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

EVALUATION OF PRODUCTION CAPACITY THROUGH A SIMULATION MODEL

SIMULATSIOONIMUDEL TOOTMISVÕIMSUSTE HINDAMISEKS

MASTER THESIS

Üliõpilane: Margo Allikmäe
/nimi/

Üliõpilaskood: ......203468 MARM...........

Juhendaja: Aigar Hermaste, lektor
/nimi, amet/

Tallinn 2022

AUTHOR’S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

“..25..” ....April.......2022..

Author: ..Margo..Allikmäe..
/signature /

Thesis is in accordance with terms and requirements

“.......” .... 20….

Supervisor: ….........................
/signature/

Accepted for defence

“.......”...................20… .

Chairman of theses defence commission: ....
/name and signature/

Non-exclusive Licence for Publication and Reproduction of GraduationTthesis[1]

I, ____Margo_Allikmäe___ (name of the author) (date of birth: 23.07.1977.) hereby

1. grant Tallinn University of Technology (TalTech) a non-exclusive license for my thesis
____
___________Evaluation of production capacity through a simulation model______
____
____,

(*title of the graduation thesis*)

supervised by

_________________________Aigar Hermaste___________________,

(*Supervisor's name*)

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.

---

[1] *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.*

__Margo Allikmäe____ (*signature*)

____25.04.2022_____ (*date*)

Department of Mechanical and Industrial Engineering

THESIS TASK

Student: Margo Allikmäe 203465MARM
Study programme, MARM06/15
main speciality: Industrial Engineering and Management (MARM)
Supervisor(s): Lector, Aigar Hermaste, 6203269

Thesis topic:
Evaluation of production capacity through a simulation model
Simulatsioonimudel tootmisvõimsuste hindamiseks

Thesis main objectives:

1. Introduction to MRP production system
2. Introduction to Sales and Operations Planning process
3. Creation of a simulation model to evaluate of production capacity

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Writing an introduction to the MRP production system and S&OP process	29.11.21
2.	Development of a production model using the Tecnomatix Plant Simulation program	21.02.22
3.	Simulation of production through a simulation model and analysing results	28.03.22
4.	Submission of master's thesis	25.04.22

Language: …English… **Deadline for submission of thesis:** ".25." April 2022

Student: …..Margo Allikmäe ………………. ".27." ...September….2021.a
/signature/

Supervisor: Aigar Hermaste ………………….. "……." ………………….202…. a
/signature/

Consultant: ………………… …………………….. "……." ………………….202…. a
/signature/

Head of study programme: …………… ……………….. "…….”…………….202...a
/signature/

CONTENTS

PREFACE

The objective of this Master's Thesis is to develop a production model that would help to evaluate the production capacities of the production lines. The production model is created using the Tecnomatix Plant Simulation computer program. The production line capacity evaluation model will be employed in the S&OP process, where an overview of the efficiency and future needs in the use of production resources would be obtained through a production simulation.

In the introduction to the research, the choice of topics for the Master's Thesis is written seeking the goal of improving the efficiency and accuracy of production resource planning via implementing a special computer program. The first chapter focuses on the theories, the key principles of which lay the foundation for compiling the production model in the second chapter. The first chapter deals with:

- S&OP process;
- Material Requirements Planning (MRP).

The theoretical part is the background to describe the structure of production simulation and its specifics.

The second part of the work is focused on the creation of a production model using the Tecnomatix Plant Simulation program. The chapter sets out the criteria for selecting the raw data that have been used as the foundation for creating the production model. The created production model is used to simulate production based on S&OP data, as well as using different production scenarios to bring out the opportunities to perform simulation. The data obtained during the production simulations are analysed and the raw data of the production models are optimized as appropriate.

The selection of topics for the dissertation rest on the work experience as a production planner for PIPELIFE EESTI AS, as well as the need to anticipate resource efficiency, along with preparing a long-term production plan. To analyse the problem and offer solutions, the author believes that it requires a systematic and academic approach, which the Master's Thesis allows.

Keywords: Tecnomatix Plant Simulation, S&OP, Material Requirements Planning, Production Simulation.

Figures

Tables

Charts

List of abbreviations and symbols

S&OP	Sales and Operations Planning
MRP	Material Requirements Planning
ERP	Enterprise Resource Planning
MPS	Master Production Schedule
FIFO	First In First Out
JIT	Just In Time
CONWIP	Constant Work In Process
MPC	Manufacturing Planning and Control System
BOM	Bill of Materials
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinyl Chloride
OD	Outside Diameter
MOQ	Minimum Order Quantity

INTRODUCTION

The Master's Thesis explores the possibility of developing a simulation model that would help determine production capacities using a special computer program. The goal is to get an overview of:

- The efficiency of the operation of production lines.
- The production quantities confirmed during the S&OP process can be achieved in a given period.

The choice of the research topic is based on work experience as a production planner of PIPELIFE EESTI AS, where one of the areas of responsibility is the assessment of production resource needs in the S&OP process.

To evaluate production resources in the S&OP process, PIPELIFE EESTI AS applies Microsoft Excel, where the calculation inputs are:

- product cycle-time;
- quantities of products produced per month;
- buffer quantities of products in stock.

The output is a table showing the planned quantity of products in tonnes and the number of working hours to produce this quantity [see Table 1]. The same information is also available on a product-by-product basis.

Table 1 The result of demand planning in excel

Production Lines Names	Sum of April, tons	Sum of April, hours
PE5	127	798
PP2	126	344
PVC1	106	356

The goal of the dissertation is to make the planning of production resources more detailed and comprehensive, using the Tecnomatix Plant Simulation computer program, which has specially been created for production simulation. The same inputs as in the Excel file mentioned above are used to create the production model.
In the Tecnomatix Plant Simulation program, production modelling is performed utilizing two production lines.

The first part of the work gives an overview of the theory on which the simulation is constructed. The first chapter deals with:

- S&OP process;
- Material Requirements Planning (MRP) Production System.

In the case of the S&OP process, the theory is reviewed, and examples drawn from PIPELIFE EESTI AS are given. Through theory, the need for the assessment of production resources becomes more obvious.

Describing the essentials of the MRP production system helps to understand the production model and the analyses rooted in it. Pipelife Eesti AS uses an enterprise resource planning (ERP) system [see Figure 1], which was created by SAP, where the module deploys MRP principles for production planning. The raw data, i.e. production quantities, are obtained from the S&OP process, which is uploaded to SAP. Being the core of the production plan.

Figure 1 Enterprise Resources Planning modules

The second part of the research is the creation of a production model and its analysis. In the beginning of the chapter, an overview of the inputs is given on which the simulation is founded:

- products;
- production volumes;
- product cycle times.

