



**TALLINN UNIVERSITY OF TECHNOLOGY**  
SCHOOL OF ENGINEERING  
Department of Mechanical and Industrial Engineering

**AN AUTOMATED SOLUTION FOR  
COMMUNICATION AND PRODUCTION PLANNING  
OPTIMISATION UNDER COVID-19 CONDITION**

**AUTOMAATNE LAHENDUS KOMMUNIKATSIOONI JA  
TOOTMISE PLANEERIMISE OPTIMEERIMISEKS COVID-  
19 TINGIMUSTES**

MASTER THESIS

Üliõpilane: Abdullah BESTIL

Üliõpilaskood: 177271MARM

Juhendaja: Eduard Ševtšenko, Senior Researcher

Tallinn 2020



## **Non-exclusive Licence for Publication and Reproduction of Graduation Thesis<sup>1</sup>**

I Abdullah BESTIL (date of birth: 25.01.1990)  
hereby

1. grant Tallinn University of Technology (TalTech) a non-exclusive license for my thesis

An automated solution for communication and production planning optimisation under  
COVID-19 condition

supervised by

Eduard Ševtšenko

1.1 reproduced for the purposes of preservation and electronic publication, incl. to be  
entered in the digital collection of TalTech library until expiry of the term of  
copyright;

1.2 published via the web of TalTech, incl. to be entered in the digital collection of  
TalTech library until expiry of the term of copyright.

1.3 I am aware that the author also retains the rights specified in clause 1 of this  
license.

2. I confirm that granting the non-exclusive license does not infringe third persons'  
intellectual property rights, the rights arising from the Personal Data Protection Act or  
rights arising from other legislation.

---

<sup>1</sup> *Non-exclusive Licence for Publication and Reproduction of Graduation Thesis is not valid during the validity period of restriction on access, except the university`s right to reproduce the thesis only for preservation purposes.*

\_\_\_\_\_ (signature)

25.05.2020 (date)

**Department of Mechanical and Industrial Engineering**

**THESIS TASK**

**Student:** Abdullah BESTIL 177271MARM

Study programme, Industrial Engineering and Management (MARM)

main speciality: Analyst, Developer

Supervisor(s): Senior Researcher, Eduard Ševtšenko, +372 55655085

Consultants: Ismail Dilek, Production Planning Manager

Sedar Electronic, +90 5345434584

**Thesis topic:**

(in English) An automated solution for communication and production planning optimisation under COVID-19 condition

(in Estonian) Automaatne lahendus kommunikatsiooni ja tootmise planeerimise optimeerimiseks COVID-19 tingimustes.

**Thesis main objectives:**

1. Define the business model and needs in production planning department.
2. Design and automated tool to fulfil short-term and medium-term production planning requirements of the company.
3. Analyse the change in communication channels and SMD line utilisation.

**Thesis tasks and time schedule:**

No	Task description	Deadline
1.	Theory research and reviewing	01.03.20
2.	Business model description and tool design	15.04.20
3.	Final reporting	05.05.20

**Language:** English **Deadline for submission of thesis:** "11"May 2020

**Student:** ..... ".....".....201....a  
/signature/

**Supervisor:** ..... ".....".....201....a  
/signature/

**Head of study programme:** ..... ".....".....201.a  
/signature/

## CONTENTS

PREFACE .....	6
List of abbreviations and symbols .....	7
INTRODUCTION.....	8
1. METHODOLOGY .....	10
1.1 Literature search .....	10
1.2 Business model .....	11
1.2.1 Medium-term planning.....	14
1.2.2 Short-term planning .....	16
1.3 Alternative solutions.....	17
1.4 Problem analysis.....	18
1.4.1 Medium-term planning.....	18
1.4.2 Short-term planning .....	21
2. SOLUTION DEVELOPMENT.....	24
2.1 Parts of the system .....	25
2.1.1 "New Items" file .....	25
2.1.2 "Database" file.....	27
2.1.3 "SEDAR ELECTRONIC Planning Tool" file.....	27
2.2 Solution functionalities .....	33
2.2.1 Medium term solution .....	34
Adding a po on the tool .....	34
Accepting a po request on the tool.....	35
Changing a po on the tool.....	37
Deleting a po on the tool .....	38
2.2.2 Short term solution .....	41
3. ANALYSIS .....	46
3.1 Medium-term analysis .....	46
3.2 Short-term analysis.....	51
4. SUMMARY (IN ENGLISH).....	55
5. SUMMARY (IN ESTONIAN).....	56
LIST OF REFERENCES .....	57
APPENDICES .....	60

## **PREFACE**

After several discussions, Sedar Electronic initiated a project to automate communication between production preparation department and production planning department and optimising production planning.

The author would like to thank Sedar Electronic Production Planning Manager Ismail Dilek and the whole planning department for all their time spent on several meetings and for their help to collect sample data and analyse processes. With their help, the author succeeded to analyse processes and point out the bottlenecks and time-consuming activities. The author also would like to thank my supervisor, Eduard Ševtšenko, for his advises and help to finalise author's ideas about the design of the tool functionalities and processes. The tool developed by author in MS Excel Visual Basic for Applications (VBA) language.

The thesis covers two main topics; automating communication between planning departments and optimising production planning for short-term.

Keywords: automated communication, production planning optimisation, COVID-19 pandemic, MS excel VBA, process analysis

## **List of abbreviations and symbols**

MS Excel: Microsoft Excel

PCB: Printed Circuit Board

PO: Production order

PP: Production Planner

PPO: Production Preparation Officer

SMD: Surface Mount Device

SMT: Surface Mount Technology

TALTECH: Tallinn University of Technology

VBA: Visual Basic for Applications

## **INTRODUCTION**

E-mail is generally the primary communication tool between departments and within the departments in big companies. Miscommunication and slow speed in communication is generally a big problem. It becomes a source of inefficiency and sub-optimal performance. On the other hand, interdepartmental misunderstandings due to manual communication are often underrated.[13] Nowadays, with the COVID-19 pandemic, the importance of on-time and correct communication increased enormously.

The decreased need for e-mail and face to face communication between departments and within departments speeds up the processes and it is much safer especially during the pandemic processes. Automating communication also minimises the chance of human errors. Besides automating communication, automating a complex algorithm to the optimisation of production planning will be an epochal change in companies' planning approaches.

Firstly, during the meetings it was evident that the company also has the main problems of manual communication like; describing the requirements of a production order (PO), changing a PO and cancelling a PO takes too much time. On the other hand, manual communication creates risks of human errors. During the COVID-19 pandemic process, Turkey has several partial-lockdowns and complete lockdowns, and this increased the risk of having problems because of manual communication channels. Slow speed and low accuracy of the communication and the health risks of face to face communication are the main problems. Secondly, another major challenge is that, the company has to assign POs to Surface Mount Device (SMD) lines for short term planning. Production preparation officers (PPO) are sending their PO related requests, and PPs are accepting if the requested PO fits the requirements or refusing if not. Then they are scheduling POs to SMD lines. The problem with the current process is that, it takes too much time to prepare the schedule and it takes even more time to change it with PO related changes. Lockdowns of COVID-19 pandemic, machine brake-downs, maintenance and some other reasons are the reason of these changes. Different SMD lines have different specifications and capacities. There are lists of products that these SMD lines can produce. PPOs are asking PP to reserve capacity for a PO on an SMD line, and when PPs are accepting these requests, this is giving company a non-optimal solution to use as a branch node in Branch and Bound tree of our integer optimisation model.[23] So, assigning the POs to these SMD lines in the frozen production plan is becoming a critical optimisation problem since the company is in a growing trend, even they are entirely new in Surface Mount Technology (SMT) business.

The purpose of the thesis is to analyse the current communication processes and move them to a tool to improve, speed up and automate them and decrease number of e-mails send between planning departments. Another purpose of the thesis is to automate, optimising POs and scheduling them to SMD lines and increase utilisation of SMD lines.

There are various reasons why the author built the tool in MS Excel environment with VBA language. One reason is that developing an Excel tool with its built-in programming language VBA is that it can be used also by users without programming background. Due to fast-changing business needs because of like COVID-19 pandemic effect, speed is crucial. The company required this kind of tool urgently. Another reason is that this tool is using another Excel workbook as the database which is located in the company's local servers in the current case. Still, it is possible to map the database to a shared online worksheet or a cloud server so outside stakeholders can use it for other processes. For example, the automated communication module can be used to receive purchase orders from customers. Finally, it is expected to build a customised tool since none of the ready-made tools can answer the company-specific requirements. Any of the ready solutions will also require some adjustments, and it thought that having the company's software tool will be a good investment since these processes can change and be improved.

There are five main parts in this thesis; introduction, methodology, solution development, analysis and summary.

# **1. METHODOLOGY**

To solve the focused problems described in previous chapter, methodology is described next. The structure of the thesis process will start with trying to understand the main problems of the current communication processes. Firstly, to find theoretical solutions and see others' ideas and solution methodologies, literature is searched. Secondly, after having some idea about possible solutions and methodologies it was required to analyse and map current processes of business model of the company. Thirdly, alternative software for applying the solutions are examined. Finally, problems are analysed in detail.

An MS Excel tool will be developed to solve speed and accuracy problems and reduce the risks of COVID-19 pandemic. Then an optimization module will be developed to schedule POs to SMD lines and provide a decision support tool for PPs. Validating the tool and processes will be the next. Finally, communication speed, data accuracy, number of e-mails send between departments and utilization of SMD lines will be analysed.

## **1.1 Literature search**

While doing the literature search, the focus was on to find similar solutions and cases about improving communication between departments. There are similar researches in the area and some of the solutions found to be applicable to the current situation.

Ammenwerth et al. develop a new device to improve and ease communication in a hospital for clinic doctors and nurses to facilitate information access, eliminate double documentation and to improve efficiency in the long run. [2] In this research, they acknowledge a result that speed is as important as the functionalities for this kind of new communication solutions to ensure practicality. Panento and Molina are exploring the latest trends about information and communication technologies that allow manufacturing enterprises to be more information driven environment. [10] They are analysing the significant problems that remain between the manufacturing job floor and corporate level concerning communication interfaces. Sarka compares different communication tools that are being used to share information internally. It is analysed and found that face to face communication is widely used in enterprises because it is known as a communication tool which builds trust most and enables to get instant feedback. [4] IT is also expressed in the research that the speed of communication is also very effective on selection. Mladkova states in his research as; "knowledge

management is a conscious activity which results in the situation when the right knowledge is possessed by right people at the right time". [5] Probst et al. add in their research: „It is vital that knowledge should be shared and distributed within an organisation so that isolated information or experience can be used by the whole company. The key question is: Who needs to know (or be able to do) how much of what, and how can we facilitate knowledge sharing?“ [6] All this literature shows us the importance of sharing the right information with the right people with the right tool.

Chanda presented an integer programming optimisation study done to improve scheduling in the mining business. [7] In this paper, they applied a computerised model for short-term production scheduling. Martinez and Newman present a mixed-integer programming solution to optimise short-term and long-term scheduling of production at LKAB's Kiruna mine located in Sweden. [8] Their model is to minimise deviations from monthly pre-arranged production quantities with consideration of the business' operational constraints. As a similar work done by Newman et al., which is a literature review work about the usage of optimisation and simulation power for planning problems of long and short-term production scheduling and equipment selection. [9]

Rohrer is expressing the importance of visualisation in simulation technology. [3] He reveals that in today's world, it can't be imagined a simulation without some kind of visualisation to help the user to communicate the results and understand the model's behaviour better.

## **1.2 Business model**

Sedar Electronic (hereinafter referred to as 'company') is a family business founded in 1964 with the aim of producing the first national radio. Today the company is specialised in electronic component sales, SMT and electronic product assembly. Company is committed to having the best customer satisfaction in the sector by providing on-time service. To achieve their goal, they are investing in smart manufacturing and IT solutions to catch up with the latest technology and to have their business on top.

Company is relatively new in SMT business, but over the last year, the demand has increased significantly, which led the company couple of new challenges to be solved. The company currently has 5 SMD lines. They are providing electronic component mounting service on Printed Circuit Boards (PCB). Customer is any company that is producing an electronic board from various sectors like agriculture machine producers, crane producers, lighting equipment producers, remote control producers and many

other industries. They have many big customers who have too many different products. There are products that the company is regularly producing but due to the fast technological developments and changes happening in every products' electronic boards, they also have a big number of new products in their list too.

SMD machines are relatively high-speed robotic machines that have feeders for electronic components. The head collects a various number of components at a time and then places them on the PCB. [Figure 1] This process can take several times based on the number of components and the number of different components on the board. Processing the same board multiple times is not the desired solution. Instead of processing the same board for the second time, the company prefer to process it in bigger machines recently added to the company's facility. These machines can mount capacitors, resistors, small integrated circuits and some other components.[Figure 2] company also has manual quality controls to check the final quality of PCBs, solders, components and general quality of the PCB.

There are various types of SMD machines; single head and double head; the various number of feeders, the capacity of feeders, the maximum size for PCB loading, head nozzle capacity etc. [Figure 3] These differences are limiting the set of products that each SMD machine can produce.

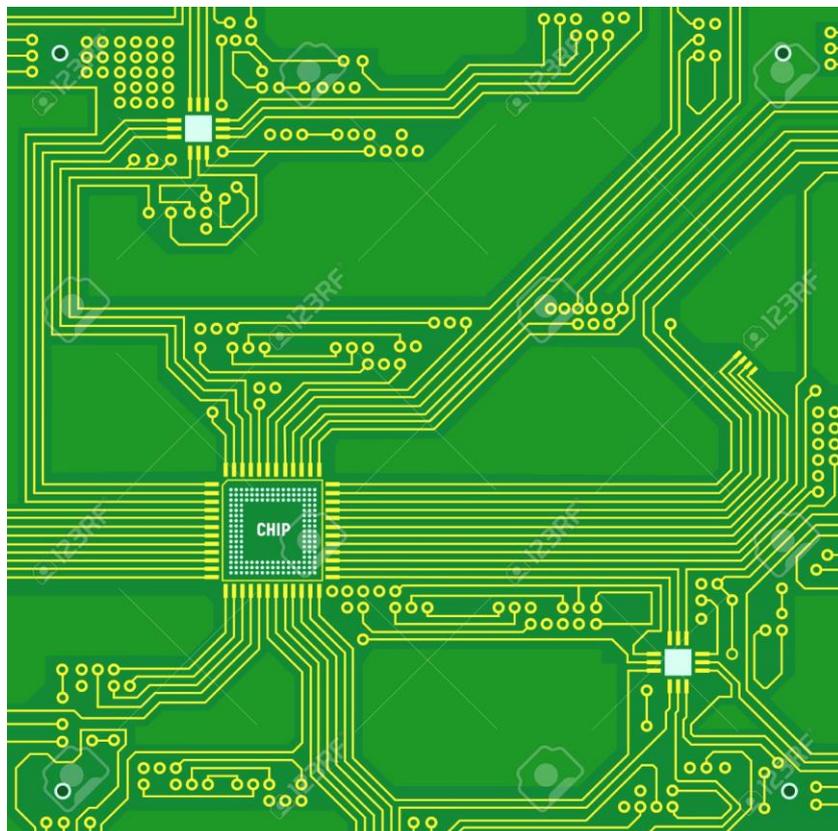


Figure 1 Example of an Empty PCB Board

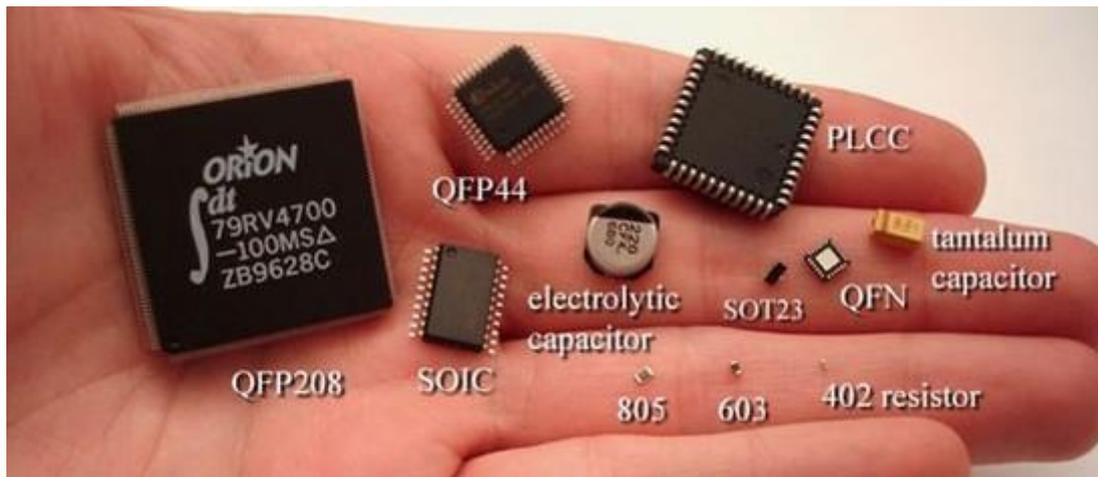


Figure 2 Different Components



Figure 3 Different SMD Machines

With COVID-19 pandemic some challenges that the company was trying to achieve become real problems. During the pandemic, most of the office workers needed to work from home in Turkey. There were several rules and changes in these rules during the pandemic process. Firstly, it was prohibited for people older than 65 years to go out, then for people younger than 20 years old. Although there were exceptions for some

sectors and for people who applies with valid reasons, there were complete lockdowns too. Most importantly, these rules sometimes announced with short notice. At the beginning of the process, the company decided to have half of the office employees work from home, and later they enlarged the scope and let all their office employees work from home until further notice.

