MASTER THESIS PUBLIC SUMMARY

Increasing the throughput of the cleaning trains at Company X

Céline Steenge

Faculty of Behavioural, Management and Social Sciences

MSc Industrial Engineering and Management

Production and Logistics Management

Enschede, 19/08/2021

UNIVERSITY OF TWENTE.

1. Main topic of the thesis

Company X wants to clean used pump sets for recycling purposes. These pump sets are first disassembled. Next, they will move through the cleaning train and the extra cleaning unit. These units contain cleaning baths and cleaning stations for properly cleaning the items. Items that are broken can now be recycled, while the good items will be used for the pump set again. When the good items of the pump set are clean, they will be assembled. Before the pump set will be released, it will be tested to guarantee that the pump set meets all its requirements.

In the coming five years, Company X wants to renew the cleaning stations to have optimal working, productive and sustainable cleaning stations. Right now, approximately twenty pump sets can be cleaned per year which is the maximum of the cleaning train. Although this throughput is enough for now, Company X would like to start cleaning the pump sets of sister Company Y as well, meaning that another fifteen pump sets should be cleaned. This means that the possible change to the current situation such that this increase in the throughput is possible should be researched. This will be done by redesigning the current situation, with the focus on the redesign of the cleaning train. Other options like changing the planning or changing the maintenance policy are not included in this research.

Next to the increment in the throughput, it should also be clear how long the pump sets stay at Company X. Only in this way, Company X can give a time frame to sister Company Y when they will receive their pump sets back. At this moment, the throughput time for one pump set is approximately two weeks on average. This average will serve as the maximum throughput time for this research.

2. Purpose of the thesis

With this research, recommendations for the new cleaning train will be generated. The recommendations will result in a cleaning train that almost doubles the current throughput while having the current average throughput time of two weeks as the maximum average throughput time. Next to the recommendations, the designed simulation model, as can be read later in Section 4 and Section 5, will be handed over as well. This simulation can be used when more research is wanted on this subject. An implementation plan will not be written since Company X has their own standard implementation plan for changes.

3. Research questions

In order to find a solution for the problem, research questions will be formulated. Each research question will contribute to the final solution. For this research, the main research question is the following:

"*What is the best design for the cleaning train that will be replaced in five years, such that the throughput can be increased to 35 pump sets while having the current average throughput time of two weeks as the maximum average throughput time?"*

In this research question, best is defined as the configuration which meets the beforementioned requirements at the least amount of intervention with a minimal waiting time.

In order to answer this main research question, information is needed on multiple aspects. First, information about the current situation is needed like the process flow. This will form a baseline for the research. Next, methods for increasing the throughput should be found in literature. From these methods, the most suitable options for Company X will be chosen. Based on the chosen method, a model should be made. The simulation model should represent the current situation in the first place. When this model is validated and verified, then different scenarios can be modelled in the experimental design. Finally, the results of the experiments need to be analysed to find out which configuration is the best configuration for Company X. After answering all the sub research questions, the main research question can be answered.

4. Literature research

An extensive literature research showed that there are multiple methods for increasing the throughput in a system. Methods that require extensive data were left out of the research, since there is only limited data available for this research. Another limiting factor in this research was the time frame. Although a combination of the Theory of Constraints, lean management and simulations would be optimal for this research, due to time only simulations are performed.

When choosing a method, it is important to keep in mind which aspects influence this research. In the case of this research, there is limited data available. Due to this, the queueing theory has already been eliminated from the possibilities. The other methods will work with the limited data but will not work optimally.

Next to this, there is a time frame in which this research needs to be performed. This means that the chosen method should be feasible within the given time frame of twenty weeks. Based on these aspects and the advantages and disadvantages of the various methods, a choice needs to be made.

The choice is between lean management, theory of constraints, network planning and simulation. Network planning approach is more for projects, which is not the case in this research where an improvement of the current situation is wanted. Therefore, this method is not chosen.