The production process is described in detail. The second part of the chapter analyses the data obtained during the production simulations.

1. MRP AND S&OP

The chapter considers the S&OP process and one of the most common MRP production systems. The goal is to highlight the pillars of MRP and S&OP in which they are rooted. At the beginning of the chapter, the concepts of Push and Pull are introduced, which form the basis for the flows of information and material moving in production systems.

1.1 Push and Pull systems

From the definition of push and pull we get a general explanation of the meanings of the words in the production system:

"A Push System schedules the release of work based on demand, while a Pull System authorizes the release of work based on system status" [2: p.317].

The following equation is common and used today:

- push = make-to-stock;
- pull = make-to-order.

In a Push System, the master production schedule (MPS) gives the right to put the product on the line. The order moves with the product in the direction of product movement [see Figure 2].

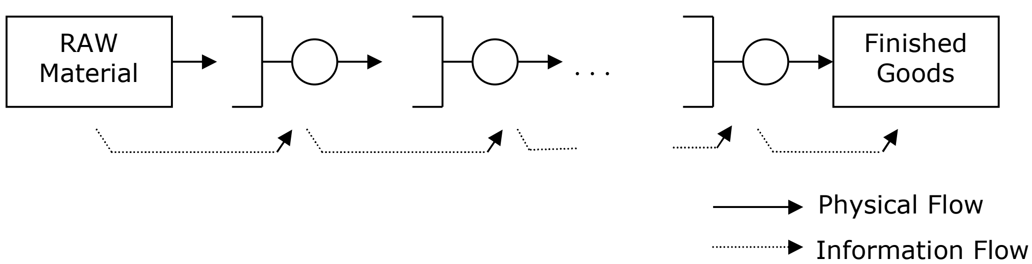


Figure 2 Push manufacturing system

In a Pull System, the route of the materials is the same as in a Push System. The difference is the direction of the order movement for making the product, which starts at the final product [see Figure 3].

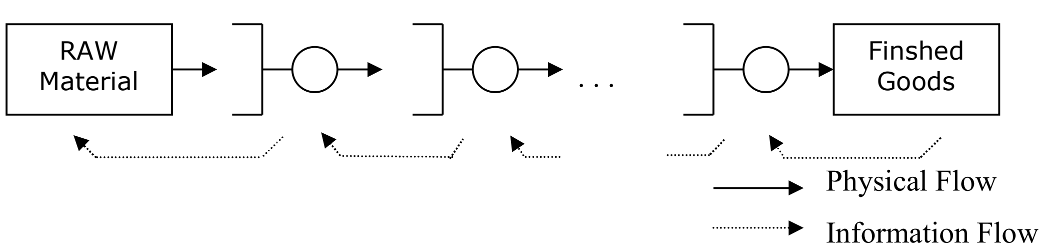


Figure 3 Pull manufacturing system

Push and Pull Production Systems have one common feature. Materials entering production, are subject to a first-in-first-out (FIFO) rule, which does not mean that the movement of materials in production is regulated in the same way. In the Push System, the movement of material is coordinated by orders from the production system based on MPS. In a Pull System, the amount of material is determined by the number of cards circulating on the WIP level of production, or by an agreed metric. A good example of using the Pull System in Pipelife Estonia AS is the pallet buffer with 8 pallets of different sizes. The vendor receives an image of the buffer [see Figure 4] by e-mail at three different times each day. If there are 2 base towers left in the row, the pallets will be added so that the maximum quantity of buffers allowed is full.

Figure 4 The buffer of pallets

Production systems are also divided on the basis of the principle of Push and Pull operation. For example, the best known:

- MRP – Push System;
- JIT – Pull System.

In the next section, we will look into the MRP system.

1.2 Material Requirements Planning

In the early 1970s, as American companies began to focus on more efficient production, with the support of the American Production and Inventory Control Society (APICS), companies introduced the MRP production system, which has become one of the most widely used production systems in the world today. The production system of Pipelife Eesti AS is also built on the principles of MRP. The production simulation in the second chapter is set up on the principles of MRP. Today, other production systems are also in use: JIT, CONWIP, etc., however, only MRP is covered in this dissertation.

1.2.1 The Basic MRP

Joe Orlickykeda, who is considered to be one of the creators of MRP has been characterized by MRP as "Copernican revolution". "MRP is as different from the traditional approaches to manufacturing planning and control as the Copernican model of the Earth rotating around the Sun was compared to the older model of the Sun rotating around the Earth. To do so, MRP provides formal plans for each part number, whether raw material, component, or finished good. "[5: p.14].

Of the MPC systems, MRP is the production system that requires the least production restructuring. MPR production is performed using two „pillars" and they are:

- quantities;
- time.

Two inputs are required for MRP to work:

- BOM (Bill of Materials)
- MPS (Master Production Schedule)

The above inputs are used to create a production model for the Master's Thesis.

Through BOM and MPS, ERP computer programs calculate material needs and production times [see Figure 5].

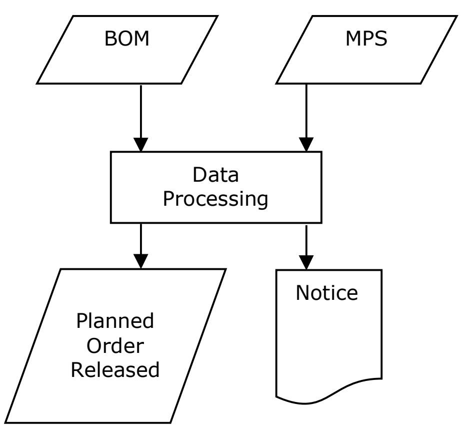


Figure 5 Simplified schematic of MRP

BOM helps identify the need in material to make a particular product and describes the relationships between products and materials using different levels of BOM [see Figure 6].

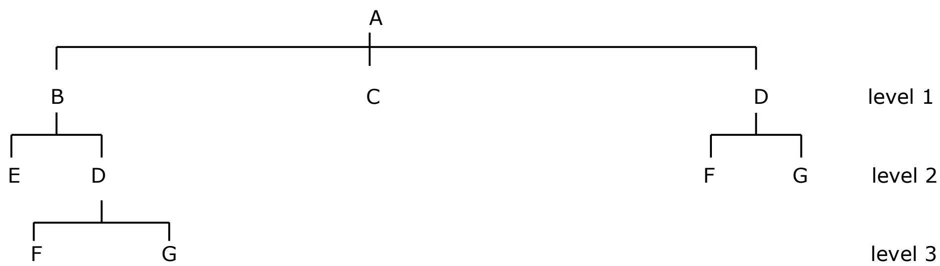


Figure 6 Multi-level tree for product A

With MPS, MRP calculates the material needs and quantities for production on time. The material movement in the MRP is done using the Push method, that is, when one production operation gets done, the product is moved to the next machine and to the final product.