Working from home brought some problems together to be solved like; communication within the department, communication between departments, increased human errors due to the lack of manual controls on job floor and decreased utilisation on SMD lines because of poor planning.

Company has an open communication culture; they share information with Excel files in departments and between departments daily, weekly and monthly. They are keeping most of the regular reports on Excel Workbooks which eases the integration of my tool with the existing system.

To understand the current way of working on processes, the author needed to investigate it into two parts; medium-term time frame and short-term time frame. There were different problems to be solved in these two different planning horizons.

### **1.2.1 Medium-term planning**

Production Preparation Officers (PPO) are in close contact with salespeople, and they are planning the production orders (PO) concerning customer orders. They generally have a time-window of two weeks in medium-term where they request the POs from production planning. Adding a PO request in the last minute is creating a big hassle in the company since it requires a lot of manual communication and approvals. PPOs sit together with Production Planners (PP) and try to find a time slot in the lines for the requested PO because each build has a different variable set. Secondly, describing a change in one of these variables to PPs can be crucial for customer satisfaction. Still, it also becomes quite hard even if the time slot or SMD line is not changing because whole communication performed manually. Thirdly, there can be decreases in online capacities because of various reasons. With the new tool, PPs can adjust the capacities of the lines dynamically whenever they have information that results in a decrease in capacity. Capacity changes can be seen by any PPO after PPs implement it to the tool.

There are around 10 PPOs with the responsibility of planning POs based on customer orders. They learn the variable set of POs from salespeople. They are also responsible

for the material drive for their POs, so they are like a link between sales, purchasing and production planning.

Whenever salespeople send a request to PPOs, they are controlling material availability to ensure that material drive will be enough. Later, with the current process, they are getting into contact with PPs and trying to get information; which line would be suitable for the specific PO, what are the appropriate time slots of that line considered to capacity and which shift can produce this product. [Figure 4]

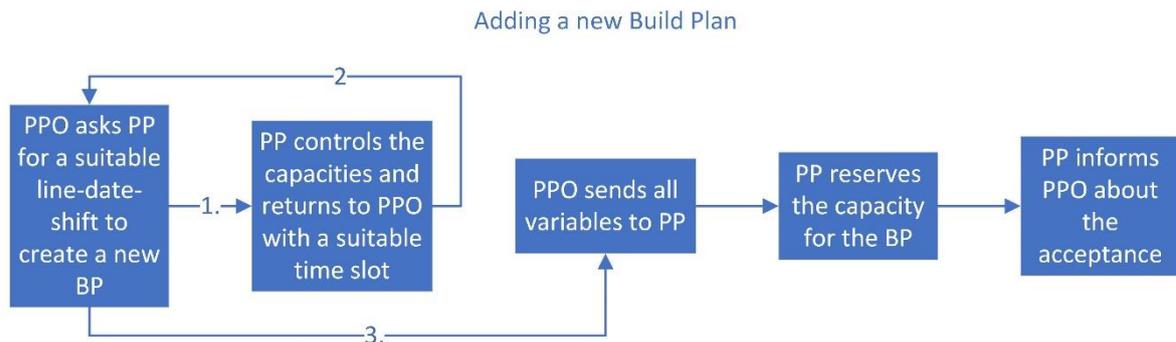


Figure 4 Current Process - Adding a PO (AS-IS)

If the PO needs to be created in the short-time window, then they get in to contact with the PPs face to face or via e-mail.

PPOs need to repeat this process if any of the variables needs a change because of customer request or any other reason. It is harder if PPO want to change the date of the build due to deadlines and it is easier if they want to change non-essential variables. [Figure 5] Essential and non-essential variables are going to be explained below.

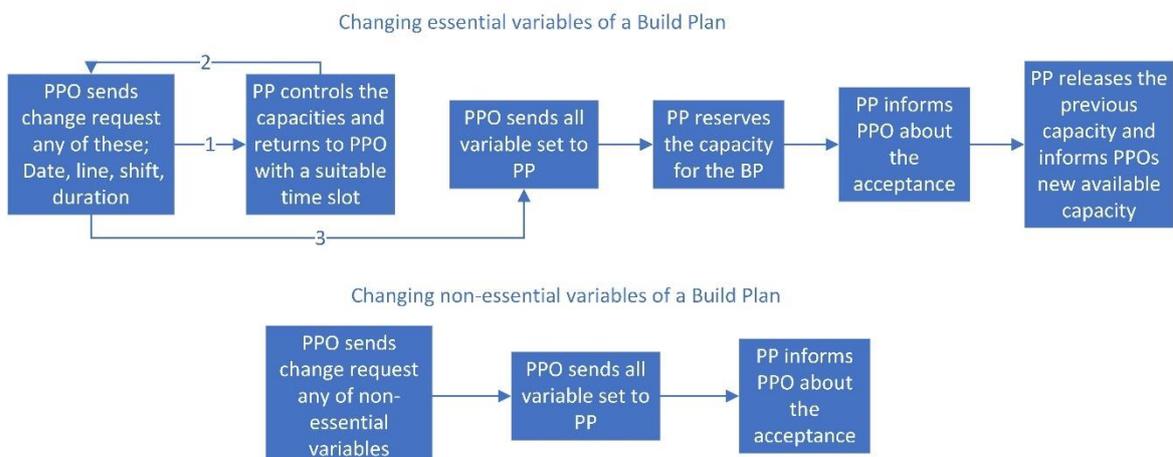


Figure 5 Current Process - Changing a PO (AS-IS)

Essential variables in a PO are; date, line, shift and duration and the others; the number of components, PCB size, company code and quantity are non-essential. Essential variables are designed to give PPOs ability to reserve capacity on a specific line on a specific time for a duration way before when they don't have all the details about the order. So essential variables are must for reserving a capacity but not enough to define a PO.

Comparatively easier than adding or changing a PO, deleting a PO also requires getting into contact with PP. When PPO want to delete a PO, they are sending the full variable set to PP and ask them to delete it. [Figure 6]



Figure 6 Current Process - Deleting a PO (AS-IS)

### 1.2.2 Short-term planning

PPs are in charge of assigning the POs on SMD lines. They are working together with production Engineers on job floor who knows about the machines' capabilities, maintenance and repair schedules. They are also receiving information from labour planning since during the pandemic they had to stop production on up-to two lines due to lack of production workers on some days.

PPs are assigning POs to SMD lines after they received all information from job floor about capacities and labour capacity from labour planning. They are using an excel file to schedule them and sharing information with PPOs whenever they changed the plan in the next two days, which is the frozen planning period. The changes happen due to capacity changes or urgent orders, mostly.

Before the developed tool, they were assigning POs to SMD line based on their experience with considering line operating costs. Each production line has a different operating cost per hour. SMD-1 and SMD-2 have similar costs are the lowest amongst others. SMD-3 and SMD-4 have higher costs than SMD-1 and SMD-2 but identical to each other and SMD-5 has the highest operating cost. This operating cost includes direct

costs; energy consumption, labour cost and indirect costs; general overhead cost to run the whole factory and depreciation of plant and machinery. [15 - 16] These costs will be used to calculate the machinery cost index for optimisation model.

### **1.3 Alternative solutions**

For the problems that we are going to solve, a tool can be developed with many different methods, languages and software. There are also some ready-made products on the market. In this part, all these alternatives will be listed and discussed their advantages and disadvantages.

Firstly, the company didn't want to use a ready-made solution because of the low capacity to customise it, questions about data security and expensive for future improvements. For the communication part, the functionalities don't require some data science solution, actually the functionalities are quite basic communication functionalities but still they are quite company specific. Columns, charts, different tables need to be adjusted with company's requirements. In long term, in case of company wants to improve this tool, they will be dependent to the bought tool. Especially on the optimisation part, a lot of changes and improvements may be necessary, and dependency to an outsourced software won't be preferred by the company.

Secondly, due to the COVID-19 pandemic process, company needs are urgent requirements. Both communication module and the optimisation module required urgently because of changed conditions of pandemic. Developing an Excel tool was a much faster solution than any other alternative.

Thirdly, company won't have an integration problem with and Excel tool since they used to use Excel files everywhere. Developing the tool with another language can be an option but in that case the development phase will be slower and extra effort will be necessary to export data to Excel user-interface.

In the market, web-based solutions and desktop applications are being used commonly. A web-based solution is not accepted by the company because of security concerns. For security of the data, more time and money need to be invested but in our case, to solve the problems an internal tool which is not communication through web can be enough. To summaries, a web-based solution will be expensive and not secure perfectly and more importantly, it will be unnecessary. A desktop application can be the strongest alternative to Excel based tool. Desktop applications also can be used internally without

communication through web, but still it also has a disadvantage which is that, it will be extra work to develop the exporting data to Excel part.

To summaries, Excel solution looks like the most advantageous solution since, it will be fast to develop, it will communicate internally and integrating with other Excel files won't require extra effort.

## **1.4 Problem analysis**

In this part, the author will show the problematic and inefficient processes of the current system. Although some many exemptions and details are complicating creating generalised solutions, there are possibilities to set new rules and processes on current ways of workings which can increase efficiency and solve big problems. Author will analyse the problems also in two parts for different time frames.

### **1.4.1 Medium-term planning**

There are multiple problems that manual communication causes. Alarcon and Calderon state that poor management of the information flow, lack of communication and transparency between departments are one of the main reasons that prevent continuous improvement in the organisation.[11] As Sahno, Shevtshenko and Zahharov state in their research that companies should satisfy their customers to survive in the competitive market conditions.[12] It is not only about the time it takes, but it is also about the data accuracy problem due to manual communication. When people share information face to face or even with e-mail, there can be cases like entering wrong values, forgetting to update the variable with the latest value or missing an e-mail etc. If we discover the problems in detail, all of them are possible to be eliminated with an Excel tool.

Firstly, when people can't work because they get sick or because of any other reasons, all e-mails they got from salespeople, PPOs or PPs are stuck in their e-mailboxes, and the information becomes unreachable. It sometimes also creates crisis because it takes time until the sender realises that the person is not working, and their e-mails weren't forwarded. During COVID-19 pandemic, it happened quite common because of last-minute announcements, and also, some officers didn't have had their laptops with them at home when they needed to stay at home.

Secondly, in normal conditions, it is PPOs' responsibility to know which line is suitable for the PO. Still, due to low speed of information change, responsibility is generally accumulating on PPs because anyways PPs are changing the whole production plan in case of last-minute changes. For example; if the capacity has decreased for a specific line on a particular day. Usually, PPs should inform PPOs and, PPOs should change the requested PO to a different date, line, or shift but sometimes this takes too much time, or the change can happen in the last minute. PP makes the changes on behalf of PPO to have a solid plan on time.

In some cases, some PPOs just ignore the capacity decrease e-mails and asks PP to set a PO on that specific line, so again, it takes more time for PP to inform PPO to change the line and send the PO back than just changing it by themselves. Below on Figure 7, both how the process should go and how it goes can be seen. This situation accumulates the responsibility of PPs, which is not the agreed way of distributing responsibilities.

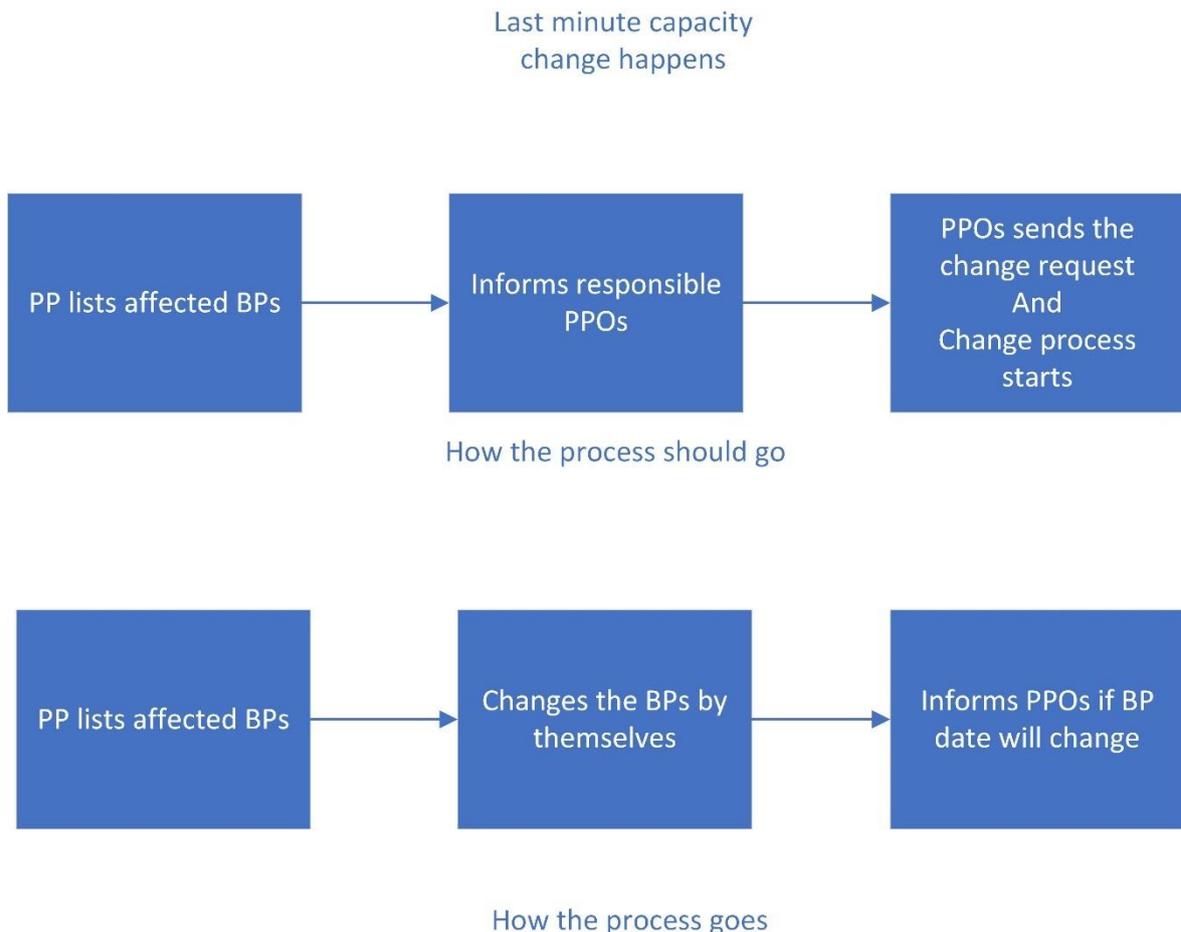


Figure 7 How last-minute changes go (AS-IS)

Thirdly, there are many reasons why a PO may need a change in the last two days before it will be built. These changes can be originated by the customer, or it can be capacity related. PPOs and surprisingly PPs prefer to communicate face to face if the change happens in the frozen production horizon, which is generally two days. This type of communication is very time-consuming mostly for the PPs and for also PPOs.

Fourthly, PPOs needs to start a new conversation about a PO if they want to change any of the 9 variables. As explained above it is getting more complicated if the change needs to happen with essential variables. It is still frustrating with non-essential variables because they need to inform PP for any small change not to create any confusion and even worse not to end up with the wrong production. For example, if PPO entered Company code wrong at first and want to change it, they need to send a separate e-mail for this which doesn't have a direct impact on production but still needs to be corrected to prevent confusion on a production level. This is creating a big e-mail traffic. Actually, most of these e-mails are being sent to update a PO way before than frozen planning time. The important point is, any update e-mail is adding an information on top of the previous e-mails, means that all e-mails are like a chain but when PO date reaches to frozen planning horizon, PP needs to review all e-mails, all links in the chain, but actually, only the last link is important for them, all the previous links are just waste of time for them. Every time it costs 4 e-mails to add a PO, 4 e-mails to change an essential variable, 2 e-mails to change a non-essential variable and 1 e-mail to delete a PO. Sometimes the change loop happens a couple of times. [Figure 8] As an example, if the PO was created with a variable set of "ABCDEFGH" where each letter represents a variable of PO. Then PPO wants to change 1 essential variable "KBCDEFGH" and the total e-mail sent will be 8 at this point. As a second move they want to change a non-essential variable "KBCDEFGL" and total e-mail sent will be 10. In this scenario we had 1 essential and 1 non-essential variable changes and costs 10 e-mails, but for PP, only the last version matters, which is "KBCDEFGL" because it is going to be produced. Number of e-mails sometimes much higher than 10 for a single PO.