Complexity could also play an important role. At this moment, the process does not have complex routings or complex structures, meaning that it is a good candidate for a pull system. However, lean management looks at improving the whole process, while the current situation showed that most time is likely lost in one of the sections of the cleaning train. Since this is already known, TOC would be a good candidate to solve first the bottleneck of that specific section and next re-examen whether there are more bottlenecks in the process.

Another approach could be to not just pick one method but combine methods. For the TOC for example, step 1 involves identifying the constraint. This could possibly be done using a simulation model. Step 2 of the TOC involves the question how to resolve the bottleneck. One could search for solutions using waste elimination (lean management) or one could simulate multiple solutions and find the most appropriate solution.

Seeing this research, the most suitable approach would be a combination of the TOC method and see whether lean management could help by solving the bottleneck. Simulation can be used for verifying the multiple solutions. Although the input data is non-optimal, it can still give an impression of the possible solutions.

Although the most suitable approach is known, it has been chosen to start with the simulation model and simulate some possible solutions. These possible solutions can be found in Section 5. This has been chosen due to time limitations. Whenever there is time left, one could identify bottlenecks and improve the system more systematically using the most suitable approach mentioned above.

After a more in-depth literature research on simulation studies, a dynamic stochastic discrete event simulation model has been chosen. This model will be built in Tecnomatix Plant Simulation 13.2 developed by Siemens PLM software. The simulation model design will follow the ten steps from the book of Law.

5. Solution design

The next step is to design the simulation model. First the current situation is designed. This is explained in Section 5.1. The simulation model also needs to be validated and verified. How this is done, is discussed in Section 5.2. After the validation and verification, experiments are designed. These are discussed in Section 5.3.

5.1. Simulation model

The simulation model will start from the moment the pump sets get delivered to the Company X and will end when the pump sets finished their final test. Normally, two employees work constantly on the pump sets. The general steps between the beginning and the end can be found in a flowchart in Figure 1. First the pump set enters and goes to the inventory. This inflow fluctuates with peaks every three months. When the cleaning train is free, meaning that there are no pump sets between the cleaning train and the additional cleaning unit, the first pump sets in the inventory can start disassembling using a crane. The items go through the sections one-by-one using a crane. In total, there are two cranes in the cleaning train. When all items have left the additional cleaning unit, then the next pump sets can be brought into the cleaning train. When all the items of the pump are cleaned, then they can be assembled again. One cannot start assembling when not all items are cleaned. Finally, the pump sets are tested and released.

The reality could not be modelled entirely, meaning that simplifications had to be made. This led to assumptions like leaving out sickness of employees, leaving out equipment failures, leaving out moving distance and more.

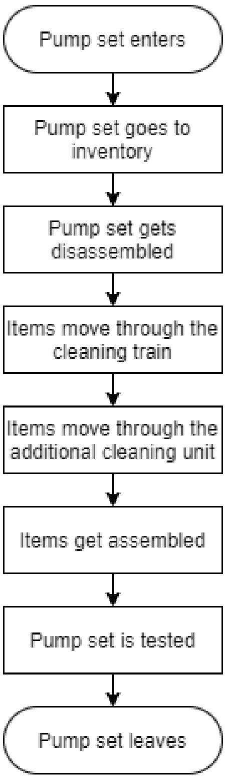

FIGURE 1: GENERAL FLOWCHART OF THE PROCESS.

The cleaning train is a system where the initial conditions influence the steady-state performance, meaning it has transient system behaviour. Since in this research there is no natural event which will stop the simulation (such as the end of a project), a non-terminating simulation is needed. The combination of a transient system behaviour and a non-terminating simulation led to a conflict. Since the data will keep changing over time, a steady-state behaviour cannot be found. There will however be a point in time where enough data is collected to which can describe how the parameters change over time. Therefore, one could chose a terminating system behaviour in this case (Law, 2015, p. 497). A warmup period is therefore not required. Since this study wants to investigate the throughput per year, it has been chosen to take a run length of 365 days. After performing the sequential procedure of Law (Law, 2015, sec. 9.4.1.) for finding the number of replications, it was found out that 43 replications are needed for a reliable outcome of the simulation model.

