutive compartment filling processes take place. Once all compartments have been filled, the truck is generally delayed for some extra time to take into account sub-processes, such as safety measures, attaching/detaching fuel arms, etc. After these the truck can move on through the filling plant. Once a truck parks at a loading bay all compartments (that can be filled) need to be refilled by matching fuel arms. Trucks can have multiple compartments requiring the same fuel and bays can have multiple arms offering the same fuel. Also, some fuel arms offer more than one type of fuel. On top of that some loading bays have swing arms, which are arms that can be used by two adjacent loading bays, but not at the same time.

After interviews with employees of filling plants and truck drivers, we identified the method that is used generally to assign arms to compartments; namely, a truck driver connects as many arms as possible, then waits till all arms are finished, disconnects them, and again reconnects as many arm as possible, continuing this loop until his order is complete. The method described above is implemented in our simulation model.

The loading bay and the fuel arm processes are modeled in FlexSim by basic fixed resources, as these object are more flexible than other fixed resources.

4 CASE STUDY

We applied our simulation tool to a lubricant filling plant in Europe. As lubricant filling plants are somewhat different from fuel filling plants this will be a good test for the flexibility of the model. The lubricant plant has 3 loading bays, with a total of 7 lubricant arms. 3 out of 7 lubricant arms are swing arms shared by bay 1 and 2. On average the plant is visited by 12 trucks each day. For fuel filling plants this would not be a problematic number, but due to the long filling times at the plant the trucks experience extreme waiting times. Our challenge will be to identify opportunities to decrease these waiting times using low-investment solutions.

4.1 Data Analysis

We obtained the order and arrival data of all trucks visiting the filling plant during a 99 days period between 5 January 2015 and 29 May 2015. Also we were provided with the layout of the filling plant, loading bay and fuel arm information, assignment method (central dispatcher) and the various time delay processes trucks go through.

4.1.1 Truck Arrivals

In the 99 days observed, 1146 trucks visited the lubricant plant, on average 12 each day. These trucks spent on average 3 hours and 56 minutes at the filling plant, where they filled an average of 3.70 compartments. Due to the density of lubricants, bottom loading is impossible, hence all trucks (and bays) are top loaders. In Figure 2 the hourly average arrival profile of the trucks is given. We use this to simulate the arrivals of the truck. It is assumed that the arrival profile is similar for each day of the week.

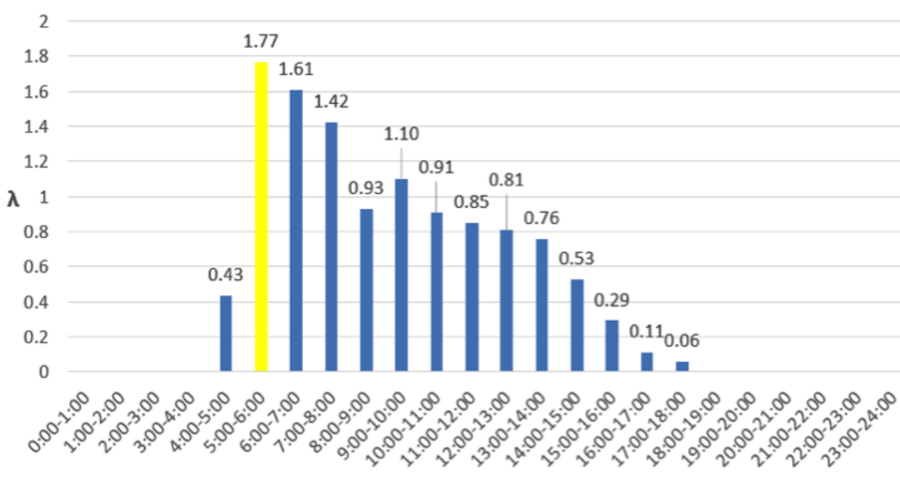

Figure 2: Hourly arrival rate.