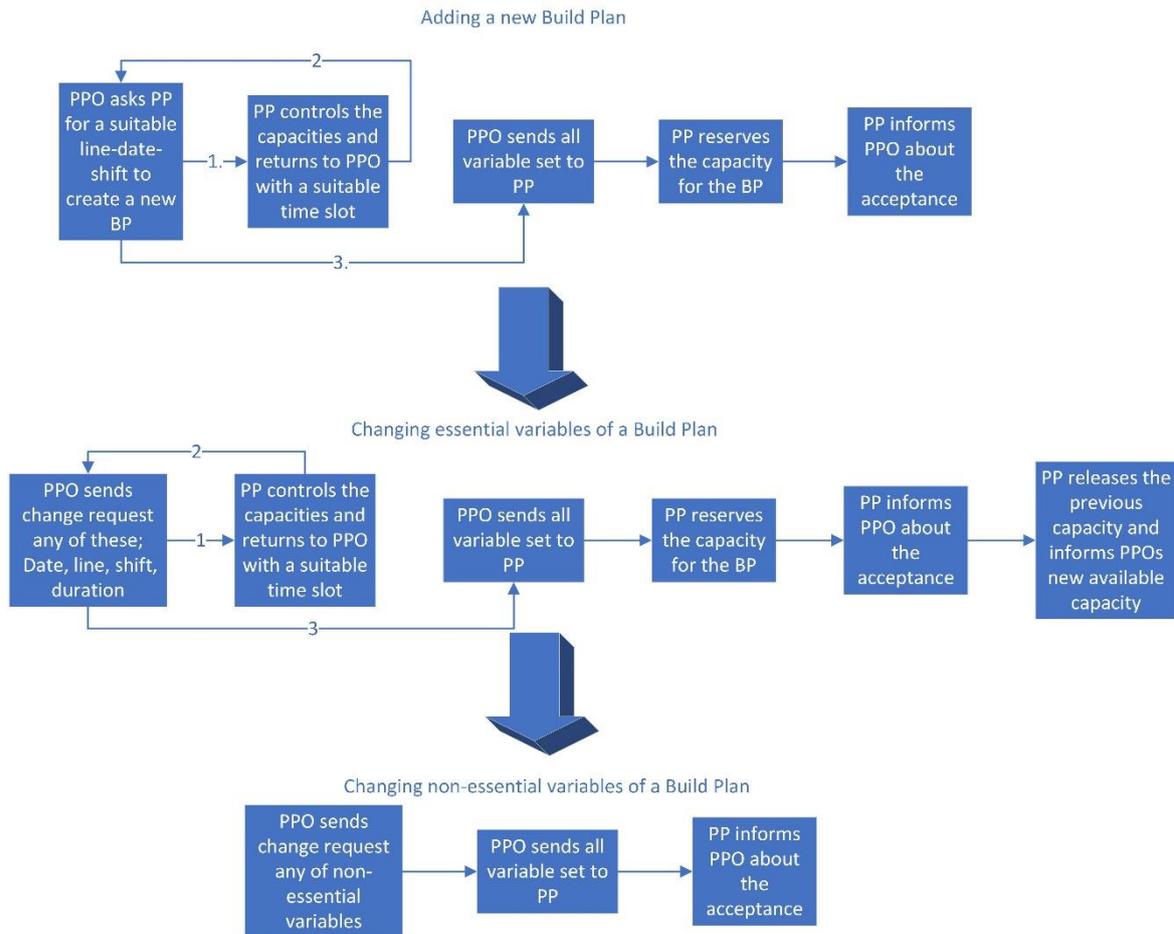


Figure 8 Current e-mail traffic (AS-IS)

As it can be seen from current process flows, there are many manual e-mail loops between PPOs and PPs which needs to be eliminated to fasten the processes and to decrease human mistakes.

### 1.4.2 Short-term planning

Currently, there is a lack of optimisation tool for production planning. Besides an optimisation tool, there is also a need for a visualisation tool.

Firstly, PPs are receiving labour capacity and SMD line capacity change information by e-mail in charts weekly and ad-hoc changes can be by e-mail or by calls. PPs are sharing these capacity changes with PPOs but informing PPOs for urgent changes and waiting them to change their POs is not very practical since waiting action from 10 different PPOs is a very time consuming process. The problem is, for last minute changes PPs are making the necessary changes. This brings two problems; PPs are getting overloaded with extra work and exhausted with extra stress and they can end up with

a delayed production which has a critical deadline and important to be produced on the first asked date but PP scheduled it to another day due to capacity decrease because they don't have all information about the sales order. According to the research done by Hadidi and Al-Turki, easing information sharing between departments increases efficiency and reduces operational cost for any production system. [17]

Secondly, PPs are assigning POs manually. They are preparing a plan for the next 2 days and changing the plan with every single change that affects frozen production plan. Even the first plan is not an optimal solution, but it is getting worse with every single change because not much space left for making changes and focusing on producing every POs. So, an automated optimisation model will be a perfect decision support tool for last minute changes since optimisation model will consider all constraints and try to maximise the objective function and it runs in a very small amount of time.

Finally, as mentioned above, PPs can focus on producing every POs on the requested date and shift and may not consider costs. Different SMD lines has different costs which needs to be considered while planning. It is understandable that the company focus is on delivering every order on time which should be kept in the objective function of optimisation model but still cost should be also in the objective function which is being ignored in manual flow time to time.

Structure is visualized with the help of DMAIC approach. For further developments, the company can follow the same structure. New solution will be next as-is.

DMAIC based framework for production planning process improvement can be seen in Figure 9. Author used DMAIC [1] to build the structure of the thesis. During AS-IS part author used business process mapping and analysis to define the company's current processes and problems, for TO-BE part author used business process mapping and analysis and constraint-based integer programming optimisation to optimise the production orders that are requested by PPOs as a decision support tool. For further improvements of planning and communication processes, the company can use continuous process improvement and the same structure where current developments will be the next AS-IS.

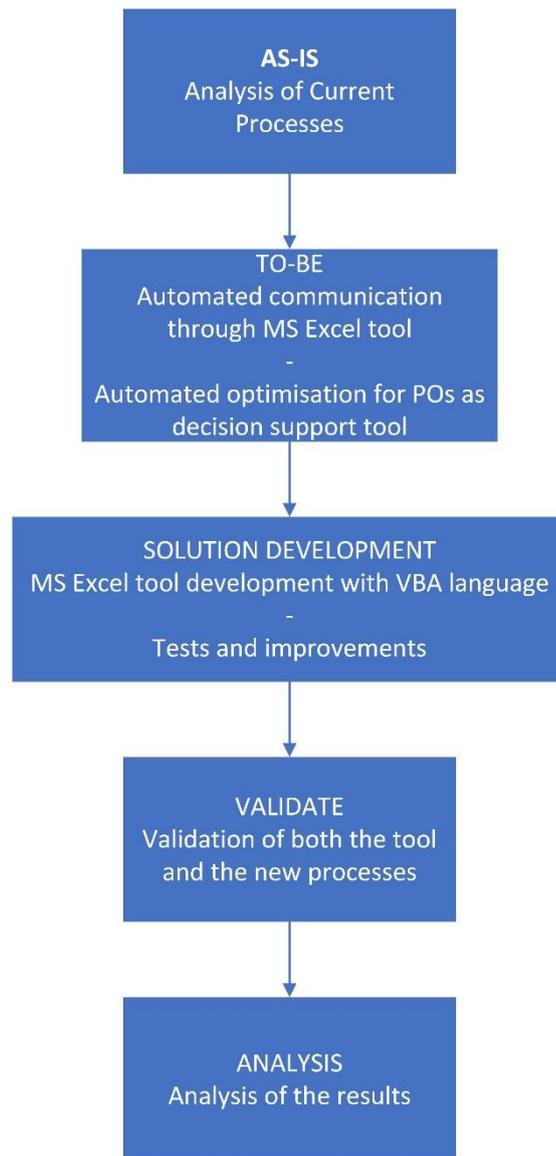


Figure 9 DMAIC Structure

## 2. SOLUTION DEVELOPMENT

I named the tool as Planning Tool since it provides solutions to various problems with medium-term and short-term problems in production planning. It has many functionalities to perform smoothly and fast enough. Most of the functions are written in a smart way with scalability approach. With this approach, adding or deleting new columns or rows is much easier. It will be shown that, there is a standardised format which is used for every single item and it is scalable. Company can add a new variable for POs or increase number of empty rows for new POs much easier.

Tool is developed with VBA language, one of the most important reasons is that, it enables users to use many Excel worksheet functions in VBA, so it makes it easier to read the code by a non-developer Excel user. It will be easier to modify code in case of small change needs. Excel VBA can use Excel's powerful data processes and visual data exporting features. [18]

There are 3 parts of this tool; "New Items", "Database" and the dashboard file which is called "SEDAR ELECTRONIC Planning Tool". Dashboard file has the companies name on it, but it is the translated version of the actual tool. [Figure 10] Headers, button names and sheet names are translated to English for this thesis and business related data is renamed (names changed, critical numbers are multiplied with random parameters) but the macro code is exactly the same.

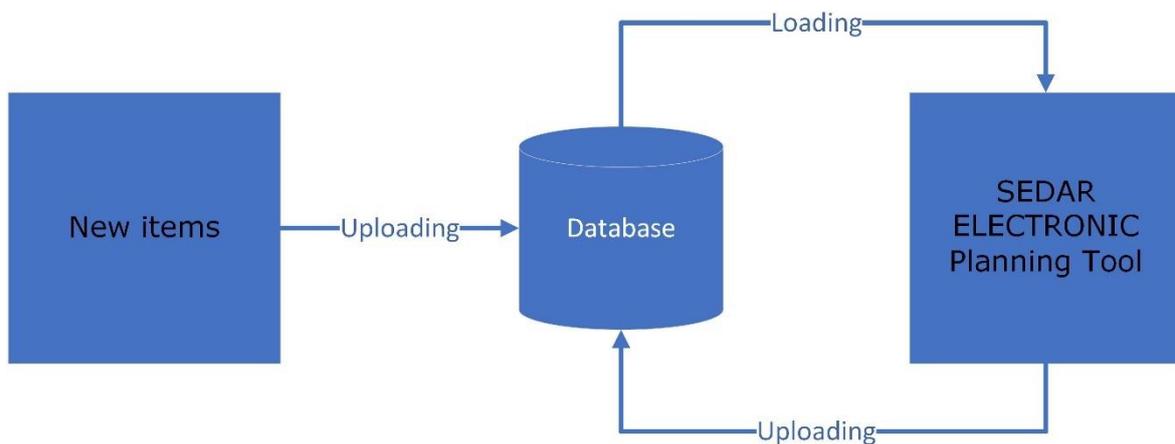


Figure 10 Planning Tool Structure (TO-BE)

Unlike the other chapters of the thesis, I will describe the parts of this tool all together for medium-term and for short-term since they are strongly interrelated to each other with functionalities. Both terms use same sheets and providing each other input data.

## 2.1 Parts of the system

All 3 elements of the system are Excel files. "New Items" and "SEDAR ELECTRONIC Planning Tool" can be used from any folder which has access to the address that "Database" is kept. Database file can be kept in a local server or cloud servers or as another solution it can be addressed to a spreadsheet.

### 2.1.1 "New Items" file

This file is to create new products in the system. The very first step is, creating new products by PPOs under their responsibilities. This step is quite an easy step from PPO point of view. They need to enter 3 variables for each new item that they want to add; PPO (generally their name, but they also can add item with their colloquies name too), item name (they can name it as they want, it is for their personal information, which generally includes company name) and item code. [Figure 11]

	A	B	C
1	Up-Load		
2	PPO	item name	item code
3	PPO-1	8ty double head crane	SVK1564989-4
4	PPO-1	8ty double head (turning) crane	SVK1564989-8
5	PPO-1	black remote 4 buttons	MIVKK104
6	PPO-1	black remote 6 buttons	MIVKK106
7	PPO-1	black remote 8 buttons	MIVKK108
8	PPO-1	LightOU-50012	AAVK50012
9	PPO-1	LightOU-50013	AAVK50013
10	PPO-1	LightOU-50015	AAVK50015
11	PPO-1	LightOU-50010	AAVK50010

Figure 11 Adding a new item (TO-BE)

As the second step PPO needs to click on "Upload to dB" button and the rest will be done by macro automatically. Below it is listed step by step how the macro works;

- It asks the user if they are sure to upload the data to database. It is giving the user a last chance; in case they clicked the button by mistake. This functionality is placed under every button in the tool.
- Then a module is called to speeds up the macro by not updating user interface until the run completes, means all calculations happen in the background. [Figure 12]

```

Sub DisableVisualUpdates ()
    Application.Calculation = xlCalculationManual
    Application.ScreenUpdating = False
    Application.EnableEvents = False
End Sub

```

Figure 12 Disable user interface updates VBA Module

- It opens the "Database" file and transfers the items to database by considering PPO name changes and item name changes.
- "New items" file uploads items to database in a standardised format. Every item will have the same columns for same variable set. Every item will also have same number of rows for PO creation. The standardised format has 13 columns and 5 rows. [ Figure 13] But as explained in previous chapters, with the help of scalable code in the background, this standardised format can be modified very easy by user.

	Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time lenght	Number of Components	PCB Size	Company Code	Quantity
2													
3		PPO-2	konya enerj t	XAC-A211			Day						
4		PPO-2	konya enerj t	XAC-A211			Day						
5		PPO-2	konya enerj t	XAC-A211			Day						
6		PPO-2	konya enerj t	XAC-A211			Day						
7		PPO-2	konya enerj t	XAC-A211			Day						

Figure 13 Standardised format (TO-BE)

- This macro ends after saving and closing the database and reversing back the user interface settings by enabling user interface updates. [Figure 14]

```

Sub EnableVisualUpdates ()
    Application.Calculation = xlCalculationAutomatic
    Application.ScreenUpdating = True
    Application.EnableEvents = True
End Sub

```

Figure 14 Enable user interface updates VBA Module

### 2.1.2 "Database" file

Database file is in the centre to store all the data of this process. New products will be sent to this file and they will be kept in a standard 'format'. There are 9 sheets in this file; 'new items', 'old items', 'production orders', 'last update', 'standardised', 'line capacity' and 'PO add-change-delete'. [Figure 15]



Figure 15 Database sheets

'New items' and 'old items' sheets are to keep the items list sent from "New Items" file. They are for tracking items list if there is a new item added to the list. 'production order' sheet is the main sheet to keep all products in standardised format. In 'last update' sheet, we are keeping the latest version of the tool and also a number to give all new POs a unique number. Keeping the latest version of the tool in database is important because every PPO will copy the tool to their laptops which will send and receive data from database, we need to be sure that everybody is using the latest version of the tool otherwise they can ruin the database because of a structural changes in their out-dated tool. With this version control we can be sure that non of the users can continue using the old version when we release a new version because of functionality change of bug fixes. 'Standardised' sheet is keeping the format. This format also includes drop-down menus which are designed for PO part to limit the PPO while they are adding or changing a PO. 'line capacity' sheet is to keep the capacities of all lines for 2 weeks and for both shifts. There are 4 charts; shift capacity, repair-maintenance, PO Occupation and final capacity which will be explained later. Final sheet is 'PO add-change-delete'. This sheet is to list all added, changed and deleted POs. Whenever a PPO adds, changes or deletes a PO, then it will be listed in this sheet.

### 2.1.3 "SEDAR ELECTRONIC Planning Tool" file

This file is the user interface of the whole system and the most important element of the whole system. All PPOs will have it in their own laptops. They can load data from database and upload their changes to database with this file. All macros are built in this user interface and calculations will use PPOs' laptops' CPU power instead of server's CPU, so there won't be any speed problems when a couple of PPOs will try to use the tool at the same time.

There are 11 sheets in this file, 7 of them will be in daily usage and 4 of them will be hidden which contains input data for calculations. 'production order', 'optimisation results', 'optimise production planning', 'time length', 'item-machine compatibility', 'line capacity' and 'po add-change-delete' are the sheets that PPOs and PPs will use daily. 'optimisation parameters', 'last update', 'name list' and 'temporary\_sheet' are the hidden sheets. [Figure 16] These sheets' functionalities in the system will be explained below.