5.2. Validation and verification

The simulation model needs to be verified, validated and its credibility needs to be established. Each of these steps will be explained here.

Verification

The basis simulation model is the current situation at Company X and is the basis for the verification step.

Verification can be achieved using multiple techniques for debugging the computer model. Law discusses eight techniques for this (Law, 2015, sec. 5.2). One of these techniques makes use of sub models. These sub models are smaller parts of the overall model which will be made and tested before implementing. This simplifies the debugging process. Another technique which will be used, is with the help of an expert. The expert can walk-through the program to see whether the model is similar to reality. This is called a structured walk-through of the program. This technique avoids that mistakes are not found since the programmer is biased. Finally, the animations from the software will be used to verify what is going on in the model. The animations together with the sample runs can give a good estimate whether the model is reasonable or not. By using these techniques, the model is verified.

Validation

After verifying the model, the model should be validated. Since there have not been any simulation research on this problem at Company X yet, the model cannot be validated using comparison to known models. Also, detailed information on all key performance indicators is not available. The user manual of the cleaning train mentions that the cleaning train has been designed to clean thirty pump sets per year (Company X, 2010). During the interviews conducted before it was mentioned that fifteen to twenty pump sets are cleaned per year. This information will therefore be used to validate the outputs of the simulation model. The simulation model should be able to clean at least twenty pump sets per year with an average throughput time of maximum two weeks. Furthermore, the simulation model should not be able to clean 35 pump sets per year with an average throughput time of maximum two weeks. This is also the case for the simulation model as is visible in Table 1. All output times are expressed as '*days:hours:minutes:seconds*'. The outcomes also make use of a 95% confidence interval for the sample means.

TABLE 1: VALIDATION DATA FOR THE SIMULATION MODEL USING A 95% CONFIDENCE INTERVAL.

Average number of pump sets cleaned	Average total waiting time	Average total processing time	Average throughput time
20 ± 0.00	09:13:26:26 ± 00:00:44:33	03:19:25:26 ± 00:00:25:50	13:08:51:52 ± 00:00:51:30
35 ± 0.00	19:00:09:45 ± 00:02:21:02	03:19:29:06 ± 00:00:19:58	22:19:38:51 ± 00:02:22:59

Next to the throughput check, the model is compared with the existing system and discussed together with experts for validating even more. This means that all three techniques for validating the output from the overall simulation model mentioned in Law are being used (Law, 2015, sec. 5.4.5). The comparison and discussion both showed that the simulation model will give outputs which are as expected.

Establishing credibility

In order to establish credibility, the verification and validation techniques already help. Since the model is widely discussed with the experts of Company X, it is most likely that Company X will find the model verified and validated. This together with the animations can establish credibility. The animations make the model easily understandable, which helps selling the results to Company X.

5.3. Experiments

Changes to the current model are tested to see which configuration could work best. The experiments that were performed are:

- Inflow of the pump sets
  Currently, the inflow of the pump sets fluctuates. This experiment looked at what would happen to the throughput and throughput time when the inflow became constant over time by spreading the inflow over the year.
- Cleaning control methods
  Instead of starting the cleaning process of the next pump set when all items have left the additional cleaning section, it was tested whether changing this to an earlier point in the process influences the process.
- Extra crane
  At this moment, two cranes are used within the cleaning train. One of them is constantly in use while disassembling the pumps. The other crane is used for moving the items through the cleaning baths. An extra crane which can be used for the cleaning baths could possibly positively influence the throughput and throughput time.
- Employee allocation
  Normally, two employees work constantly at the pump sets. When changing this number to a maximum of six employees, one can test whether the throughput and throughput time can be improved.

Although it was assumed that the baths in the cleaning train were a bottleneck, the utilization rates showed that they were not the problem. All utilization rates were below 14%, with most of the sections a utilization rate below 3%. This concluded that the baths should be able to handle the increment in the throughput.