With the introduction of computers and the creation of special programs that monitor the principles of MRP, there was a breakthrough and rapid spread of the MRP production system. The best-known computer programs today - SAP, Oracle ERP Cloud, Infor M3. Computer programs provide centralized material planning and control at the component level. The programs help:

- Monitor material quantities.
- Ensure timely ordering of materials.
- Plan production.

1.2.2 MRP operation

As noted in the previous section, the triumph of MRP began with the introduction of computers capable of managing thousands of different material codes and product names. For a better overview of the computational logic and process that works in MRP, I have provided an example of how a computer program based on MRP works [see Table 2].

		Period				
		1	2	3	4	5
Gross requirements			30		65	35
Scheduled receipts		100				100
Projected available balance	10	110	70	70	5	70
Planned order releases					100	
Lead time = 1 period						
Lot size = 100						

Table 2 MRP calculating system

Explanation of the meanings of the table for MRP calculating system:

- Gross requirements – forecast demand, period.
- Scheduled receipts - an order placed in production that is completed within a given period.
- Projected available balance – the stock of finished products at the end of the period.
- Planned order releases – is related to the projected available balance line. To prevent the stock from turning negative in the next period, MRP calculates the quantity that should be produced into the warehouse, while taking into account the parameters entered in the program – lead time, lot size, safety time, etc.
- Lead time – the time taken to make the product.
- Lot size - the batch size to be produced.

The logic of Table 2 is that stocks are not left negative or a minimum stock is set below which stocks must not fall.

In MRP, the task of a computer program is to calculate the times and quantities of ordering materials. An important aspect is the accuracy of stock balances, which is one of the biggest challenges to the operation of the MRP system. When working for a production company yourself, the wrong stock balance can cause untimely fulfilment of a customer order and lead to additional costs:

- In the form of a production line downtime.
- Contractual penalties by customers, for delayed delivery.
- Increase in logistics costs due to the need to use sub-optimal transport solutions to obtain the missing material into production.

There are two terms used in MRP to calculate needs:

- Gross requirement – component needs.
- Net requirement – the quantity of component actually needed. The result is obtained by deducting the quantity in stock from the quantity of component required.

In production, product BOMs are the basis for calculating the gross requirement. This approach is called *dependent demand*, which is considered to be one of the cornerstones of the MRP production system.

Dependent demand means that the need for one component affects the need for other components. To give an example of pipe production, the need for a pipe, in turn, creates a demand for raw materials, packaging materials, seals, and so on.

To obtain the necessary component for timely delivery, lead time is a critical part of the MRP system.

MRP uses a back-schedule approach:

- Back schedule – the first is the date on which the materials must be in production in order to begin with production of products. Purchase of materials needed for production or production of by-products is based on lead-time. With the aim that everything necessary is in stock for a specified time.

In the MRP system, it is common to add safety-time to lead-time to ensure that the material is available for a predetermined time. Normally, the material is ordered to the warehouse one period before the required time. Depending on the specifics of the production, this can be – week, month, etc. Such action should eliminate problems if the order is delayed or provide an opportunity to order the goods elsewhere if the main supplier has difficulties with delivery. As a rule, it is considered that ten to twenty percent of the materials on the list require closer monitoring by planners to ensure smooth production. [5: p.38].

1.3 Sales and Operations Planning

Our S&OP planning began in the late 1980s, with the need to provide timely and detailed financial forecasts by companies to investors. S&OP is a cyclical planning process. In manufacturing companies, the first input in the process is the sales forecast, used as a basis for the production volumes to be produced in a given period. Production volumes themselves are required:

- To assess the needs of production resources.
- To make a plan for purchasing raw materials.
- To determine inventory in stock.

The present dissertation focuses on the development of a production model that would help to estimate production capacities, and one of the main inputs to production simulation is the production volumes determined during the S&OP process. The objective is to assess the production capacity to produce a given quantity in a given period.

1.3.1 S&OP process

S&OP was invented in 1984 by Dick Ling, with the aim of reconciling the sales forecast, as the action plans needed to meet the budget and the company's strategic goals. Prior to that, in many companies, sales, finance and production operated separately in their own divisions. As a result, the goals were set separately, which could be contradictory. The goal of S&OP is to establish a common understanding of sales forecasts, delivery plans and inventory within the company. Over the years, the S&OP process has become the 5-step process we know today. The five stages of S&OP are:

1. Sales forecasting – making a sales forecast. Taking into account sales team input, sales from previous periods and analysing sales trends.
2. Demand planning – sales forecast evaluation and numbering. Where do the needs, stocks, agreements with customers, etc. originate from?
3. Supply Planning – the ability to make a given production volume is assessed. Assessment of the availability and risks of the required raw materials.
4. Pre-S&OP Meeting – bottlenecks are reviewed and solutions are proposed. The bottlenecks that can be identified can be:
    - There is not enough production capacity to produce predetermined quantities.
    - There are problems with the supply of raw materials.
5. Finalize S&OP and link to implementation – decisions are made on open issues and an action plan is put in place. .

The S&OP process is considered an important part of the management system through which management can ensure the implementation of its decisions. The cyclical nature of the process increases the chances of making the right decisions in a timely manner. The goal is to synchronize supply and demand [see Figure 7]. The better the balance between supply and demand, the more profitable the company's operations become.

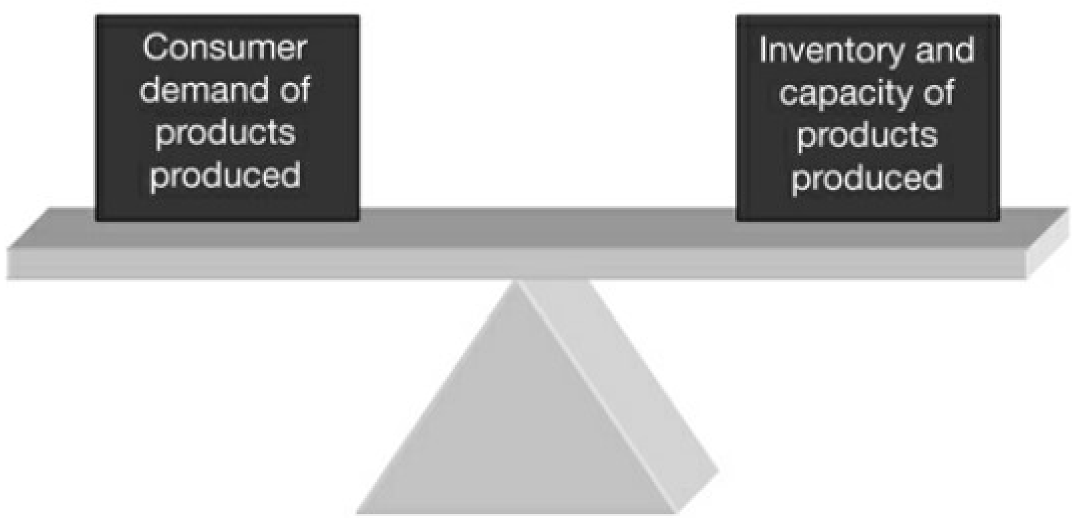


Figure 7 The balancing act between demand and supply

In the S&OP process, it is customary to look ahead to 12 months, with a main focus on 3 months. But a lot depends on the specifics of the companies. It is considered important that the process owner belongs to the management of the company in order to ensure the smooth operation of the process. Pipelife Eesti AS is the owner of the supply chain manager.