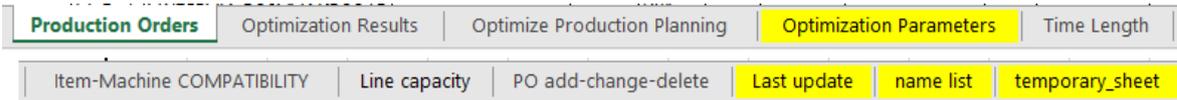


Figure 16 Sheets of Sedar Electronic Planning Tool

'Production order' sheet is the sheet which is going to be used mainly by PPOs daily where they can see company name, PPO name, item name, item code and variables of a PO; PO number, date, shift, line, time length, number of components, PCB size, company code and quantity. There is a drop-down menu [Figure 17] for PPOs to select their name from the list. There are 2 buttons; download and upload. When a PPO selects their name and then clicks on download, macro will list all items under that specific PPO's responsibility from database. PPOs will see all items which are under their responsibility and then they can add new POs to their items to send new PO requests to PPs, they can change an existing PO or delete a PO. After all these changes they need to click on upload button to send all these changes to database. When they upload all data to database, any other PPO and PP can see these data. This fast information exchange flow enables to communicate without any e-mails. General view of the sheet and the variables that a PPO needs to fill when they create a PO, can be sheet in Figure 18.

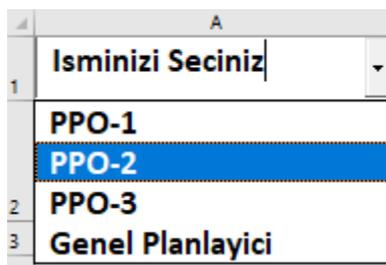


Figure 17 Drop-down menu for PPO names (TO-BE)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Isminizi Seciniz	Downl	Up-Load										
2	Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time length	Number of Components	PCB Size	Company Code	Quantity
3		PPO-1	8ty double head	SVK1564989-4	PO - 10039	01.06.2020	Day	SMD-2	2	23	1		15
4		PPO-1	8ty double head	SVK1564989-4	PO - 10040	02.06.2020	Day	SMD-2	3	23	1		22
5		PPO-1	8ty double head	SVK1564989-4			Day						
6		PPO-1	8ty double head	SVK1564989-4			Day						
7		PPO-1	8ty double head	SVK1564989-4			Day						
8		PPO-1	8ty double head	SVK1564989-8	PO - 10041	01.06.2020	Day	SMD-1	3	20	1		66
9		PPO-1	8ty double head	SVK1564989-8			Day						
10		PPO-1	8ty double head	SVK1564989-8			Day						
11		PPO-1	8ty double head	SVK1564989-8			Day						
12		PPO-1	8ty double head	SVK1564989-8			Day						
13		PPO-1	black remote 4 b	MIVKK104	PO - 10042	01.06.2020	Day	SMD-3	2	42	2		12
14		PPO-1	black remote 4 b	MIVKK104			Day						
15		PPO-1	black remote 4 b	MIVKK104			Day						
16		PPO-1	black remote 4 b	MIVKK104			Day						

Figure 18 General view of 'production orders sheet (TO-BE)

Related to previous sheet, 'name list' sheet is to update the drop-down menu for PPO names. It is going to be updated every time a new PPO joined to the list.

Before explaining Optimisation related sheets, I want to mention other sheets that has functionalities to support PPO when they are filling their PO requests.

'Time length' sheet is to help PPOs to calculate how much time will a PO take for each SMD line. In this sheet they have all the items they are producing and can estimate a production time per item for different SMD lines. They are using an algorithm to estimate these durations but also corrects them by time with actual durations. Number of components on the PCB, PCB size, SMD line speed and specifications have the biggest weights on this duration but there is a stochastic variable on the model that comes mostly from setup time, cleaning time and labour speed as Kallio, Johnson and Nevalainen states in their research. [19] Other than times per item and per SMD line, setup and cleaning times are also kept in this sheet. Once they have all these data, they are calculating the required time length for the PO with a basic function which shown below. [(1)]

$$Total\ time\ length\ (SMD(i),\ item(j)) = ((quantity(j) * time\ per\ item(i, j) + setup\ time(i) + cleaning\ time(i)) * (1 + error\ handling\ percentage)) * machine\_compatibility(i, j) \quad (1)$$

As there is an error handling percentage in the function which is generally between 10 and 20. PPOs are updating these percentages with real data and production engineering feedback but if an item is new for the company or it is a prototype item then this parameter is generally 20 percent. [20] After calculating total required time, we are

rounding them up to give an approximate time for the PPO when they are entering their POs. To clarify, rounded times are for PPOs to enter as the required time to reserve from SMD line capacity when they enter a new PO and the exact times are for optimisation model. This sheet needs to be updated regularly to have a better precision on required times and as a result better production plan optimisation result. General view can be seen in Figure 19.

1	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
2	Item	per item					quantity	Total time length					Rounded time					setup times	SMD-1	SMD-2	SMD-3	SMD-4	SMD-5
3	SVK1564989-4	0.18	0.17	0.00	0.00	0.13	15	3.9	3.8	0.0	0.0	2.8	4.0	4.0	0.0	0.0	3.0	cleaning times	0.35	0.42	0.35	0.3	0.15
4	SVK1564989-8	0.22	0.22	0.15	0.10	0.00	20	5.8	6.0	4.3	3.0	0.0	6.0	7.0	5.0	3.0	0.0						
5	MIVK1104	0.18	0.22	0.00	0.12	0.10	15	3.9	4.7	0.0	2.7	2.2	4.0	5.0	0.0	3.0	3.0						
6	MIVK1106	0.00	0.13	0.13	0.12	0.10	20	0.0	4.0	3.9	3.4	2.8	0.0	5.0	4.0	4.0	3.0						
7	MIVK1108	0.00	0.17	0.10	0.10	0.13	15	0.0	3.8	2.5	2.4	2.8	0.0	4.0	3.0	3.0	3.0						
8	AAVK50012	0.00	0.00	0.00	0.00	0.13	20	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	4.0						
9	AAVK50013	0.00	0.00	0.12	0.15	0.13	15	0.0	0.0	2.8	3.3	2.8	0.0	0.0	3.0	4.0	3.0						
10	AAVK50015	0.15	0.18	0.15	0.00	0.15	20	4.2	5.2	4.3	0.0	4.0	5.0	6.0	5.0	0.0	5.0						
11	AAVK50019	0.00	0.22	0.20	0.10	0.17	10	0.0	3.4	3.1	1.8	2.4	0.0	4.0	4.0	2.0	3.0						
12	PAAVC62003	0.00	0.00	0.00	0.00	0.10	10	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	2.0						
13	AAVC62004	0.00	0.12	0.10	0.15	0.07	10	0.0	2.2	1.9	2.4	1.2	0.0	3.0	2.0	3.0	2.0						
14	P-AAVC62006	0.00	0.00	0.00	0.00	0.12	10	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	2.0						
15	12SVK1564989	0.00	0.00	0.13	0.17	0.13	10	0.0	0.0	2.3	2.6	2.0	0.0	0.0	3.0	3.0	3.0						
16	13SVK15IVKK10	0.18	0.22	0.00	0.13	0.15	10	2.8	3.4	0.0	2.2	2.2	3.0	4.0	0.0	3.0	3.0						
17	53MIVKIVKK10	0.22	0.18	0.17	0.00	0.00	10	3.2	3.0	2.7	0.0	0.0	4.0	4.0	3.0	0.0	0.0						
18	55MIVKIVKK10	0.18	0.18	0.00	0.10	0.13	10	2.8	3.0	0.0	1.8	2.0	3.0	4.0	0.0	2.0	3.0						
19	15MIVKIVK500	0.00	0.18	0.10	0.10	0.10	10	0.0	3.0	1.9	1.8	1.6	0.0	4.0	2.0	2.0	2.0						
20	53PAAVKV500	0.00	0.20	0.20	0.13	0.00	10	0.0	3.2	3.1	2.2	0.0	0.0	4.0	4.0	3.0	0.0						
21	45AAVK5VK500	0.00	0.00	0.00	0.00	0.10	10	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	2.0						
22	22AAVK5VK500	0.00	0.00	0.20	0.13	0.10	10	0.0	0.0	3.1	2.2	1.6	0.0	0.0	4.0	3.0	2.0						
23	21AAVK5VC620	0.20	0.18	0.17	0.08	0.15	10	3.0	3.0	2.7	1.6	2.2	3.0	4.0	3.0	2.0	3.0						
24	32PAAVCVC620	0.00	0.15	0.18	0.10	0.00	10	0.0	2.6	2.9	1.8	0.0	0.0	3.0	3.0	2.0	0.0						
25	21AAVC6VC620	0.00	0.00	0.00	0.00	0.12	10	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	2.0						
26	46P-AAVVC620	0.00	0.17	0.20	0.12	0.13	10	0.0	2.8	3.1	2.0	2.0	0.0	3.0	4.0	2.0	3.0						
27	45AAVC6	0.00	0.00	0.00	0.00	0.08	10	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	2.0						
28	1454SVKIVKK10	0.22	0.12	0.12	0.08	0.07	10	3.2	2.2	2.1	1.6	1.2	4.0	3.0	3.0	2.0	2.0						
29	2635SVKIVKK10	0.20	0.12	0.00	0.10	0.12	10	3.0	2.2	0.0	1.8	1.8	3.0	3.0	0.0	2.0	2.0						

Figure 19 General view of Time Length sheet (TO-BE)

'Item-Machine Compatibility' sheet will be the next to be explained since it also a supporting sheet for PPOs while they are entering their POs. This sheet has a list of all items that company can produce and their compatibility information with all 5 SMD lines. As mentioned in previous chapters, all machines have different specifications, and this bring us to have a compatibility list. Besides SMD specifications like, feeder capacity, PCB table size, number of heads, types of feeders there are other factors affecting this list like keeping unit production cost at competitive levels and producing prototype products within a reasonable time. As an example, all prototype products are produced in SMD-5 even it has the highest running cost. [Figure 20]

	A	B	C	D	E	F
1	<b>Item-Machine COMBATIBILITY</b>					
2		SMD-1	SMD-2	SMD-3	SMD-4	SMD-5
3	PAAVC62003	0	0	0	0	1
4	P-AAVC62006	0	0	0	0	1
5	P2352025108	0	0	0	0	1
6	P-4205333012	0	0	0	0	1
7	P-111454S106	0	0	0	0	1

Figure 20 Prototypes' item-machine compatibility

With the help of this list, we can include 2 variables of POs into optimisation model easily; number of components and PCB size since the compatibility list is produced by regarding these variables. Similar to time length sheet, compatibility sheet also needs continuous updates.

'Line Capacity' sheet is to keep capacity charts of all SMD lines. There are 4 charts for both shifts; shift capacity, repair-maintenance, PO occupation and final capacity. This sheet is to be used by both by PPOs as input when they are looking for a suitable SMD line and time slot for their POs and by PPs to maintain regularly with the information they get from production. There are two buttons; one for loading data from database and the other to upload adjusted charts to database. [Figure 21]

Download	Up-Load	
Shift Day	Line	0
	SMD-1	

Figure 21 PP-Capacities sheet buttons (TO-BE)

Load button basically takes all 4 charts from database and shows them in this sheet. Shift capacities chart is for the daily gross capacities which is 8 by default if PPs won't change it later. Repair-maintenance chart is to set any planned repair or maintenance on the lines. Third chart is PO occupation chart which contains the durations of POs which are entered by PPOs. Final chart is final capacity chart. This chart is going to be used by both PPs and by PPOs. This chart is giving one of the information that PPOs trying to learn with their first e-mail to PPs with current process which is the current available capacity of an SMD line. [(2)]

$$Final\ Capacity = Shift\ capacity - repair, Maintenance - PO\ Occupation \quad (2)$$

'PO add-change-delete' sheet is to list all added, changed and deleted POs. This sheet is the main sheet for PPs. There are 2 buttons also in this sheet similar to other sheets. PPs can load all 3 lists when they click to download button. If they accept with adding, changing the PO, they write "yes" at the beginning of the row and upload it back to database. Both buttons and list of added POs can be seen in Figure 22. Basically, any change that PPOs makes on their side will be listed in this sheet for PPs to act.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Download	Up-Load												
										Added				
2	Accepted	Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	Time length	Number of Components	PCB Size	Company Code	Quantity
3	yes		PPO-1	Sekizli cift	SVK1564989-4	PO - 10019	01.06.2020	Day	SMD-	2	23	1		
4	ves		PPO-1	Sekizli cift	SVK1564989-8	PO - 10020	01.06.2020	Dav	SMD-	3	20	1		

Figure 22 PP-changes sheet / list of added POs (TO-BE)

'Temporary sheet' is to speed up the macro runs. When PPOs or PPs loads some data from database, macro opens the database and takes needed data to do the required calculations. This macro takes all data from database and pastes it to this temporary sheet and then closes the database and does all calculations inside itself. With the help of this approach database will be used for less time which is a must for our case since at least 12 people will use the same database.

Next sheets are related to optimisation of production planning. 'Optimisation results', 'Optimise production planning' and 'optimisation parameters' are the sheets that will be explained next.

'Optimisation parameters' sheet is to keep the structure of the optimisation, formulas, constraints, SMD line running cost index, constraints and also objective function. This sheet is a hidden sheet and needs to be updated only if any of the rules of optimisation or raw data need to be changed. To clarify, macro uses this sheet to copy the basis of optimisation.

'Optimise production planning' sheet is the main optimisation sheet which collects all data from other sheets and runs the optimisation model. It takes the POs to optimise from 'Production Orders sheet', compatibility data from 'item-machine compatibility' sheet, times from 'time length' sheet (after updating the quantities with actual numbers), capacity of the day and shift combination from 'Line capacity' sheet and finally it takes all formulas and basis for optimisation model and SMD line cost indexes from 'optimisation parameters' sheet. SMD line cost index will be explained in solutions

chapter. This sheet has 1 button to start optimisation model which can be seen in Figure 23 Optimisation start button.

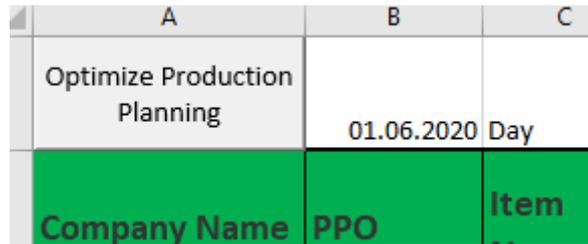


Figure 23 Optimisation start button (TO-BE)

'Optimisation Results' sheet is the final output sheet of the optimisation run. It contains 2 charts; scheduled items under SMD lines and SMD line capacity allocation rates. We are also showing how many POs scheduled out of how many to be produced. We also visualising the SMD capacity allocation rates in a chart. An example can be seen in Figure 24 Optimisation result sheet example

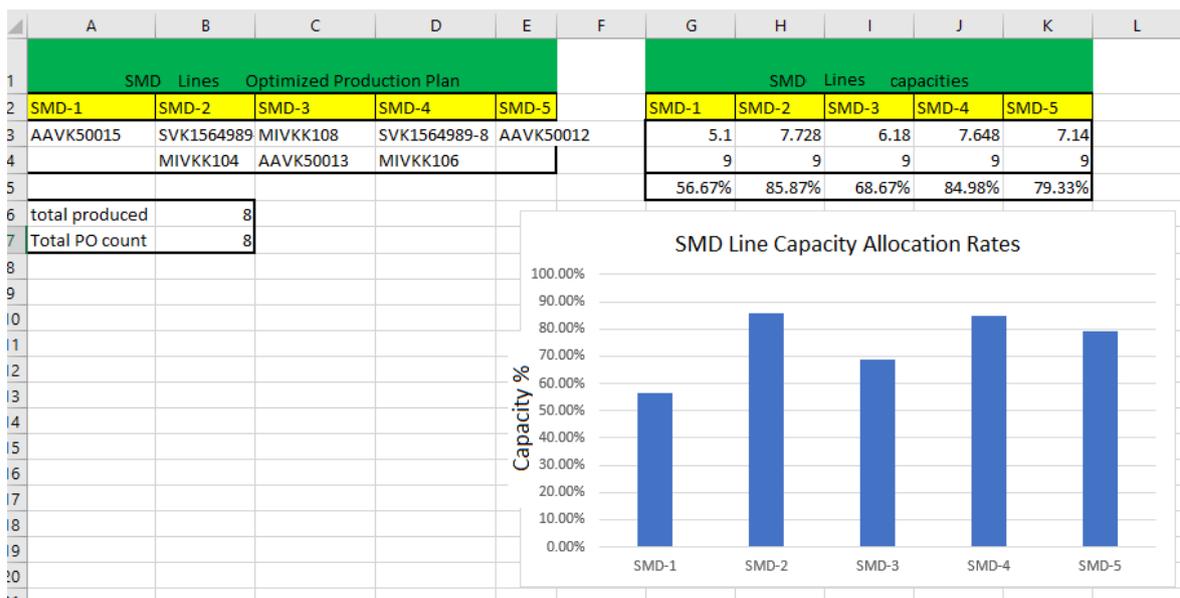


Figure 24 Optimisation result sheet example (TO-BE)

## 2.2 Solution functionalities

In this part I will go through the solutions that this tool brings to solve problems in the current processes. As I did in current processes and problems part, I will explain solutions in two parts; medium-term and short-term.