After conducting the experiments, the best configurations were taken. These best configurations were compared to the simulation where nothing was changed to the current design, but yet more pump sets were cleaned.

6. Results

In Table 2, one can find the best alternative configurations with their average total waiting time and their average throughput time. All average throughputs were 35 pump sets per year. These configurations can also be compared to the situation where nothing is changed on the cleaning train and the inflow is increased. In this situation, an average throughput time of approximately 22 days can be found. Comparing this to the outcomes in Table 2 shows that improvements can be made.

TABLE 2: OVERVIEW OF THE BEST CONFIGURATIONS USING A 95% CONFIDENCE INTERVAL.

	Constant inflow	**Three cranes, four employees**	**Three cranes, three employees**	**Two cranes, three employees**	**Three cranes, two employees**
Average total waiting time	08:05:18:58 ± 00:01:00:58	09:21:20:04 ± 00:00:59:48	11:06:03:49 ± 00:01:04:58	12:05:04:59 ± 00:01:01:12	14:17:44:18 ± 00:00:57:52
Average throughput time	12:00:41:59 ± 00:01:07:18	13:16:35:50 ± 00:01:09:37	15:01:27:21 ± 00:01:10:20	16:00:29:48 ± 00:01:05:50	18:13:18:55 ± 00:01:06:00

If one can change the inflow of the pump sets, the best option would be to get a constant inflow. In this way, no adjustments to the current situation are needed leading to no extra costs. An average throughput time of approximately twelve days can be seen with this option, which is below the maximum of two weeks.

If the inflow of the pump sets cannot be changed, one needs to look how strict the requirements are. When the average throughput time of maximum two weeks is a hard requirement, then one should choose to add a crane and two employees to the current situation. With this configuration, an average throughput time of approximately thirteen days can be achieved. This configuration also has the highest annual profit of €225.500 when looking at the cost and benefits analysis.

When the inflow cannot be changed and the average throughput time of maximum two weeks is not a hard requirement, then two other options are available which have lower costs per year compared to the last configuration. These options involve less change to the current situation, but the average throughput time is larger than two weeks. When a crane and one employee are added to the current situation, the average throughput time will be approximately fifteen days. When only an extra employee is added to the current situation, then an average throughput time of approximately sixteen days can be found. Depending on how much Company X wants to deviate from the maximum of two weeks, a choice can be made.

Finally, when the inflow cannot be changed and extra employees are not available, then an extra crane can be added to the current situation. With this configuration, an average throughput time of approximately eighteen days is found. Although this is an improvement compared to the configuration where nothing is changed, the maximum average throughput time of two weeks is not met.

To check whether one of the configurations is more sensitive to changes than others, a sensitivity analysis is done. The sensitivity analysis showed that three out of the five configurations are not sensitive to changes in the processing time distribution, but two of the configurations are. These are the configurations with the constant inflow and the configuration with three cranes and two employees. Although the change in distribution resulted in better outcomes, it is not guaranteed that this will also be true when other distributions are used.

7. Conclusion and recommendations

So, when answering the research question, the best design would be to include three cranes at the cleaning train and to have four employees working constantly on the pump sets. This configuration has the highest annual profit and is known to not be sensitive to changes in the processing time distribution. This does however require a significant investment of buying an extra crane and allocation two employees extra to the cleaning train. This means that not only investments on the short term with the crane are needed, but also on the long term by allocating extra employees. Therefore, Company X should look at their requirements and how much they are willing to invest. Next to that, Company X could discuss on the possibilities to create a more constant inflow of the pump sets. Although the results for the configuration with the constant inflow are sensitive to the processing times, it is likely that this can improve the average throughput time compared to the situation where nothing is changed at relatively low costs.

References

Company X. (2010). *User manual Cleaning Train*.

Law, A. M. (2015). *Simulation modeling and analysis* (5th ed.). Mcgraw-Hill Education. https://doi.org/10.1201/9781315183176