1.3.2 Sales forecasting process in S&OP

Compiling sales forecast consistently requires a lot of effort from many companies, as the number of sales items in a company can reach hundreds. Therefore, various computer programs are used, which try to predict the sales of future periods from the sales of previous periods through statistical methods.

Pipelife Eesti AS uses Optimact computer program, which communicates with ERP program or SAP. The data are uploaded to Optimact, which processes the data using statistical models and offers sales volumes for future periods [see Figure 8].

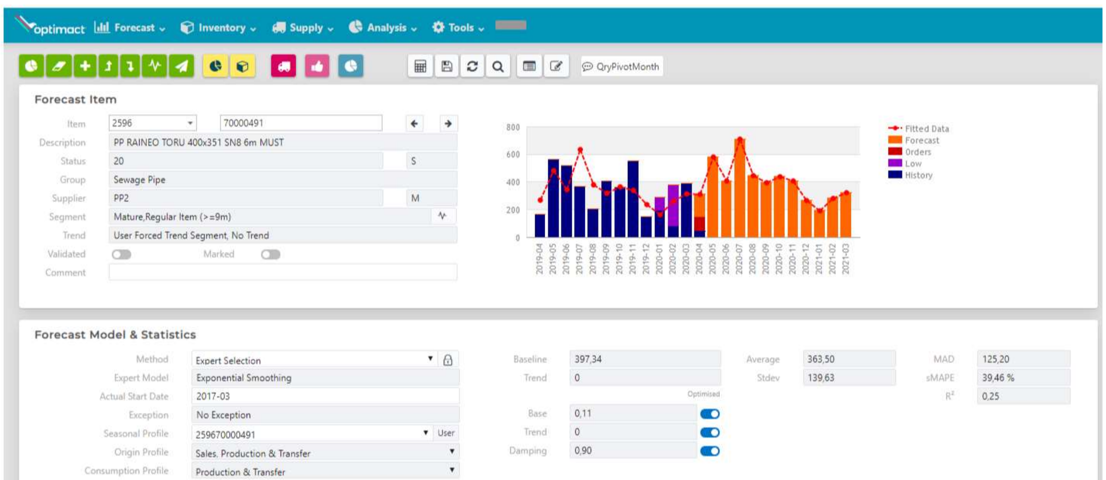


Figure 8 Optimact view of one product

Quantities offered by Optimact are sent to the sales team for review. Outliers are mentioned separately, i.e. products that then sold significantly more or less compared to the forecast in the previous period.

1.3.3 Demand planning process in S&OP

The purpose of the demand planning is to review the forecast for the future period and, if necessary, adjust the sales volume figures. Inputs for making changes come from:

- the sales team;
- the management.

For example, it is decided that certain products may not be out of stock in the following period, which will be avoided by increasing the amount of safety stock [see Figure 9] – to ensure product availability also in terms of growing demand.

Figure 9 Diagram of safety stock

Within Demand Planning process the following points are reviewed:

- Future sales campaigns.
- Launching new products.
- Products for which production is to be discontinued.

1.3.4 Supply planning process in S&OP

In the process of Supply Planning, sales volumes and production capacity are assessed. The ability to manufacture products is assessed in a given period. Assessing production capacity is the goal of this Master's Thesis, bearing in mind the purpose of finding the Golden mean between need and production capacity [see Figure 10].

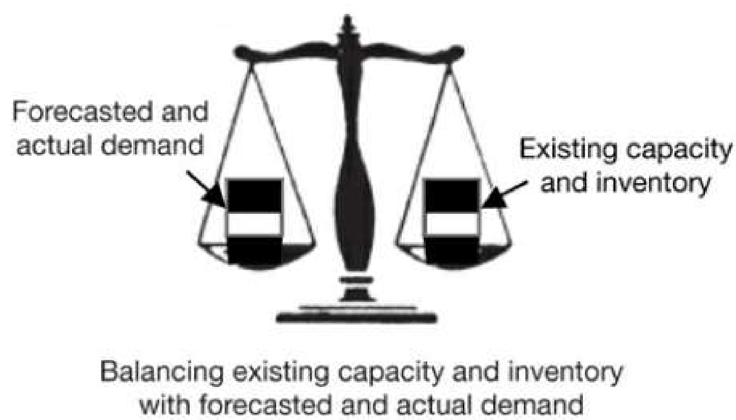


Figure 10 Operations planning

Capacity needs are reviewed in 12 monthly periods, as more detailed in analyses of one to three months. Classic ERP power planning hierarchy [see Figure 11].

Figure 11 Class A ERP planning hierarchy

1.3.5 Pre-S&OP and Finalize S&OP meetings

At the pre-S & OP meeting, solutions to the bottlenecks identified during the supply planning process will be found and coordinated between the departments. The final plan, which will be implemented, is approved at the final meeting of the S&OP process.
One of the results of the S&OP process is the production volumes to be produced. The agreed production volumes are uploaded to the ERP system. The output is the quantities offered by the ERP system:

- purchase of raw materials;
- to open production orders.

An example would be the view of the ERP system, where production recommendations for the production planner for one product are shown [see Figure 12].