## 2.2.1 Medium term solution

Medium-term is currently 2 weeks and it is to request POs by PPOs. PPOs are creating POs for their items with respect to customer orders. As explained in problems chapter, main problem of this process is manual communication. I analysed these manual processes and understand users' problems and their extra needs that can be good to have. Before listing the solutions for the existing problems, it is going to be explained how a PPO can add a PO, how PP accepts the requests, how PPO changes or deletes a PO.

### Adding a po on the tool

It became very practical to send a PO request to PP by any PPO. They need to follow the steps below;

- Load their items in 'production order' sheet.
- Fill the necessary variables (date, shift, line, time length, number of components, PCB size, company code and quantity) to add a PO.
- To fill these variables, they can get support from 'line capacity', 'time length' and 'item-machine compatibility' sheets.
- Another functionality to help PPOs and to increase accuracy on data, we have drop-down menus on shift, line, time length and PCB size columns. [Figure 25]

The image shows a portion of a spreadsheet with four columns highlighted in green: 'Shift', 'Line', 'time length', and 'PCB Size'. Each of these columns has a small square icon indicating a drop-down menu. Below the 'Shift' column, a list is visible with 'Day' selected and 'Night' as an option. Below the 'Line' column, a list shows 'SMD-1' through 'SMD-5'. Below the 'time length' column, a list shows numbers 1 through 8. Below the 'PCB Size' column, a list shows numbers 1, 2, and 3.

Figure 25 drop-down menus to increase accuracy of data (TO-BE)

- Click on Up-Load button.
- If PPO misses any of the essential variables, macro won't take any action for that filled pre-PO. An example pre-PO without date can be seen in Figure 26

Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time length	Number of Components	PCB Size	Company Code	Quantity
	PPO-3	cvs dem. High (lig	XUD-A1PSML2			Day	SMD-1	2	23	2	78965	35
	PPO-3	cvs dem. High (lig	XUD-A1PSML2			Day						

Figure 26 a pre-PO without date (TO-BE)

- If all essential variables are filled, macro will check if the capacity is enough for the selected date-shift-line combination.
- If the capacity is enough, a unique number will be given to this PO as an ID. PPO and PP can use this unique number to identify the specific PO. [Figure 27]

Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time length	Number of Components	PCB Size	Company Code	Quantity
	PPO-3	cvs dem. High (lig	XUD-A1PSML2	PO - 10036	05.06.2020	Day	SMD-1	2	23	2	78965	35
	PPO-3	cvs dem. High (lig	XUD-A1PSML2			Day						

Figure 27 Unique PO number is given to an uploaded PO (TO-BE)

- There is an extra functionality in this tool that currently they don't which is to be able to reserve a capacity even if they don't have the final details of a PO. PPO can reserve a capacity only with essential variables and then they can update the PO when they have the final specifications.
- But if the capacity is not enough for the PO then this PO number will appear as "Capacity problem" [Figure 28]

Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time length	Number of Components	PCB Size	Company Code	Quantity
	PPO-3	cvs dem. High (lig	XUD-A1PSML2	Capacity Problem	05.06.2020	Day	SMD-1	2	23	2	78965	35
	PPO-3	cvs dem. High (lig	XUD-A1PSML2			Day						

Figure 28 PO doesn't send to PP because of capacity problem (TO-BE)

- After this point PPO needs to change any of the essential variables and sent the request again until the macro gives a PO number to the PO.

### Accepting a po request on the tool

When PPO adds a PO, that add request will be created by the tool. A PP can see these requests by following the steps below;

- PP loads the add-change-delete lists on 'PO add-change-delete' sheet by clicking "download" button. The added PO on Figure 27, will be seen as below. [Figure 29]

Added													
Accepted	Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time lenght	Number of Components	PCB Size	Company Code	Quantity
		PPO-3	cvs dem. Hig	XUF-N123	(PO - 10036	05.06.2020	Day	SMD-1	2	23	2	78965	35

Figure 29 Added PO to be accepted (TO-BE)

- PP has to review on the requests and evaluate them.
- PP needs to add "YES" on the first column of all the rows that they accept to let PPO know that PO put to production planning. [Figure 30]

Added													
Accepted	Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time lenght	Number of Components	PCB Size	Company Code	Quantity
YES		PPO-3	cvs dem. Hig	XUF-N123	(PO - 10036	05.06.2020	Day	SMD-1	2	23	2	78965	35

Figure 30 PO add is accepted (TO-BE)

- PP clicks on Up-Load button to send these data to database.
- After this point if the PPO loads their POs, they will see this PO number as green which indicates that it is accepted by the PP and now it is going to be produced. [Figure 31]

Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time lenght	Number of Components	PCB Size	Company Code	Quantity
	PPO-3	cvs dem. Hig	XUF-N12301	PO - 10036	05.06.2020	Day	SMD-1	2	23	2	78965	35

Figure 31 PO add request is accepted (TO-BE)

- This process is the same for sending a delete-PO request, except there won't be any feedback to PPO.
- There is a difference on the process for sending a change-PO request.
- Macro highlights the changed variables on the have PP to see the changes easier.
- A change request that date and quantity changed can be seen in Figure 32. As it can be seen both previous and the new variable set in shown to the PP.

Changed												
Company Name	PPO	Item Name	Item Code	Production Order Number	Date	Shift	Line	time lenght	Number of Components	PCB Size	Company Code	Quantity
	PPO-3	cvs dem. H	XUF-N123	PO - 10049	05.06.2020	Day	SMD-1	7	23	2	78965	35
	PPO-3	cvs dem. H	XUF-N123	PO - 10049	06.06.2020	Day	SMD-1	7	23	2	78965	40

Figure 32 PO change request (TO-BE)

## Changing a po on the tool

Changing PO request has two kinds; changing an essential variable or non-essential variable. If an essential variable change, then capacity needs to be controlled again for the new request.

### Changing an essential variable follows the steps below;

- Load their items in 'production order' sheet.
- Change the desired essential variable (date, shift, line, duration) on the desired PO. (PO needs to have PO number already)
- Click on Up-Load button.
- Macro will check if the capacity is enough for the changed date-shift-line combination.
- If the capacity is enough, PO number will remain where it is but cell colour will be changed back to white if the previous PO already accepted by the PP since this change request needs to be accepted by PP before showing it as green.[Figure 27]
- But if the capacity is not enough for the PO then this PO number will appear as "Capacity problem" [Figure 28]

### Changing a non-essential variable follows the steps below;

- Load their items in 'production order' sheet.
- Change the desired non-essential variable (number of components, PCB size, company code) on the desired PO. (PO needs to have PO number already)

- Click on Up-Load button.
- Macro will list this change request on 'PO add-change-delete' sheet without controlling capacity.
- PO number cell colour will be changed back to white if it was accepted and painted to green.

### **Deleting a po on the tool**

- Load their items in 'production order' sheet.
- Delete all variables of the PO and also PO number.
- Click on Up-Load button.
- Macro will list this delete request on 'PO add-change-delete' sheet after releasing the capacity for next requests.

After listing how PPOs add, change of delete a PO and how PPs accept these, author will analyse the solutions for the problems listed in previous chapters.

Firstly, to overcome the problem that process has when someone can't work because they got sick or they can't come to work because of sudden lockdown announcements and don't have their laptops with them, macro gives the possibility to read and change any other PPOs data in database. The agreed rule is that there won't be any restriction on data loading and uploading for others. Any one who has the tool can load any PPO's data and can change it. This seems to be against data safety, but it is not different than the current ways of working and a necessity for this kind of processes and for substituting colleagues. With this solution, no more data will be stuck in personal e-mail boxes anymore. This benefit applies to PPs too, they may have PO add, change and delete requests in their e-mail boxes and with this tool, other PP can see these requests. All e-mail loops shown in Figure 4, Figure 5 and Figure 6 are eliminated.

Secondly, thanks to the automated information flow, PPOs can reach many information without asking to PPs. They can find capacities for every line-date-shift combination on 'line capacity' sheet. They can find the updated time estimations and compatibility data in respective sheets. This enables the organisation to have PPOs to take the responsibility of their items to have proper POs on system. So, we are changing the

process that we can see in Figure 7 back to how it should go. PPs will deal only with the requests which will be fully filled by PPOs with the solution which enables them to focus on production planning optimisation and improvements more. As an example, if PP is informed by production with a capacity decrease due to maintenance or by management due to the freshly announced lockdown, they can send an e-mail to all PPOs to revise their POs which are affected from this capacity decrease instead of changing all of them by themselves.

Thirdly, PPOs and PPs prefer to communicate face to face when a PO needs to be added to production planning or an existing one needs a change. It is preferred instead of e-mail communication because, it is a complicated process to find a capacity for the new PO on already full schedule. PPO and PP trying to find a solution by changing other POs and they may need to get into communication with other PPOs to have some of the scheduled POs delayed. The very first step for a PPO before adding a PO or changing an essential variable in an existing PO is to find capacity on SMD lines. They can try to add the PO from 'production orders' sheet and will see if the capacity is enough or not for the desired line. They can understand it by the help of a very smart functionality of the tool by having PO number or "capacity problem" message. If it is for short-term than mostly the lines are already occupied so "Capacity Problem" message won't be a surprise in those cases. In case they see "Capacity Problem" as PO number they can understand that the capacity of the line they entered is not enough. In that case they have 2 possibilities to find a capacity for their PO. They can see the current capacities on 'line capacities' sheet by clicking load button. They can see all updated data in the charts. From the final capacity they can find suitable capacities. [Figure 33 Final capacity chart]

		Final Capacity						
Shift Day	Line	01.06.2020	02.06.2020	03.06.2020	04.06.2020	05.06.2020	06.06.2020	07.06.2020
	SMD-1	2	2	2	2	2	2	2
	SMD-2	0	0	0	0	4	0	0
	SMD-3	2	2	2	2	2	2	2
	SMD-4	1	1	1	1	1	1	1
	SMD-5	4	2	3	2	4	5	4

Figure 33 Final capacity chart (TO-BE)

Or they can load every other PPOs' items by selecting 'general planner' and see which POs are using the capacity on that specific line. [Figure 34] Then can contact the other PPOs who are using the required capacity on their POs and can negotiate on the schedule. They can ask them if it is possible to change their PO date for another date.



### **2.2.2 Short term solution**

Short-term production planning is mainly scheduling the POs on SMD lines. Scheduling POs on SMD lines process needs some tasks to perform beforehand. Capacity, compatibility and PO specifications are the input of this process. The solutions are developed by focusing on mainly information flow problems and automated solutions. Before analysing the solutions, author will go through the process steps, quality aspect, capacity of the model and optimisation model itself.

Line capacities, item-machinery compatibility, time lengths, SMD line cost index and requested POs are the input of the optimisation model. Before starting the optimisation model, PPs need to maintain health input for the model to have reasonable results. PPs need to update capacities, compatibility data, time length calculation algorithm and SMD line cost indexes if needed. PPs can use simulation power of the optimisation model. They can manipulate the input data and run the model again and see the differences and value the differences. They can add new POs on top of daily POs to optimise and see how the utilisation changes with a different set of POs. Or if they have a risk of not having enough labour power to run all SMD lines, they can set the capacity of the line and try to fit all POs without 1 line, and increase the other lines' capacity incrementally until they all fits in the capacity. This gives them an idea if it will be possible to produce all POs with 1 line missing and with increasing other's capacity with overtime.

Quality rates are analysed in the company manufacturing to identify a quality index as an input for the optimisation model. As Orr states in his research that there have been many empirical researches that examines the quality management affect on decision making in manufacturing. He continues with stating that, quality is the most important competition area after cost. [24] Quality is a very important feature for company to satisfy customer and ensure customer satisfaction. Company is investing on Lean six sigma analysis. As Yilmaz describes it in his research that, achieving six-sigma level on quality ensures the company not only with quality but also with production efficiency. [25] Company data provides us an information that all 5 SMD lines has the same sigma level with number of defective items per million items produced. This enables us to be able to observe that there is no significant quality differences between SMD lines. At this point it is decided to descope quality from optimisation model.

Capacity of the optimisation depends on the software and the structure of the model. An integer programming model is developed to optimise scheduling POs on SMD lines. Foster describes some methods to relax an optimisation model and methods to solve it faster in his research. [26]

Optimisation model is designed to run for a scope that can be adjusted by the user, means that if they want to run it for 3 days and for both day and night shifts, they can run it but due to the Excel Solver's capacity [21], they may need to reduce their scope to 1 day and 1 shift. The tool designed to optimise maximum 18 POs, and it is observed from the simulation data which provided by the company that, this capacity is enough for 1 day and 1 shift optimisation. All tests done with the model also confirmed that, the designed capacity is enough for any day and any shift to optimise all POs. I used a PC that has i7 processor and 16GB ram and the run times were in reasonable limits. Since none of the run didn't take more than 20 minutes to find the solution, it is observed that it is not necessary to try to relax a constraint and try to solve it by mixed integer programming or linear programming or try to solve it by a heuristic approach. Operation time is showed below. From the equation, it can be understood that it is not an NP-hard [22] model to solve. [Equation (3)]

$$\begin{aligned}
 \text{CPU run time} &= O(mn + m + n) \\
 m &= \text{number of POs} \\
 n &= \text{number of SMD lines}
 \end{aligned}
 \tag{3}$$

Integer programming model is developed based on the variables that need to be included in the model. Variable set is capacity for each SMD line, compatibility data for each item-SMD line pair, time length for each PO and cost index for each SMD line. Model is trying to produce as much PO as possible and at the same time producing it with the minimum cost. To ensure the model produces the maximum number of PO even it is not very cost effective, we weighted number of produced PO with a big number. This method is called as 'big M method', which is to priorities one of the variables in objective function over the others. Gupta et al and Ding et al used this method in their dual simplex models. [27, 28] This M is a real number which is set as 1000 in our case. PP has possibility to change this method and use a different number between 1 and 2 if they want to weight the number of produced PO less and give more importance to cost. In that case they can enable model to find a solution with a smaller number of produced PO but average cost per item will be less. For our model, it is agreed to use big M method since the output is quite satisfactory. Mathematical model can be found below. [Equation (4a)]

*Objective Function;*

$$\text{Max} \sum_{j=1}^J \sum_{i=1}^I X_{ij} * M - \sum_{j=1}^J \sum_{i=1}^I X_{ij} * T_{ij} * MCI_i \quad (4a)$$

*Subject to:*

$$X_{ij} \leq C_{ij} \quad \forall i \in I, \quad \forall j \in J \quad (4b)$$

$$X_{ij} \text{ is integer } \quad \forall i \in I, \quad \forall j \in J \quad (4c)$$

$$\sum_{i=1}^I X_{ij} \leq 1 \quad \forall j \in J \quad (4d)$$

$$\sum_{j=1}^J X_{ij} * T_{ij} \leq Cap_i \quad \forall i \in I \quad (4e)$$

*I = set of SMD lines*

*J = set of items – POs*

*MCI<sub>i</sub> = Machine cost index of SMD i*

*C<sub>ij</sub> = Compatibility data for item j and SMD i*

*T<sub>ij</sub> = Time length for PO j and SMD i*

*Cap<sub>i</sub> = Capacit of SMD i*

*M = Big M*

*X<sub>ij</sub> = { 1 if item j is produced by SMD i | 0 if o/w }*

Objective of this optimisation model is to maximise number of produced PO and keeping the cost as low as possible. Constraint (4b) is to be sure that model is obeying the compatibility rule, produce an item with one of the allowed SMD line. Constraint (4c) is to keep POs in 1 piece. If we don't set (4c), then this optimisation model will be a linear model and will be much easier and faster to solve but that will complicate to calculate time lengths and hence the costs. When we keep all X(i,j) as integer, POs won't be divided into 2 batches and will be produced in one piece. Constraint (4d) has a mathematical value. It is to produce any PO for once. We sup up X(i,j) for an item and force it to be less than or equal to 1. Constraint (4e) is to use line capacities correctly. We are being sure that we are not exceeding the capacity of a line. Here we are using the time lengths which are calculated with the actual quantities of each PO.