The trucks are classified in three different categories (priority 1, 2 and 3). Priority 1 trucks are dedicated suppliers delivering large quantities of lubricants to factories and refineries. It is important that they deliver their orders on time, so they are given priority over other trucks. Priority 2 and 3 trucks deliver to the other customers and differ in size and demand (priority 2 trucks have more compartments). Priority 2 trucks are given right of way over priority 3 trucks. The priority measure is applied when multiple trucks are waiting in a loading bay queue. The queue will then re-order such that the trucks with highest priority are first in line, no matter which truck arrived in the queue earliest.

4.1.2 Lubricant Demand

The order data of the trucks can be used to form an image of the lubricant demand. The first thing that stands out is the amount of lubricants available at the plant. In comparison to fuel plants, that rarely offer more than 20 different types, there are a staggering amount of 128 different lubricants available (and demanded) at the lubriacant plant. First we observed how the demand for these lubricants is distributed. By collecting different variations of the same base lubricant into groups, we created 36 categories out of 128 lubricants. The proportional demand for these categories is visualised in Figure 3. Of the 36 categories only 12 have a demand of more than 1%, while the two most popular categories take up more than 50% of the total pie. The demand for lubricants is skewed if we look at it from a group level.

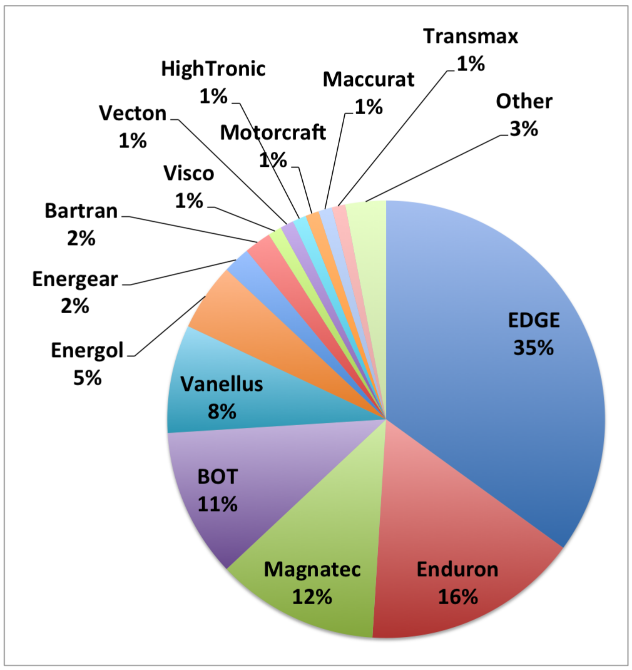

Figure 3: The lubricant demand.

In Table 1 the demand for the five most popular lubricants is given. Together they account for 43% of the total lubricants demand. This confirms our earlier observations that the demand for lubricants is heavily skewed. Table 1 also gives the arms on which these lubricants are available. The seven arms are labeled A to G. Arms A, B and C are swing arms serving both bay 1 and 2, arm D is dedicated to bay 1, and arms E, F and G are serving bay 3.

The data of Table 1 indicate that there there is potential for improvement. Even though most of the popular lubricants are available at all bays, they are only offered through one swing arm for two bays. This leads to the hypothsis that trucks spend long periods waiting for the swing arms. We will test this statement and the potential improvement to be made by making the popular lubricants more available.

The analysis of demand on bay level is captured in Table 2. The low percentages of priority 2 trucks that can complete their full order at a single loading bay are worrying, as it implies that many splitloadings are required for priority 2 trucks.

Table 1: Popular lubricants.

most popular lubricants	arms	percentage of total demand
EDGE Prof LL III 5W-30	C,E	11.29 %
Enduron Low SAPS 10W-40	A,E	9.84 %
EDGE Profess LLIII 5W-30	A,E	9.24%
EDGE Professional A3 0W30	A,E	8.07 %
BOT 950 0W-30	A	5.46%

Table 2: Lubricant offerings per bay.