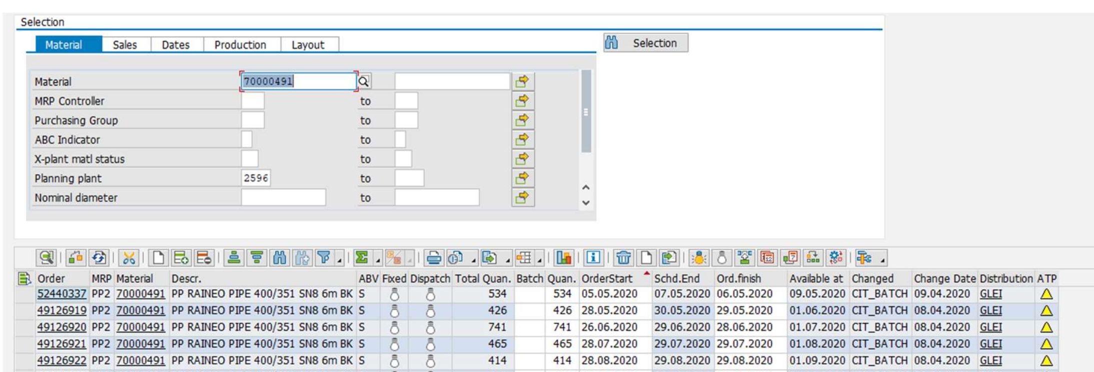


Figure 12 ERP system offers job opening

1.4 Summary of chapter

The purpose of the chapter was to introduce two processes:

- MRP – the fundamentals of which are the basis for the production model in the next chapter.
- S&OP – Introduce a process that results in the determination of production volumes as input to production simulation.

In the second chapter, the purpose of developing a production model is to find answer to the formulated question. Are there enough production resources to produce the production volumes determined during the S&OP?

2. PRODUCTION SIMULATION

The chapter deals with the creation of a production simulation model to estimate production capacities on the production lines of Pipelife Eesti AS. The production simulation model is created using the Tecnomatix Plant Simulation program.

Plant Simulation is a computer program developed by Siemens PLM Software. The software allows to simulate, visualize, analyse and optimize production systems.

2.1 Pipelife Estonia AS

Pipelife Eesti AS is a provider of plastic pipe systems, belonging to the Pipelife group, which operates in 26 different countries. Since 2012, it has belonged to the Pipelife, Wienerberger group. Pipelife Eesti AS is the largest manufacturer of plastic gas, water and sewerage pipes in Estonia. The Estonian pipe production unit is located in Jüri, Rae municipality. Pipelife Eesti AS uses three common plastics for the production of plastic pipes:

- Polyethylene (PE) – for producing pressure pipes (water supply, etc.), cable protection pipes, risers and telescopic pipes for hand-made PE wells;
- Polypropylene (PP) – for manufacture of external and internal sewerage pipes, storm water and drainage pipes, cable protection pipes;
- Polyvinyl Chloride (PVC) – for manufacture of external sewer and cable protection pipes

Plastic pipes are produced using extrusion. Extrusion is a method in which a molten polymer is forced through a moulding nozzle into a product of constant cross-section, in the case of Pipelife, into a tube. Pipelife Estonia uses eleven pipe production lines and a typical pipe production extrusion line structure [see Figure 13].

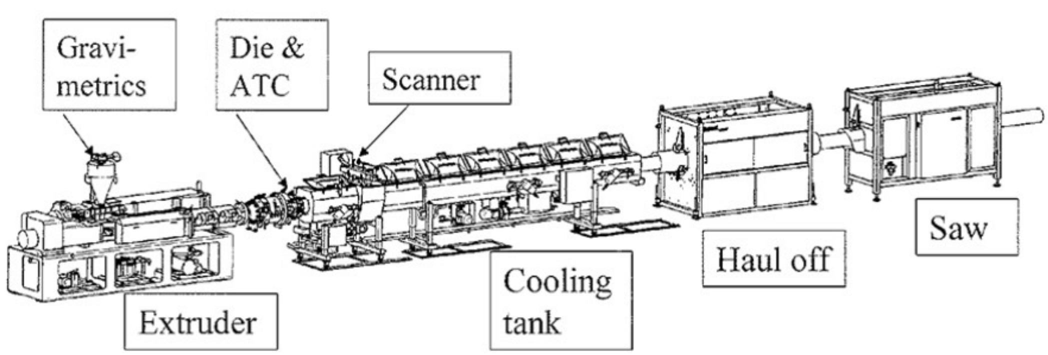


Figure 13 A common setup of pipe extrusion line

Below is a list of Pipelife Eesti AS production lines. The designations are the same as those used in Pipelife. The line designations show the abbreviation of the main raw material from which the pipes are manufactured on the production line. Each production line is accompanied by detailed information concerning pipes produced on the line and the nominal field diameters of the pipes that can be produced on the line:

- PE-2 – OD63-250 pressure and cable protection pipes, risers and telescopic pipes for manually made PE wells;
- PE-3 - OD160-400 pressure pipes, risers and telescopic pipes for manually made PE wells;
- PE4 - OD20-50 pressure pipes;
- PE5 - OD50-160 corrugated double-wall cable conduits;
- PE6 - OD110 corrugated double-wall cable protection and construction drainage pipes;
- PP1 - OD32-110 internal sewer pipes;
- PP2 – OD160-400 storm sewer pipes;
- PVC1 - OD100-200 sewer pipes;
- PVC2 - OD50-100 cable protection pipes;
- PVC3 - OD16-50 single-layer corrugated cable trays;
- PVC4 - OD58-160mm corrugated agricultural drainage pipes.

2.2 Tecnomatix Plant Simulation

The Tecnomatix Plant Simulation program was chosen for the dissertation as the program is available for study at Tallinn University of Technology.
The purpose of production simulation is to analyse production capacity through product cycle times and product exchanges.
In the course of the Master’s research, simulation models of two production lines were created. The production lines are as follows:

- PP2 – with 16 products;
- PVC1 – with 9 products.

Two simulation models were created to have a reference moment between production lines and to better find bottlenecks in the model.
The inputs of the simulation are the same inputs as in the MRP production system:

- time;
- quantity.

The following chapter provides a detailed overview of the inputs to the production model.

2.2.1 Inputs for simulation

The raw data of the production simulation are summarized in four tables:

- production information [see Appendices A 1];
- product information [see Appendices A 2];
- bill of materials for products [see Appendices A 3];
- products forecast per month [see Appendices A 4].

Due to the large amounts of data, the tables are presented in the annex.
The production information table has the following columns:

- Product code – unique product code.
- OD – the outside diameter of the pipe is the basis for grouping the pipes into a single product family. One of the main outputs of line setup is diameter, i.e. as a result of setup it is possible to produce pipes of a certain diameter. Setup is a long process that does not add direct value, so pipes of the same diameter are produced in succession thus increasing the efficiency of the line and the number of products produced over time.
- Cycle time – time per minute to make one product.
- A pack quantity - the size of the pack.

The Product information table contains the following information:

- Product code – unique product code.
- Description – in the product description. The description of the product includes the abbreviation of the main material of production of the product, the name of the product, the outside diameter of the product and the length of the product.
- Product line – the name of the production line where the product is produced.
- Bar or Roll – whether the product is roll or bar
- Length in meters – the length of the product.