After analysis of process steps and optimisation model, solutions for existing problems will explained below.

Firstly, PPs can update capacity of the lines much easier and faster with PPOs. PPs are using their tool, 'Line capacity' sheet to fill the charts with updated values. They need

to update shift capacity chart if there is a line stop and repair-maintenance chart if there is a planned repair or maintenance on the lines. Because of COVID-19 pandemic, they need to stop some of the SMD lines due to lack of labour or some partial decrease in capacity. In that case they can update the shift capacity and upload the changes to database. If this happens very late and the line is already occupied, they need to analyse if they can move the accepted POs to other identical lines or not. If they can't fit all accepted POs to other lines, then they need to inform PPOs to act and move their POs to other dates. Since some of the POs need to be postponed, the agreed ways of working for these kind of situations is, PPOs won't try to schedule their POs on the same date which has insufficient capacity, if their PO is not urgent so, urgent POs can be scheduled to the same day. This solves responsibility problem and PPOs takes the scheduling their urgent POs liability.

Secondly, when PPs are scheduling the 2 days window for short-term production planning, they are not using any decision support tool, instead they are scheduling POs on lines based on their pure experience. When we analyse their utilisation rates of SMD lines, it is easy to see that there is a gap to improve this process. [Figure 36] Main reason behind this is last minute changes and lack of optimisation tool. With every change in capacity or with PO sets, PP needs to review and change the scheduled plan. Even it is agreed to have the next 2 days as frozen, they need to change the plan for this frozen time frame time to time and the need of the new plan urgently, makes planning inefficient. With this automated solution, they can optimise the scheduling with one click. The model will give them the best solution that can be produced. They have possibility to run it several times with every change and also for simulation purpose. They can manipulate the inputs based on possibilities and see what will be the optimum schedule in case of a capacity decrease, for a different PO set (quantity decrease, increase etc.) As mentioned before, the capacity check done by the tool when a PPO requests a PO, enables us to have a non-optimal solution that we can use as a starting node for our optimisation model. This has another benefit which is, technically we won't have any missing POs which won't be in the optimum schedule since capacity is reserved for it already. On the other hand, this may end up with un-utilised SMD lines because of two reasons; differences on the requested essential variables and time lengths between the initial solution and optimum solution. To overcome this problem, while simulating optimisation with different input, PP can add new POs here to utilise SMD lines. They can add prototype POs which may not be in company's list yet or they can add POs from next days.

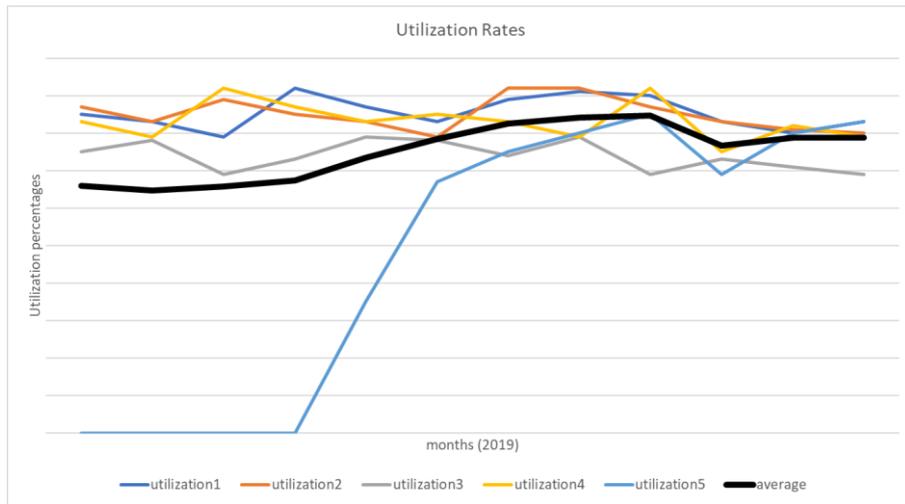


Figure 36 Utilisation of SMD Lines

Finally, company's 5 SMD lines has different costs as discussed in previous chapters. Company attaches importance to customer satisfaction and production costs is not their priority. This propriety is valid for most of the items but for some items that are in mass production which have competitive prices need to be produced on specific SMD lines (generally SMD-1 and SMD-2). The good thing is that, these constraints applied to compatibility list. To consider operating costs in optimisation model we applied a method to find cost indexes. Indexing method is being used in optimisation models frequently. [14] With the help of calculated indexes, line operating costs are included in the optimisation model. [Figure 37]

Machine Costs Index				
SMD-1	SMD-2	SMD-3	SMD-4	SMD-5
1	1	1	2	3

Figure 37 SMD line Cost Indexes

### **3. ANALYSIS**

During COVID-19 pandemic business conditions changed unusually around the world. New conditions let the company have some new challenges during these days. When the new tool is designed, they got excited and contributed in the design phase which is the key factor to have a useful software. They started using the tool after the very first tests which enable our research to analyse the results. It is going to be analysed in two parts for medium-term and short-term.

#### **3.1 Medium-term analysis**

They were in a need of this kind of communication tool even before this challenging process. So, after the development of the first part of the tool, a group of test users start using it to see if it fits their requirements and if it is practical enough to use it in daily business. There were some model related bugs in the tool that are reported by the users. These bugs are fixed, and tests continued. Speed of the tool is also important for users besides the functionalities.

With this test users, it is planned to have some simulations that includes all possible scenarios that described by users. These simulations are; adding, changing and deleting a PO, adding, changing, deleting multiple POs at a time, doing all these for another PPO, changing a PO after it is accepted, using the tool at the same time with other PPOs, controlling capacities, updating time length and compatibility lists and some speed tests like adding too many items and POs. All these tests enable us to validate that the speed of the calculations is quite fast and if there won't be any connection problems with the database, tool won't take more than 1 minute to do any task assigned to any buttons with reasonable number of POs. We also tried massive uploads to see the speed of the tool in extreme conditions. Uploading POs takes the longest since it includes controlling capacity of the lines. This test showed us that, calculations are not taking too much time. The results can be seen in Figure 38. This chart shows us even the run time increases by number POs to be uploaded, Average time per PO decreases. This also shows us that run time relation with number of POs is not linear. It is mostly because, it takes the most to connect the database and opening and closing it.

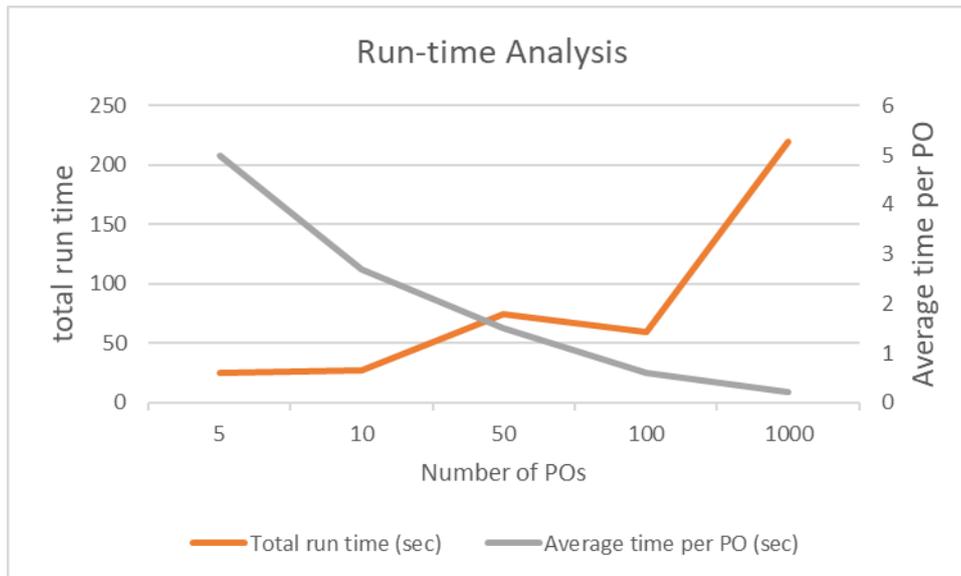


Figure 38 Run time analysis

While these testing period, we faced a problem which is related to speed of connection. The problem is that, macro is being stuck while opening, saving and/or closing the database file. This problem is not happening when the user is located in the office but it happens when they are using the tool from their homes which they do during the pandemic. After several trials, it is found that there are 2 reasons behind this problem. Since VPN (Virtual Private Connection) is used by users when they are not connected to office network, which can be slow time to time, opening of closing database file takes more than usual. This unusual time creates a bug in macro which is related to time limit that MS Office allows macro to open a file because of various reasons like security. With the research done on web, it is found that there is no specific solution for this since it is related to backend development of the MS Excel. The good thing is that, this problem does stop the macro but doesn't crush and it can continue working if the user clicks on 'cancel' button which can be seen in Figure 39.

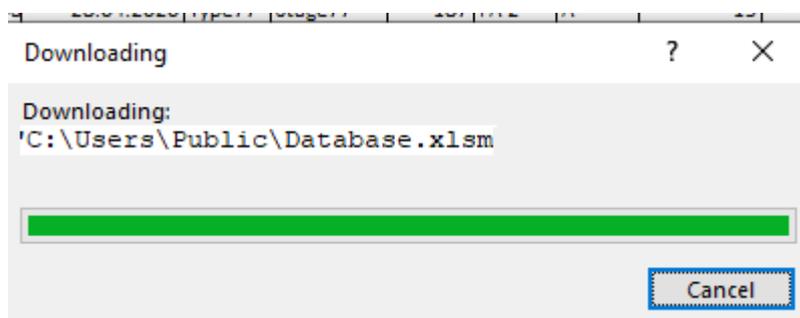


Figure 39 VBA stops while opening and closing the database

To overcome this small problem, we can address an online spreadsheet, or a file located in a cloud server as the database. Since the problem is not interfering using the tool and more importantly it is not happening always, it is preferred to continue using database in company servers since it is more secure.

Another purpose of this development was to decrease dependency on e-mail and face to face communication. To validate if tool achieved to improve communication and decrease manual communication in planning department, company's IT department analysed number of e-mails sent between the test users which includes both PPOs and PPs. For this purpose, an analysis structure prepared, and company's IT department filled the number of e-mails and shared the final change percentages with the author. The structure is designed to normalise number of e-mails with number of POs, so we can have an idea of the change free from independent effects like demand changes since number of e-mails is strongly related with the total POs produced. According to the company, number of e-mails sent per PO after the tool being started to be used is decreased by 27% if we compare it with last year's same month average and by 32% if we compare with previous month. These results are not the best measures to see the affect of the tool on number of e-mails since, the sent e-mails are not always about POs so we can't end up saying a certain percentage that the tool decreased the e-mail by. Still it is obvious that tool is affective on decreasing the need of manual communication. We also can state that, tool can be more affective in case users are not in office. This can be because they are sending more e-mails when they are not in office than when they are and since the tool decrease the need of manual communication, it is more efficient during when people are staying at home like pandemic times.

As a final validation method, a survey is prepared and applied to test users and the results analysed. For this survey, questions are designed to receive direct answers from the users. The survey questions can be seen below in Figure 40.

## Planning Tool Survey

	Question	Strongly Disagree			Strongly Agree	
		1	2	3	4	5
1	Speed of the tool is good.					
2	Logic of the tool serves the needs					
3	Tool decreases the need of face to face communication					
4	Tool decreases the need of mail communication					
5	Tool decreased number of last-minute changes with production					

Figure 40 Survey for tool

When we analyse the results of the survey [Figure 41] it is clear that it serves the designed purposes. Although, having all users happy is very hard, they liked it generally. One of the most important reflection of this survey is that, users don't think that the tool decreased need for face to face communication that much. It is understood that during pandemic, they needed to communicate with production more often to be sure that correct items are produced and called production engineers more. It can be understood that the question and the scope of the tool is not understood from both side perfectly since decreasing face to face communication with production was not in the scope. It is believed that the low result of the last question is also due to the same reason. After discussing the results with the users, it became clear but still, it is proffered to share the results as they are.

	<b>Question</b>	<b>Average result</b>
1	Speed of the tool is good.	4.8
2	Logic of the tool serves the needs	4.5
3	Tool decreases the need of face to face communication	3.6
4	Tool decreases the need of mail communication	4.6
5	Tool decreased number of last-minute changes with production	4.1

Figure 41 Results of the tool survey

There can be some future improvements done about the medium-term part of the tool and general process.

Firstly, it is agreed to have PPOs fill time length data manually for requested POs. They are using the calculation formula in 'time length' sheet by entering the correct quantity. The reason why this step left as manual is, to have a manual control on time data since these length data calculations are giving rough numbers and need continues update. In future items can be identified as new and mature and for mature items, the time length data can be filled automatically when PPO enters the quantity.

Secondly, in the current process, PPOs are requesting an SMD line based on their experience and the compatibility data. For scheduling purpose this line is considered just as the starting node of the solution tree, but this line is used for reserving the capacity from lines. As an improvement if model suggests a line by itself, it would be more practical for the PPO.

Thirdly, in 'PO add-change-delete' sheet a model can be developed to identify middle changes and then deletes them from the list. This can save a lot of time of PPs. As an example, if a PO is added and than had several changes and at the end PPO deleted it, in this example, none of the lines have to be in the list since the PO is deleted at the end.

Fourthly, database file located in the company servers. Although, there are automated backup processes for all data in the server, it will be better if we can take a copy of the database after any upload to have a track of changes. This can slow down the process a little but worthy.

Finally, capacity change information is quite important for PPOs. Whenever PP changes capacity of a line, an automated module can send e-mail to all PPOs with the details of the change which is very valuable for PPOs.

### **3.2 Short-term analysis**

For short-term, the tool is expected to answer the needs of scheduling. Company is in growing trend, and number POs are increasing to a scale that, manual scheduling becoming impossible to reach near to optimum point.

The company provided two weeks of PO data to test the short-term production planning optimisation. Since the problems were; not having a decision support optimisation tool and having low utilisation rates of SMD lines. Author expects the tool to find a solution fast enough to run it multiple times in a day to perform simulation and also to increase utilisation of SMD lines.

To test the model, we had 130 POs belong to 14 days which was enough to test the speed and performance of the optimisation.

To start the optimisation model, all POs should be accepted by PP. We had all 130 POs accepted and all items in 'item length' and 'compatibility' sheets with proper data. The test is done for every day and day shift, 14 runs in total. During these runs some of the days took less than 2 minutes but some of them took up to 20 minutes to find the optimal solution. The average time it took was about 7 minutes which is considered as acceptable by the PPs. When the author analyses the final solution of one sample day, he discovered a misbalance between SMD lines. It is straightforward to understand that there is some unused capacity even if we don't give the utilisation rates. [Figure 42] First week's days' results can be seen in appendices.