			% trucks completing full order		
loading bay	# arms	# lubricants	all	priority 1 & 3	priority 2
1	4	91	53 %	91 %	10 %
2	3	74	51 %	91 %	7 %
3	3	100	70 %	87 %	50 %

4.2 Model Construction

Our simulation model of Section 3 had to be customized to deal with a few particularities of the lubricant plant. Firstly, we added the priority rules of trucks to the arrival module of section 3.2. The second issue concerns the variable flow rate. To cope with the large number of lubricants, lubricant arms are connected to a number of different tanks in which lubricants are blended by the plant employees. This causes that the flowrate is not constant as is shown in figure 4 which depicts the histogram of 343 data of average flow rates. Denoting the capacity of a compartment by C, and the filling time by T, the average flow rate is $f = C/T$. Clearly, the flow rate is is not constant, but rather bell-shaped around its mean 200.6.

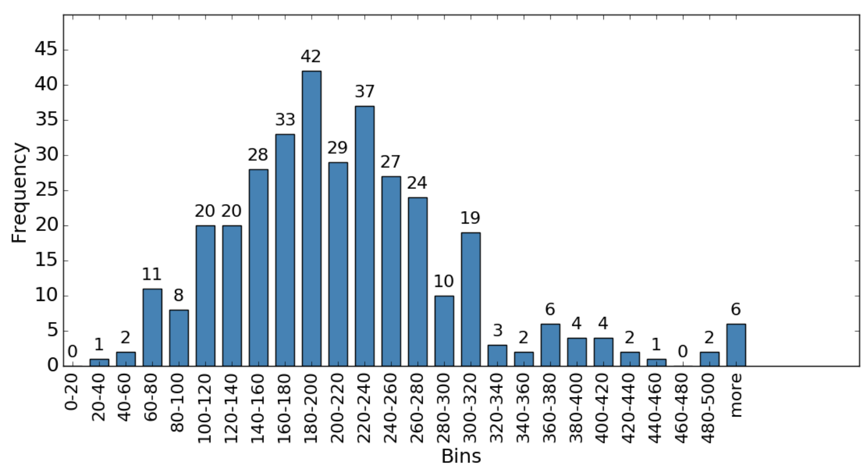

Figure 4: Histogram of the average flowrates of 343 filling jobs. The mean is 200.6; standard deviation is 106.6.

Furthermore, we found correlation between the compartment capacities and the average flow rates, the reason being that the ramp-up and ramp-down times of the filling process become less influential for larger compartments. The scatter plot in Figure 5 illustrates this correlation.

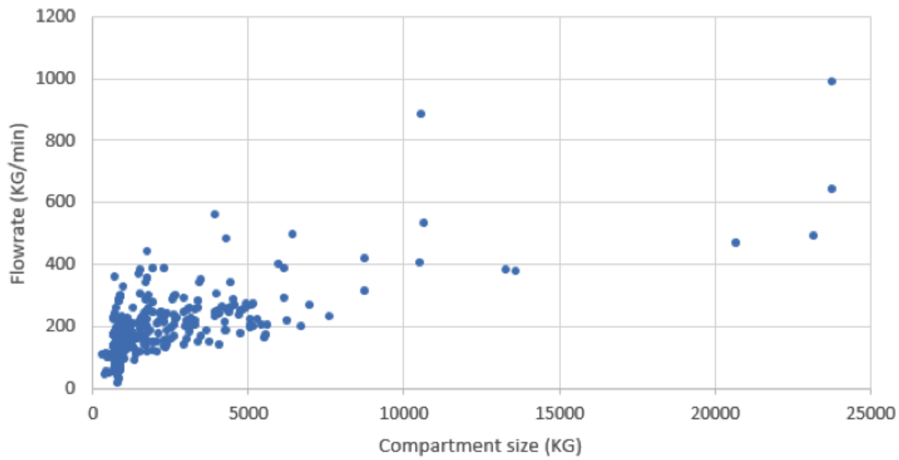

Figure 5: Scatter plot of flow rate against compartment size for the 343 cases.