The table of ‘Bill of material for products’ contains information on the materials used for the production and packaging of the pipe. Table information:

- Product code – unique product code.
- Base quantity – the quantity of products for which the amount of material required to produce is given in the Quantity column.
- Component code – unique code of material.
- Description – description of the material used to make the pipe.
- Quantity – the amount of material required to produce the quantity in the Base quantity column.
- Unit – symbol of the unit of raw material.

The ‘Products forecast per month’ table shows the production quantities per month for the products that should be produced in a given month during the S&OP process. The table shows the unique product code and month numbers. Under the numbers of months there is a quantity of products that should be produced per month to cover product needs.
The data in the four tables are used as a basis in the simulation model.

2.3 Creating a simulation

When creating the simulation model, the aim is to get an overview of the production line capacity through time use. In addition, by increasing the functionality of the Simulation Model program, collect the following information:

- Needs in material for pipe production and packaging.
- Number of packages of products entering the warehouse.

The data obtained during the simulation should make it possible to estimate production capacity and answer the question: *Can pre-determined quantities in the S&OP process be made within a specified period of time?* Additional information to be collected in the model:

- Material needs in the production and packaging of pipes on a monthly basis helps to assess the risks for the purchase of materials, as well as to plan purchases and deliveries.
- Receiving the quantities of product moving to the warehouse in a month allows you to plan storage, but also to assess the filling of the warehouse in future periods.

Production simulation models are made for two production lines and both models feature the same structure.
The structure of the production model of the Tecnomatix Plant Simulation program is explained through the PVC1 production line
[see Figure 14].

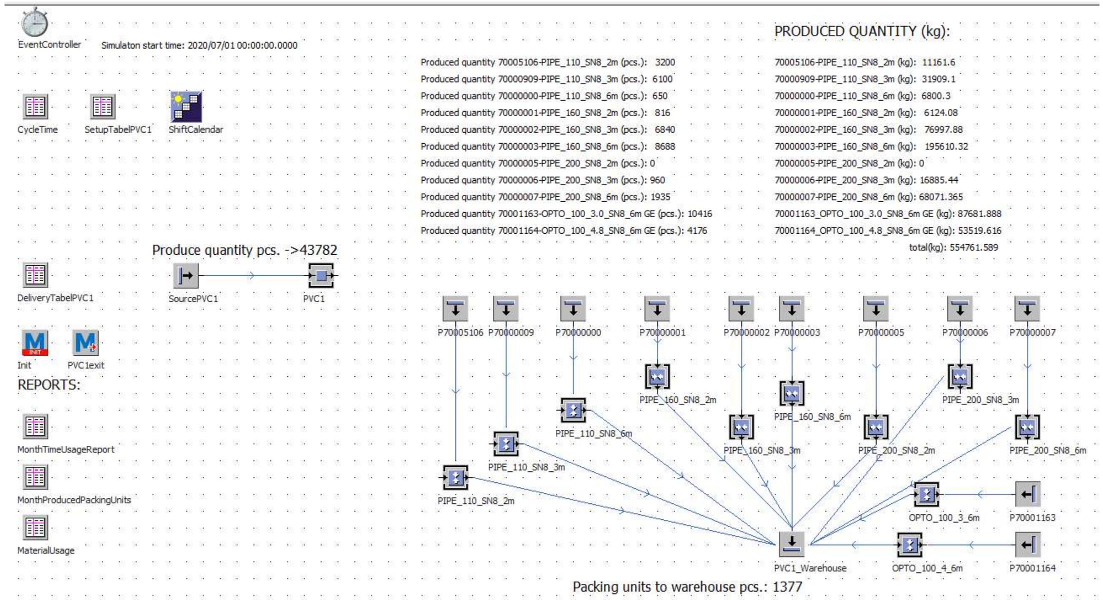


Figure 14 The model 2D view

2.3.1 Inputs tables for program

The inputs with the information necessary for the operation of the production simulation are given in the following tables:

- CycleTime;
- SetupTabelPVC1;
- DeliveryTabelPVC1.

The CycleTime table shows the Cycle times of the products manufactured on the production line [see Figure 15]. The format of the production time in the table is DDD: HH: MM: SS. XXXX i.e., when placing 111 seconds in the table, the result is 1:51. The same time format is used throughout the Tecnomatix Plant Simulation program.

	string 1	time 2
string	SAPItemCode	ProductionTime
1	PVC1_70005106	54.6000
2	PVC1_70000909	1:13.8000
3	PVC1_70000000	2:19.8000
4	PVC1_70000001	1:47.4000
5	PVC1_70000002	2:23.4000
6	PVC1_70000003	4:34.2000

Figure 15 Cycle time table from Tecnomatix Plant Simulation program

SetupTabelPVC1 is a matrix table [see Figure 16]. The first column of the table shows the products and the following columns – the transition times. The first row of columns shows the product in that column.

	string 0	time 1	time 2	time 3
string		PVC1_70005106	PVC1_70000909	PVC1_70000000
1	PVC1_70005106	0.0000	10:00.0000	10:00.0000
2	PVC1_70000909	10:00.0000	0.0000	10:00.0000
3	PVC1_70000000	10:00.0000	10:00.0000	0.0000
4	PVC1_70000001	11:00:00.0000	11:00:00.0000	11:00:00.0000

Figure 16 Setup table from Tecnomatix Plant Simulation program

DeliveryTabelPVC1 [see Figure 17] presents information about the products and quantities that must be produced by the beginning of the period specified in the table. The order of the products in the table is the order of production in the simulation model. The table has the following columns:

- Delivery Time – the end of the period by which the product should be ready. The time in the table 31: 00: 00: 00.0000 means that the product must be ready within 31 days from the start date of the simulation.
- MU – the location of the object in the model.
- Quantity – the quantity produced.
- Name – the name of the product in the simulation model.

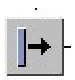
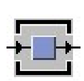
	time 1	object 2	integer 3	string 4	table 5
string	Delivery Time	MU	Quantity	Name	Attribute
10	31:00:00:00.0000	.UserObjects.PVC1_70001163	1440	PVC1_70001163	July_2020
11	31:00:00:00.0000	.UserObjects.PVC1_70001164	720	PVC1_70001164	July_2020
12	62:00:00:00.0000	.UserObjects.PVC1_70000000	0	PVC1_70000000	August_2020
13	62:00:00:00.0000	.UserObjects.PVC1_70000001	816	PVC1_70000001	August_2020

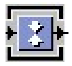
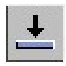
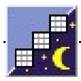
Figure 17 Delivery table from Tecnomatix Plant Simulation program

2.3.2 Objects used in the simulation

The following objects from the simulation program are used to create the simulation.

Objects:

- PVC1_70000000 - part – – in the simulation model, the product or pipe.
- P70000000 - container - a package unit that moves to a warehouse.
-  - source - starting point of the movement of the product or package.
-  - station - in the simulation model it is the symbol of the production line.