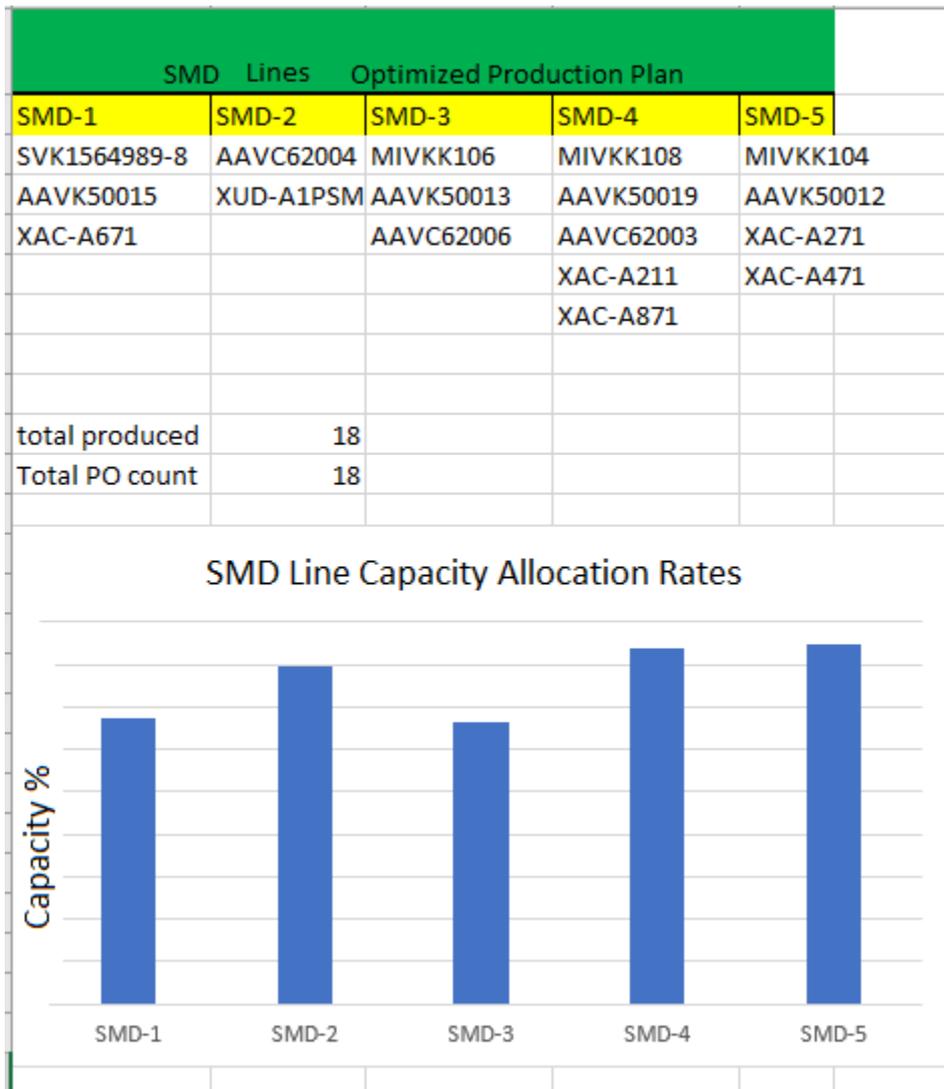


Figure 42 Result of optimisation Day – 1 (TO-BE)

The first source for this problem is because PPOs are not entering all POs that they are requesting to this tool, which are generally small prototype batches. The second source is the difference between the requested time and the real time that the PO will take to produce. PPOs are entering time lengths roughly with rounded values. There are reasons behind these ways of working and why we designed this tool instead of just taking the real durations directly from 'time-length' sheet. Firstly, the company is not targeting 100% utilisation with SMD lines not to have a fragile production plan. As Atwater et al. state in their research that 100% utilisation is not optimal, and the optimal target utilisation needs to be found for different systems separately. [29] Second reason is that the company want to leave some capacity for last-minute orders which are generally prototype items and have significant importance for the company for customer satisfaction. Thirdly, the company wants to keep a position on the safe side and fulfil the SMD lines even lower than their target utilisation rates and fill the gap

with smaller batches in case of need. They are generally trying to schedule POs to SMD-5 line at last, and when we analyse the results, our model also followed the same aim, which is a desired solution by the company.

The company shared the average utilisation rate of the last three months of SMD lines. When we analyse the first results of the optimisation, we can state that at average optimisation model gave a 9% worse utilisation at an average of all lines and all days. It is quite reasonable to get lower utilisation rates since the lines have unused capacity. As a second step, extra POs are added from next days on top of the daily POs. Generally, 2 or 3 more POs can be produced. This process is based on trials and after adding every single PO, model needs to run again, and the results need to be observed. Since this manual step takes too much time, the author analysed only the first three days. Average utilisation of 5 lines on these three days succeeded to increase by 13%.

We can end up by stating that this model enables to increase utilisation of the lines by 4% on average which serves the designed purpose of the tool.

Even this tool serves the purpose successfully by increasing the utilisation in acceptable time limits many points can be improved with the optimisation part of the tool.

Firstly, the current optimisation model has a capacity of a maximum of 18 POs at a time which is generally one day and one shift. Running the model for each day separately disable the model to find many better solutions. IT will be much better results if the model can run for two weeks' time or as a start at least for the whole short-term planning, which is four times bigger problem than the current one. Due to the capacity of Excel solver, it is not possible to fit it into Excel.

Secondly, because of the capacity of Excel and more importantly because of the speed, more developed solver engines need to be used. Although the company expressed that running times are in acceptable limits, time to time PPs are running the model multiple times for simulating purpose and also for increasing utilisation by manual PO adding. For these cases, PPs need to run the model sometimes for 30 times which is expected to take 210 minutes in total at an average which becomes unacceptable. To overcome speed issue, there can be two-step improvement. As step 1, the company needs to buy a licence for an integer model solver which can be Xpress, CPLEX or GAMS which are the most popular ones on the market. The second step should be automating these repetitive runs.

Repetitive runs, which is a simulation, can be designed by PPs by giving different values to different variables. As an example, they can try the model with an increased line capacity by 1 hour.

Thirdly, not to waste PPs time, these runs can be scheduled daily at night-time, and the model can run with input data provided the previous day. The results can be ready when PP starts working in the morning. With this automation, PPs can set many other simulation parameters and observe the results.

For now, the company needs to get used to the optimisation model and understand that by improving the model and investing in fine tuning of the optimisation model enables the company to get much better utilisation rates.

## **4. SUMMARY (IN ENGLISH)**

In conclusion, the author studied the theoretical research of internal communication solutions and short-term scheduling optimisation models focusing on fast and applicable alternatives. Main objectives of the thesis are; to decrease face to face and e-mail communication dependency among production planning departments to speed up the processes and to reduce human mistakes and to have a decision support tool for short-term scheduling to increase utilisation of machinery.

Business processes of the company analysed to find out the best solution to solve the problems. It is found out that each process takes too much time because of too many e-mails need to be sent.

Advantages and disadvantages of alternative solutions are discussed, and it is found that an internally developed Excel tool has a lot of benefits for today and also for long-term improvements.

A module to add new items to the system is developed, which is communicating with the same database that the planning tool is communicating. Communication between two departments for production order related communications are moved to this tool. Integer programming optimisation is applied to utilise machinery as high as possible while considering business constraints. During development, the scalability aspect is considered to have future developments possible. Both models are tested with sample data that the company provided, and a survey is applied to test users.

All possible functionalities are tested in communication module, and the speed was very satisfactory for the author. Test users also found the communication module easy to use, fast and useful. With the start of using the communication module, the average e-mail used per production order decreased 30% on average. Optimisation module simulation is done for 14 days, and detailed simulation applied for three days. On average, a 4% increase in utilisation achieved. It has to be noted that both results captured from the first stages of quality evaluation with limited data. Tests and simulations need to be done with more extensive sample data, preferably with at least three months data.

All in all, the author and the company satisfied with the results of the study addresses the research problem. It would be beneficial to continue improving both of the modules with changing business needs.

## 5. SUMMARY (IN ESTONIAN)

Kokkuvõtteks - lõputöö autor uuris sisekommunikatsiooni lahenduste ja lühiajalise planeerimise optimeerimise mudeleid, keskendudes kiiretele ja rakendatavatele alternatiividele. Selle uuringu peamiseks eesmärgiks on: vähendada tootmise planeerimise sõltuvust osakondadevahelisest suhtlemisest nii näost näkku kui e-posti teel ning kasutades rohkem tehnikat, omades tugivahendit lühiajalise plaani koostamiseks, kiirendada tootmisprotsesse ja vähendada inimlikke vigu.

Analüüsi ettevõtte äriprotsesse, et leida parim lahendus probleemide lahendamiseks. Selgus, et toimingud võtavad palju aega just sellepärast, et tuleb saata liiga palju e-kirju.

Arutledes alternatiivsete lahenduste eeliste ja puuduste üle leitakse, et ettevõttesiseselt välja töötatud Exceli tööriistal on palju eeliseid nii tänapäeval kui ka pikemaajalisteks täiustusteks.

Töötati välja moodul uute üksuste lisamiseks süsteemi, mis suhtleb sama andmebaasiga, millega suhtleb planeerimistööriist. Selle tööriista alla viiakse kahe osakonna vaheline tootmistellimustega seotud suhtlus. Arvestusliku programmeerimise optimeerimist kasutatakse tehnika võimalikult kõrgeks rakendamiseks, võttes samal ajal arvesse ettevõttele eripäraseid piiranguid. Arenduse ajal peetakse oluliseks aspektiks mastaapsust ja võimalikkust edaspidisteks täiendusteks. Mõlemat mudelit testiti valimi andmetega, mille esitas ettevõtte, ja viidi läbi uuring testkasutajatega.

Kommunikatsioonimoodulis sai testitud kõiki võimalikke toiminguid ja autori jäi kiirusega väga rahule. Ka testkasutajad leidsid, et suhtlusmoodul on hõlpsasti kasutatav, kiire ja kasulik. Kommunikatsioonimooduli kasutuselevõttuga vähenes keskmine e-kirja arv ühe tootmistellimuse kohta umbes 30%. Optimeerimismooduli simulatsioon tehti 14 päevaks ja üksikasjalikum simulatsioon rakendati kolmeks päevaks. Keskmiselt saavutati selle kasutamises 4% kasv. Tuleb välja tuua, et mõlemad tulemused on saadud kvaliteedi hindamise esmastest etappidest ja põhinevad piiratud andmetel. Katsed ja simulatsioonid peab läbi viima ulatuslikumate testidega ja eelistatavalt vähemalt kolme kuu andmetega.

Kokkuvõttes on autor ja ettevõtte käsitletud probleemi uurimise tulemustega rahul. Oleks kasulik jätkata mõlema mooduli arendamist ja täiendamist seoses muutuvate ärivajadustega.

## LIST OF REFERENCES

- 1 Jevgeni S. *Dynamic Management Framework for Continuous Improvement of Production Processes*. 2015 Tallinn University of Technology, PhD Thesis, *Digikogu*, <https://digikogu.taltech.ee/en/item/9429b014-6392-4af1-9fcf-9c50b546f66c>
- 2 Ammenwerth, E., Buchauer, A., Bludau, B., & Haux, R. (2000). Mobile information and communication tools in the hospital. *International Journal of Medical Informatics*, 57(1), 21-40. doi:10.1016/s1386-5056(99)00056-8
- 3 Rohrer, Matthew. (2000). Seeing is believing: The importance of visualisation in manufacturing simulation. *Proceeding of the 2000 Winter Simulation Conference*, IEEE Computer. 2. 1211-1216 vol.2. 10.1109/WSC.2000.899087.
- 4 Hudcova, Sarka. (2014). Tools of Internal Communication from Knowledge Transfer Perspective. *Journal of Competitiveness*. 6. 50-62. 10.7441/joc.2014.04.04.
- 5 Mladkova, L. (2004). *Management znalostí v praxi*. Praha: Professional Publishing.
- 6 Probst, G., Raub, S., & Romhardt, K. (2000). *Managing Knowledge. Building Blocks for Success*. New York: John Wiley and Sons.
- 7 Chanda, Emmanuel Knox Chikutwe. "An application of integer programming and simulation to production planning for a stratiform ore body." (1990).
- 8 Martinez, Michael A. and Alexandra M. Newman. "A solution approach for optimising long- and short-term production scheduling at LKAB's Kiruna mine." *Eur. J. Oper. Res.* 211 (2011): 184-197.
- 9 Newman, Alexandra M. et al. "A Review of Operations Research in Mine Planning." *Interfaces* 40 (2010): 222-245.
- 10 Panetto, H., & Molina, A. (2008). Enterprise integration and interoperability in manufacturing systems: Trends and issues. *Computers in Industry*, 59(7), 641-646. doi:10.1016/j.compind.2007.12.010
- 11 Alarcón, Luis Fernando and Rodrigo Calderón. "A Production Planning Support System for Construction Projects." (2003).

- 12 Jevgeni, S., Eduard, S., & Roman, Z. (2015). Framework for Continuous Improvement of Production Processes and Product Throughput. *Procedia Engineering, 100*, 511-519. doi:10.1016/j.proeng.2015.01.398
- 13 Bloch, B. (1988), "CONFLICT BETWEEN DEPARTMENTS MANAGERS' OPINIONS", *Industrial Management & Data Systems*, Vol. 88 No. 9/10, pp. 11-13.
- 14 Rogozhin, A., Gallaher, M., Helfand, G., & Mcmanus, W. (2010). Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry. *International Journal of Production Economics, 124*(2), 360-368. doi:10.1016/j.ijpe.2009.11.031
- 15 Gordon LA, Loeb MP. Distinguishing Between DIRECT and INDIRECT COSTS Is Crucial for INTERNET COMPANIES. *Management Accounting Quarterly*. 2001;2(4):12-17.  
<http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=12085704&site=eds-live>. Accessed May 8, 2020.
- 16 Foster, G., & Gupta, M. (1990). Manufacturing overhead cost driver analysis. *Journal of Accounting and Economics, 12*(1-3), 309-337. doi:10.1016/0165-4101(90)90052-6
- 17 Hadidi, L.A., Al-Turki, U.M. and Rahim, A. (2012) 'Integrated models in production planning and scheduling, maintenance and quality: a review', *Int. J. Industrial and Systems Engineering*, Vol. 10, No. 1, pp.21–50.
- 18 J. Liang and T. Niu, "The Application of Excel VBA in the Prequalification of EPC BID," 2010 3rd International Conference on Information Management, Innovation Management and Industrial Engineering, Kunming, 2010, pp. 335-338, doi: 10.1109/ICIIE.2010.560.
- 19 Kallio, Kai & Johnsson, Mika & Nevalainen, Olli. (2010). Estimating the Operation Time of Flexible Surface Mount Placement Machines. *Production Engineering*. 6. 10.1007/s11740-012-0380-z.
- 20 SHU-HSING CHUNG & HUNG-WEN HUANG (2002) Cycle time estimation for wafer fab with engineering lots, *IIE Transactions*, 34:2, 105-118, DOI: 10.1080/07408170208928854
- 21 <https://www.solver.com/standard-excel-solver-dealing-problem-size-limits>

- 22 Colorni, A., Dorigo, M., Maffioli, F., Maniezzo, V., Righini, G. and Trubian, M. (1996), Heuristics from Nature for Hard Combinatorial Optimization Problems. *International Transactions in Operational Research*, 3: 1-21. doi:10.1111/j.1475-3995.1996.tb00032.x
- 23 PETER PINTO, DAVID G. DANNENBRING & BASHEER M. KHUMAWALA (1975) A branch and bound algorithm for assembly line balancing with paralleling, *International Journal of Production Research*, 13:2, 183-196, DOI: 10.1080/00207547508942985
- 24 Stuart Orr (1999) The role of quality management in manufacturing strategy: Experiences from the Australian wine industry, *Total Quality Management*, 10:2, 271-279, DOI: 10.1080/0954412997992
- 25 Mustafa R. Yilmaz & Sangit Chatterjee (2000) Six Sigma Beyond Manufacturing- A Concept for Robust Management, *Quality Management Journal*, 7:3, 67-78, DOI: 10.1080/10686967.2000.11918907
- 26 Foster, B., Ryan, D. An Integer Programming Approach to the Vehicle Scheduling Problem. *J Oper Res Soc* **27**, 367-384 (1976). <https://doi.org/10.1057/jors.1976.63>
- 27 A. Gupta, O. V. G. Swathika and S. Hemamalini, "Optimum Coordination of Overcurrent Relays in Distribution Systems Using Big-M and Dual Simplex Methods," 2015 International Conference on Computational Intelligence and Communication Networks (CICN), Jabalpur, 2015, pp. 1540-1543, doi: 10.1109/CICN.2015.341.
- 28 T. Ding, R. Bo, W. Gu and H. Sun, "Big-M Based MIQP Method for Economic Dispatch With Disjoint Prohibited Zones," in *IEEE Transactions on Power Systems*, vol. 29, no. 2, pp. 976-977, March 2014, doi: 10.1109/TPWRS.2013.2287993.
- 29 ATWATER, J.B. and CHAKRAVORTY, S.S. (2002), A STUDY OF THE UTILISATION OF CAPACITY CONSTRAINED RESOURCES IN DRUM-BUFFER-ROPE SYSTEMS\*. *Production and Operations Management*, 11: 259-273. doi:10.1111/j.1937-5956.2002.tb00495.x