To deal with this correlation, we decided to construct an approximation for determining the fill time T given a capacity C. Let F be the maximal flow rate of a fuel arm. It takes a time T_U before the arm is able to inject at the maximal rate. We assume that the flow rate increases linearly from 0 to F, which we call the ramp-up. Similarly, there is the ramp-down for the flow to decrease from F to 0, with duration T_D. We get for the fill time,

$$T = \frac{C}{F} + \frac{1}{2}(T_U + T_D), \tag{1}$$

if the capacity of a compartment satisfies $C \geq F(T_U + T_D)/2$. However, for small capacities, $C < F(T_U + T_D)/2$, the maximal flow rate cannot be reached. We now get after standard calculus

$$T = \sqrt{\frac{2C(T_U + T_D)}{F}}. \tag{2}$$

The data of the average flow rates gave us observed values of the fill times ($T = C/f$). Hence, minimizing the sum of squared differences (SSD) between the observed and the calculated fill time values, we obtain optimal values for the F, T_U, and T_D parameters. In this way we compute the fill times in our simulation model.

4.3 Model Verification and Validation

Our simulation model has been validated, and our computer programs have been verified by various common methods (Sargent 2013). We sketch here the truck filling times as validation, and the demand processes as verification.

- Data of 4714 truck visits during 365 days were provided. Table 3 gives the average sojourn times at the filling plant for the different priorities versus the 95% confidence interval of the corresponding simulations. Although the real average is not covered in one case, the credibility of our model was ascertained after careful considerations with the filling plant manager (Law 2014).
- We tested the sampling procedure of a specific lubricant demand in our programs. Figure 6 compares the accumulated demand from the sample data with the output data, from which we were ascertained of correct sampling.

Table 3: The real versus 95% confidence interval of the average sojourn times (in minutes) at the filling plant.

		95% conf int	
priority	real	LB	UB
all	228.4	216.5	229.0
1	188.5	188.0	204.0
2	268.3	238.6	258.4
3	205.0	193.7	231.6

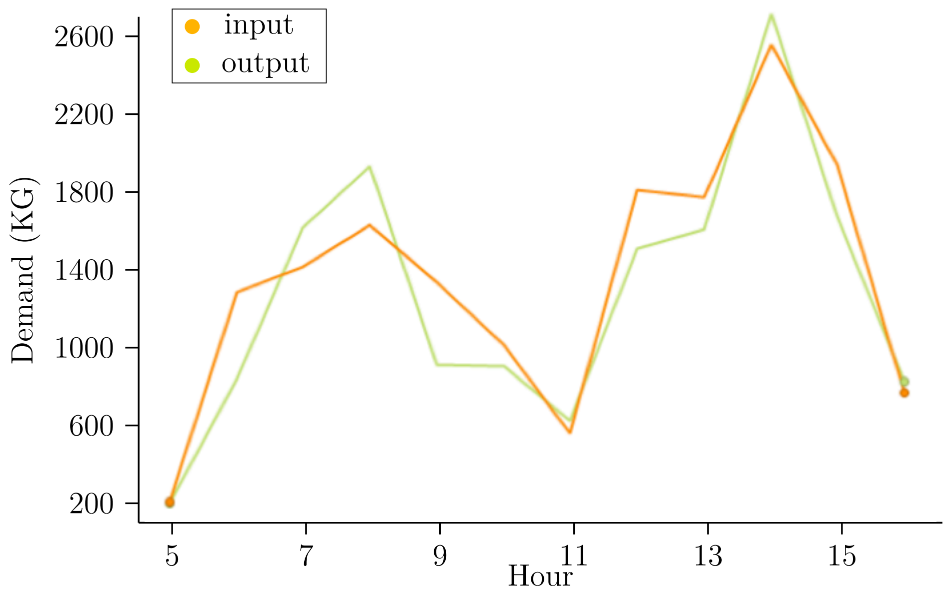

Figure 6: Average hourly demand for a specific lubricant from model input and output data.

4.4 Design Scenarios

The purpose of this case study was to identify opportunities for improvement and then compare the impact on the lubricant plant throughput time. We report here two potential scenarios. The first scenario that we suggested, focused on making the most popular lubricants to become more available. In the other scenario the loading bays are dedicated to trucks of specific priorities, as was suggested by the plant employees.