-  - assembly station - forms packages of products which move to a warehouse.
-  - drain - the endpoint of the simulation model, which is the warehouse in this simulation.
-  - shiftCalender – production schedule for the simulation model.
-  - eventContorller – determining the start and end time of the simulation.

2.3.3 Functions used in the simulation

The programs are written to operate the simulation model and to obtain data from the program. Programs are related to specific objects in the model. Except for the Init Method, which is responsible for deleting old data from reports when the simulation is started and adding a monthly column to the reports [See Appendices A 9].

2.3.3.1 Station related functions

Station is a simulation model of the production line and has been additionally written to compliment the program to move the products to the next stage [see Figure 18]. The task of the program is to route the pipes coming from the production line to the assembly station assigned to them, where the pipes are piled into a package.

```
if @.Name = a product name
        @.move(assemby station name)
elseif @.Name = a product name
        @.move(assemby station name)
end
```

Figure 18 The method structure

To obtain downtime and product change times from the production line, a program [See Appendices A 5] has been written that retrieves data from the station with the following commands:

- ?.statWorkingTime;
- ?.statSetupTime;
- ?.statSetUpCount;
- ?.statEmptyTime.

Based on the data gained, calculations are performed in the program and the results are added to the MothlyTimeUsageReport table.

2.3.3.2 Assembly station related function

At the assembly station, packages are formed from pipes that move on to the warehouse, getting the number and weight of packages moving to the warehouse in the MonthProducePackingUnits report. To do this, a program is written that adds the number and weight of the package moving to the warehouse under the correct month [See Appendices A 7]. There are as many assembly stations in the model as there are different products on the production line. [See Appendices A 7].

2.3.3.3 Drain

Drain is the end point of the simulation. Drain provides an overview of the quantities of packages that have moved to the warehouse. To obtain the data in the MaterialUsage table, a program [See Appendices A 8] has been added, where the quantities of materials needed for production are calculated on the basis of the product BOMs. The calculation results are added to the MaterialUsage table.

2.3.4 Data from simulation

The data obtained from the simulation are stored in three tables:

- MonthTimeUsageReport [See Figure 19] – The table provides an overview of production line operating hours, product changes and downtime by month. The most important columns in the table are:
  - Working time per month – aggregated production line operating time per month.
  - Setup time – the total time of product changes per month.
  - Setup account – number of product changes per month.
  - Station empty time – provides an overview of whether the production line has free time or not. If the station in the empty time column is minus, the specified quantities cannot be produced in the specified month.
- MonthProducedPackingUnits [See Figure 20] The table shows the monthly quantities of the products entering the warehouse and also shows the weight of the products. Each product is in a separate column.
- MaterialUsage [See Figure 21] the table presents the quantities of raw materials needed to produce the given quantities. The time period is a month.

The data in the three tables are the outputs of the simulation model. These data are the basis for the subsequent analysis.

Figure 19 MonthTimeUsageReport table

	string 0	time 1	time 2	time 3	time 4	time 5	integer 6	integer 7	time 8	time 9	integer 10
string	Month	Cumulative working time	Working time per month	Cumulative setup time	Setup time	Sum = production + setup time	Cumulative setup count	Setup count	Cumulative station empty time	Station empty time	Setup helping column
1	7_2020	0.0000	9:11:24:28.8000	0.0000	1:09:00:00.0000	10:20:24:28.8000	0	4	19:00:00:00.0000	8:03:35:31.2000	1
2	8_2020	9:11:24:28.8000	21:22:34:43.2000	1:09:00:00.0000	2:07:30:00.0000	24:06:04:43.2000	4	8	37:03:35:31.2000	4:17:55:16.8000	5
3	9_2020	31:09:59:12.0000	16:21:22:25.2000	3:16:30:00.0000	2:18:10:00.0000	19:15:32:25.2000	12	7	42:21:30:48.0000	10:08:27:34.8000	13
4	10_2020	48:07:21:37.2000	14:21:26:16.8000	6:10:40:00.0000	2:07:10:00.0000	17:04:36:16.8000	19	6	54:05:58:22.8000	13:19:23:43.2000	20

Figure 20 MonthProducedPackingUnits table

	string 0	integer 1	weight[kg] 2	integer 3	weight[kg] 4	integer 5	weight[kg] 6
string	month	70005106_PIPE_110_SN8_2m		70000009_PIPE_110_SN8_3m		70000000_PIPE_110_SN8_6m	
1	7_2020			48	12554.4		
2	8_2020	32	5580.8				
3	9_2020			26	6800.3	13	6800.3
4	10_2020			24	6277.2		

Figure 21 MaterialUsage table

	string 0	weight[kg] 1	weight[kg] 2	weight[kg] 3	weight[kg] 4
string		923100599_PVC K67	923101402_STABILOX G-TU/1113/5 XO PVC	923101443_PVC FILLER CHALK HYDROCARB 75T	923101402_STABILOX G-TU/...
1	7_2020	45999.601	670.952960000002	10311.48279	416.2881
2	8_2020	113784.66102	2133.9474	30556.60293	549.80706
3	9_2020	85866.8991200001	1488.18088	21601.99635	538.55266

3. Analysis of simulation results

The input to the simulation model is the production quantities of the products, which are determined during the S&OP process. The quantities of products produced are set out in the table in the Annex [See Appendices A 4]. Different production scenarios have been performed on the PVC1 production line during production simulations to analyse different results. On the PP2 production line, the production simulation has been performed only with S&OP data to check the operation of the simulation model on the other line. The time results of the simulation are presented in the format of Tecnomatix Plant: DDD:HH:MM:SS.XXXX (days:hours:minutes:seconds.split seconds). Through simulations, we want to get an answer as to whether the product quantities determined during the S&OP can be made in a given time period.

3.1 PVC1 and PP2 product lines work calendar

When performing simulations on the PVC1 and PP2 production lines, the production work schedule is 24/7 and production downtime related to production leave has been determined. [see Table 3].

Month	Work days per month	Production holidays
7_2020	19:00:00:00.0000	12:00:00:00.0000
8_2020	29:00:00:00.0000	2:00:00:00.0000
9_2020	30:00:00:00.0000	
10_2020	31:00:00:00.0000	
11_2020	30:00:00:00.0000	
12_2020	13:00:00:00.0000	18:00:00:00.0000
1_2021	28:00:00:00.0000	3:00:00:00.0000

Table 3 Work schedule

3.2 PVC1 product line

Three simulations with the following scenarios have been performed on the production line:

1. Quantities of products determined during the S&OP process. The products are divided into production groups by diameter and each product is on the line once a month.
2. In the first simulation, the quantities per month are divided into two, i.e. the same products are produced twice a month. For the simulation period 3 months have been chosen – July, August and September. Instead of the original 19 production orders, there are now 38 production orders in the simulation.