# APPENDICES

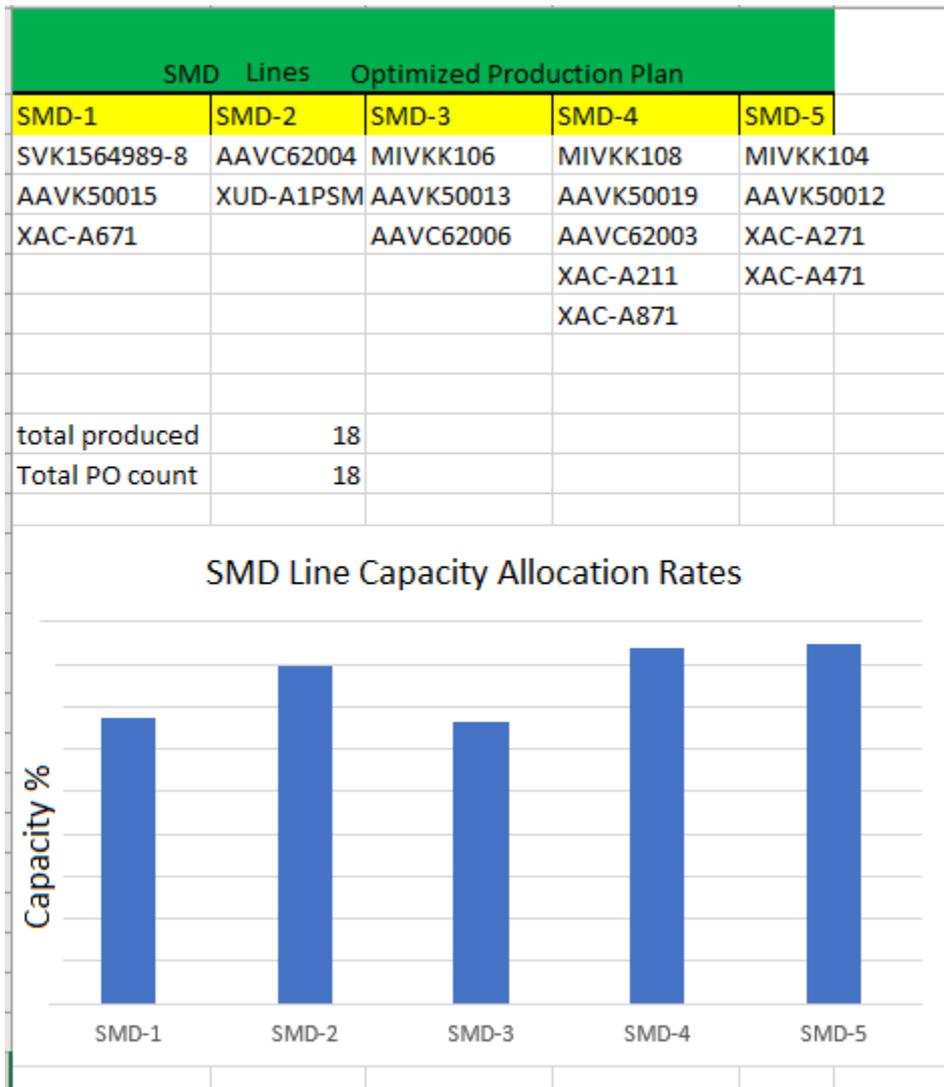


Figure 43 Optimisation results day-1 (TO-BE)

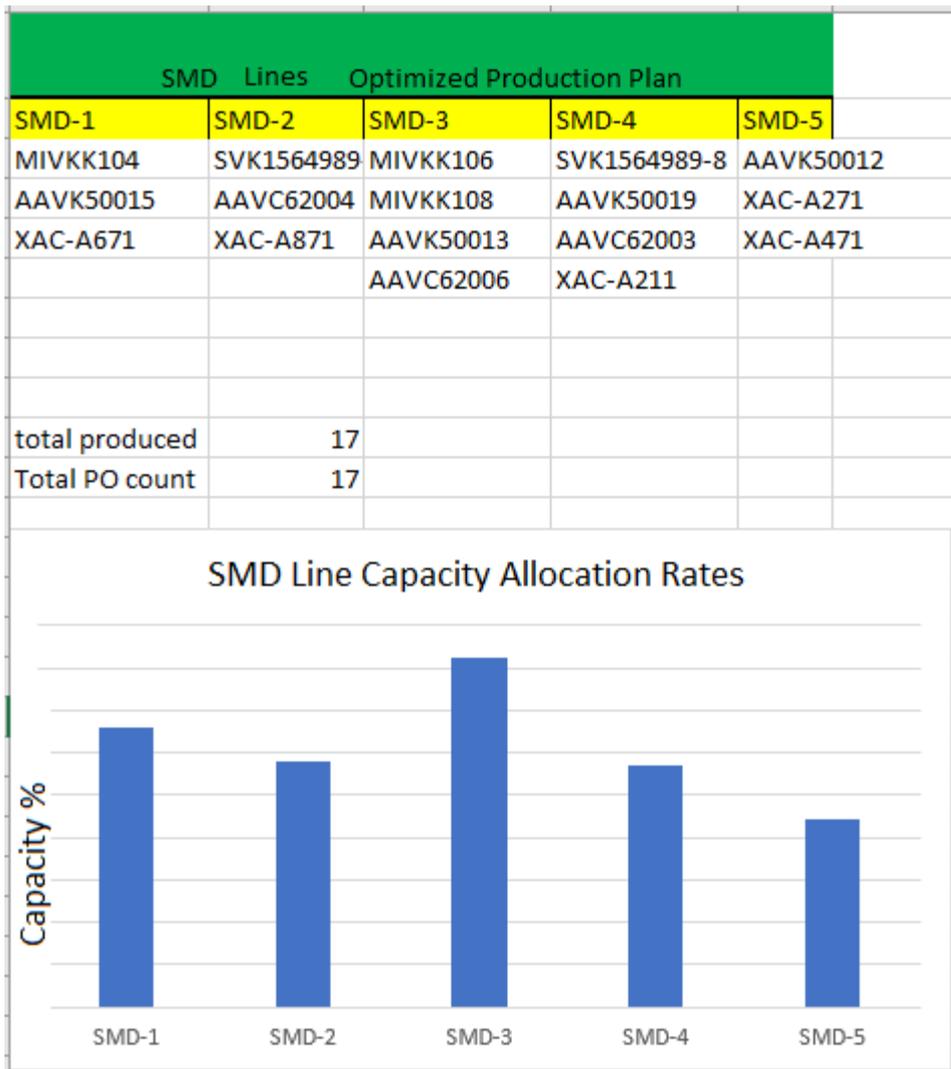


Figure 44 Optimisation results day-2 (TO-BE)

SMD Lines Optimized Production Plan				
SMD-1	SMD-2	SMD-3	SMD-4	SMD-5
AAVK50015	SVK1564989	SVK1564989-8	MIVKK108	MIVKK104
XAC-A671	MIVKK106	AAVK50013	AAVK50019	AAVK50012
	XAC-A871	AAVC62004	AAVC62003	XAC-A271
		AAVC62006	XAC-A211	XAC-A471
total produced	17			
Total PO count	18			

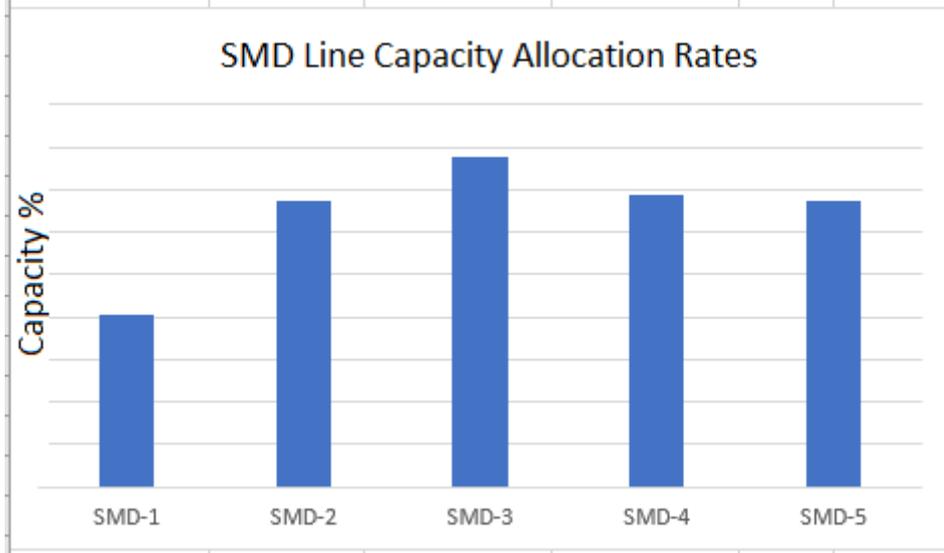


Figure 45 Optimisation results day-3 (TO-BE)

SMD Lines Optimized Production Plan				
SMD-1	SMD-2	SMD-3	SMD-4	SMD-5
MIVKK104	SVK1564989	MIVKK108	SVK1564989-8	AAVK50012
AAVK50015	MIVKK106	AAVK50013	AAVK50019	XAC-A271
XAC-A671	XAC-A871	AAVC62004	AAVC62003	XAC-A471
		AAVC62006	XAC-A211	
total produced		17		
Total PO count		17		

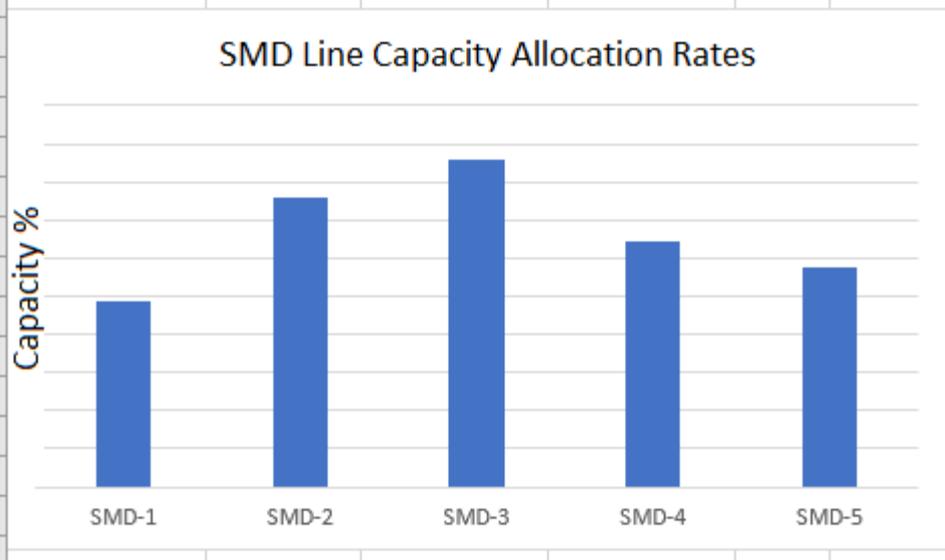


Figure 46 Optimisation results day-4 (TO-BE)

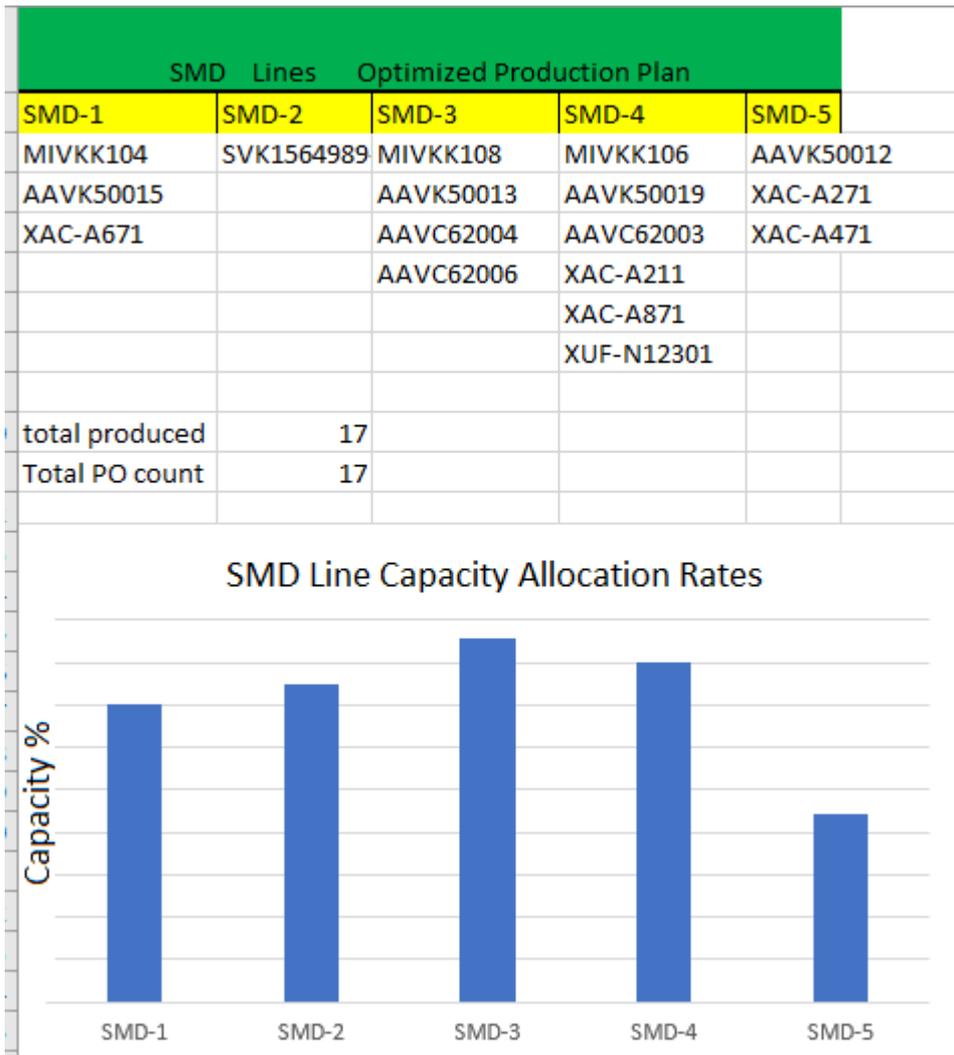


Figure 47 Optimisation results day-5 (TO-BE)

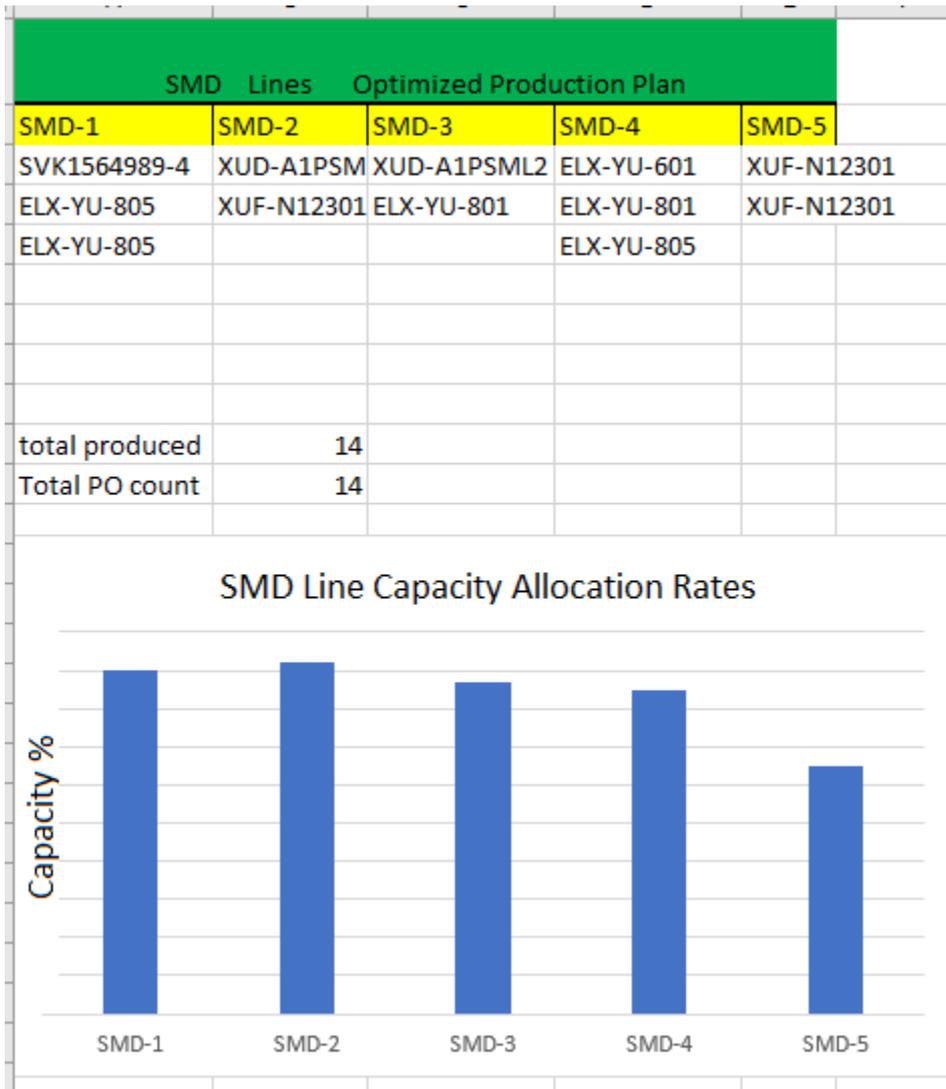


Figure 48 Optimisation results day-6 (TO-BE)