4.4.1 Scenario 1

Recall from Table 1 in section 4.1.2 how the five most popular lubricants are available at the bays. When the swing arm A is in use at bay 1, then it is not available for the truck at bay 2, while typically it has the need of it. In scenario 1 we have investigated the potential impact of making these lubricants available at more arms. Table 4 gives an overview of the extra availabilities.

4.4.2 Scenario 2

In this scenario we make two loading bays exclusively available for the priority 2 trucks, and the remaining one exclusively for the priority 1 and 3 trucks. It was hypothesised that this split would speed up the processes for all trucks. Under this scenario, the available lubricants per priority are decreased as it becomes prohibited to visit some loading bays. Therefore, to make the scenario feasible, it was required that some

Table 4: Scenario 1: the 5 lubricants are made available at 6 extra points.

most popular lubricants	arms currently available	arms extra available
EDGE Prof LL III 5W-30	C,E	A
Enduron Low SAPS 10W-40	A,E	C
EDGE Profess LLIII 5W-30	A,E	C
EDGE Professional A3 0W30	A,E	C
BOT 950 0W-30	A	C,F

lubricants are added to certain arms, so that all trucks can complete their full order at their exclusive loading bay(s).

We have done an analysis of the possible loading bay-priority combinations to see which setup would require the least configurations. With the least configurations we mean to assign the priorities to loading bays such that the least lubricants would have to be added to arms to make sure all trucks can complete their orders without doing a split load. The priority to loading bay assignment that requires the least amount of configurations is when priority 2 trucks exclusively go to loading bays 1 and 3, and priority 1 and 3 trucks go to loading bay 2. For this assignment 21 lubricants need to be added to loading bay 2.

4.5 Results

For every scenario we ran the simulation model for 365 days. and compare the overall results. The main results are given in Table 5. The average time delay from processes outside the loading process is 57 minutes for all scenarios. As this does not change under the diffferent scenarios, we will only focus on the loading process time in the result analysis. Scenario 1 shows potential improvements, while scenario 2 actually does worse than the base case.

Table 5: The main results for the base case and both scenarios.

	base case			scenario 1			scenario 2		
priority	1	2	3	1	2	3	1	2	3
avg time at plant (mins.)	188	268	205	173	258	188	242	256	383
loading process time (mins.)	131	210	149	117	200	133	184	199	329
loading time (mins.)	105	111	98	96.9	106	92.3	98.4	130	93.1
waiting time for bay (mins.)	24.7	32.7	45.7	19.4	28.0	36.1	85.6	41.7	235
split load loading time (mins.)	0.7	41.9	3.0	0.5	23.4	1.5	0	6.1	0
split load waiting time for bay (mins.)	0.8	42.0	3.0	0.5	42.2	2.9	0	21	0
waiting time for swing arm (mins.)	10.1	10.7	8.1	1.7	4.6	1.9	-	-	-
split loaders (%)	2	62	4	1	62	3	0	21	0

4.5.1 Results for scenario 1

The results for scenario 1 are promising. The loading process times are improved for all priorities, to an average of 158 minutes. This corresponds to an improvement of 14 minutes, or 8.1%, over the base case. As expected, making the lubricants more available drastically decreases the time wasted waiting for swing arms. This decreases loading time, which in turn has the positive effect that the waiting times become shorter. The effects of the added lubricants can be seen clearly if we compare the arm utilization for scenario 1 and the base case. In Figure 7 we have plotted the utilization for the two most used swing arms at loading bay 1 and 2. Note that arm 3, the arm to which most popular lubricants were added in scenario 1, relieves the high utilization of arm 1 somewhat.

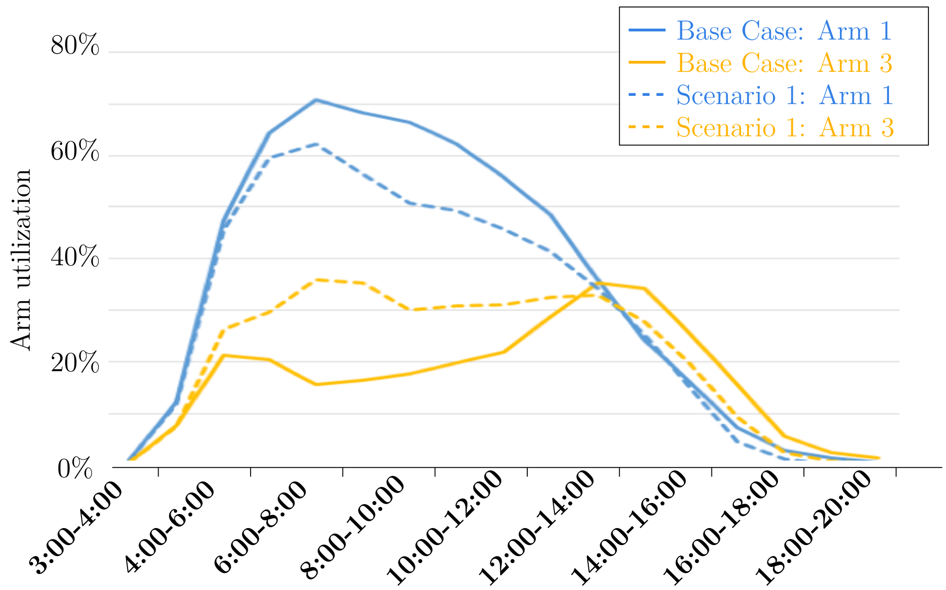

Figure 7: The arm utilizations for the two most used swing arms at loading bay 1 and 2.

4.5.2 Results for scenario 2

Even though the lubricant offering is increased in scenario 2, the results are worse than the base case. By introducing the exclusive loading bays we are actually adding a restriction to the model. In this case the added value of the extra lubricants does not weigh up against the restriction of exclusive loading bays. For priority 1 and 3 trucks, who are assigned to a loading bay 2, the loading process times go up drastically. This is caused by an exploding waiting time, as loading bay 2 cannot handle all priority 1 and 3 trucks. As the queues become longer, the waiting times for priority 3 trucks increase, because they will be overtaken by priority 1 trucks. There is a small advantage in loading process time for priority 2 trucks, which is accounted by the fact that they have relatively more loading bays available.

4.5.3 Evaluation of Results

From the input analysis it became clear that the most popular lubricants were not available enough. As the top 5 is responsible for 43% of the total demand, it seems merely logical that they should be directly available at every loading bay. We hypothesised that making them more available would decrease loading process time. Our simulation model confirmed this hypothesis, indicating that an 8% gain can be made by adding 5 lubricants in 6 positions. We recommended the management of the lubricant filling plant to follow this strategy. More research should be done to identify the optimal lubricant adding, where the financial investment needed for the configuration has to be considered. As the oil & gas industry is suffering from the low crude oil prices, a lot of capital investments are put on hold. Also for this project, the management of the lubricant filling plan decided that for now there is not enough cash flow to support the investment and therefore the project is put on hold.

Splitting the trucks into two groups that are assigned to exclusive loading bays is not a good strategy. It needs a considerable larger investment (under the notion that adding a lubricant to an arm has a constant cost), but the results are worse than in the base case, because the split is effectively adding a restriction to the filling plant process.

5 CONCLUSION

In this paper the processes of truck filling at fuel plants are discussed. These logistical processes become very complex at large plants, or at plants offering a wide range of fuel products, or for trucks with many compartments for different fuel products, or for a combination of these layouts. It is argued that a suitable software tool can support management and employees to model the plant, analyze performance, identify bottlenecks, and compare assignment rules of trucks to bays, and bay arms to truck compartments. The platform we have developed is capable to build such a software tool. In this paper we have shown these capabilities by studying a case study of a lubricant filling plant for which we implemented a simulation model in FlexSim. Using the software tool we have studied alternative logistical scenarios at the plant for performance improvements.

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