3. The simulation uses the same data and period as the other simulation. The difference is that we multiply the September quantities by two. Which means that instead of 25333 products, 33562 products are due in three months.

3.3.1 PVC1 the first simulation

The most important information for the simulation is available in the MonthTimeUsageReport table [see Table 4], which provides an overview of the use of the production time resource. Based on the information in the table, the products planned for December will not be produced. However, in November, the occupancy rate of the production line is low, and the line is idle for 16 days. Re-planning means that half of the six given December products will be actually made in November. Carrying out this change in the raw data of the simulation, the result is as follows [see Table 5]. The partial production of the December products in November gives a result where we can say that the quantities given in S&OP can be made taking into account the time resources of the line. Products that were imported from December to November and the same product was planned to be produced in November, then the given quantities were added together. As a result, the number of product exchanges decreased by two. The initial number of product exchanges was thirteen in two months, then eleven after the changes.

Table 4 Production time usage table

Month	Working time per month	Setup time	production + setup time	Setup count	Product line empty time
7_2020	9:11:24:28.8000	1:09:00:00.0000	10:20:24:28.8000	4	8:03:35:31.2000
8_2020	21:22:34:43.2000	2:07:30:00.0000	24:06:04:43.2000	8	4:17:55:16.8000
9_2020	16:21:22:25.2000	2:07:20:00.0000	19:04:42:25.2000	7	10:19:17:34.8000
10_2020	14:21:26:16.8000	2:07:10:00.0000	17:04:36:16.8000	6	13:19:23:43.2000
11_2020	11:00:46:43.2000	2:07:20:00.0000	13:08:06:43.2000	7	16:15:53:16.8000
12_2020	10:21:11:24.0000	2:07:10:00.0000	13:04:21:24.0000	6	-4:21:24.0000
1_2021	13:13:37:34.2000	2:07:30:00.0000	15:21:07:34.2000	8	12:02:52:25.8000

Table 5 Production time usage table after optimization

Month	Working time per month	Setup time	production + setup time	Setup count	Product line empty time
7_2020	9:11:24:28.8000	1:09:00:00.0000	10:20:24:28.8000	4	8:03:35:31.2000
8_2020	21:22:34:43.2000	2:07:30:00.0000	24:06:04:43.2000	8	4:17:55:16.8000
9_2020	16:21:22:25.2000	2:07:20:00.0000	19:04:42:25.2000	7	10:19:17:34.8000
10_2020	14:21:26:16.8000	2:07:10:00.0000	17:04:36:16.8000	6	13:19:23:43.2000
11_2020	17:03:17:12.0000	2:07:30:00.0000	19:10:47:12.0000	8	10:13:12:48.0000
12_2020	4:18:40:55.2000	1:09:00:00.0000	6:03:40:55.2000	3	6:20:19:04.8000
1_2021	13:13:37:34.2000	2:07:30:00.0000	15:21:07:34.2000	8	12:02:52:25.8000

The simulation model allows to get the following information about the use of the time resource:

- Tonnage of pipes produced.
- The need in materials for the produced pipes by months.
- Quantities of pipe packaging moving to the warehouse.

The simulation shows that in seven months we plan to produce 659.2 tons of pipes. The MaterialUsage table shows the raw material needs by month. Of the raw materials needed to make the pipe, the three main materials account for 96.68% of the total weight, or 637.5 tonnes [see Table 6]. Specifying the need in raw materials by months helps to plan the long-term purchase of materials. Let's take K67 and knowing that one load is 25 tons and having information about the need in material on a monthly basis, we can construct a monthly supply need for the material, taking into account that the warehouse must not go into the red [See Table 7]. The MonthProducedPackingUnits table provides information on the quantities of packages moving to the warehouse per month [see Table 8]. Keeping in mind the information in the table, it is possible to plan the placement of goods in the warehouse and calculate the need for storage space.

Table 6 Material needs for three main materials per month

Month	PVC K67	STABILOX G-TU/ 1113/5 XO PVC	PVC FILLER CHALK HYDROCARB 75T
7_2020	46 000	671	10 311
8_2020	113 785	2 134	30 557
9_2020	85 867	1 488	21 602
10_2020	75 317	1 235	18 756
11_2020	89 489	1 804	24 546
12_2020	22 796	161	4 177
1_2021	67 789	1 215	17 648
Total (kg)	501 042	8 708	127 597

Table 7 Delivery schedule for k-67

Month	PVC K67 demand	Truck loads	kg	Delta
7_2020	46 000	3	75 000	29000
8_2020	113 785	4	100 000	15215
9_2020	85 867	4	100 000	29438
10_2020	75 317	3	75 000	29031
11_2020	89 489	3	75 000	14542
12_2020	22 796	2	50 000	41746
1_2021	67 789	3	50 000	23957

Table 8 Movement of packing units to the warehouse by month base

Month	70000001_PIPE_160_SN8_2 m pcs.	70000002_PIPE_160_SN8_3 m pcs.	70000003_PIPE_160_SN8_6 m pcs.
7_2020		88	
8_2020	34	47	111
9_2020		47	79
10_2020		43	71
11_2020		60	101
12_2020			
1_2021	34	34	56

3.3.2 PVC1 the second simulation

In the second simulation, we only look into quarterly data, that is, the period from July to the end of September. The production quantities by months are divided into two production cycles i.e., the same product is on the production line twice a month. Result of simulation time resource usage [see Table 9]. Compared to the first simulation, the number of product changes doubled. The total time of product exchanges increased from 5 days to 12 days [see Table 10]. Demonstrating the importance of the number of product changes in the planning of the time resource of the production line. One hundred and forty-three product change hours became two hundred and ninety-eight hours, or an increase of one hundred and eight percent.

Table 9 Production time usage table

Month	Working time per month	Setup time	Production + setup time	Setup count	Station empty time
7_2020	9:11:24:28.8000	3:05:00:00.0000	12:16:24:28.8000	8	6:07:35:31.2000
8_2020	21:22:34:43.2000	4:15:00:00.0000	26:13:34:43.2000	16	2:10:25:16.8000
9_2020	16:21:22:25.2000	4:14:40:00.0000	21:12:02:25.2000	14	8:11:57:34.8000

Table 10 Comparison of product changes data between two simulations

Month	Setup time		Setup count	
	Simulation one	Simulation second	Simulation one	Simulation second
7_2020	1:09:00:00.0000	3:05:00:00.0000	4	8
8_2020	2:07:30:00.0000	4:15:00:00.0000	8	16
9_2020	2:07:20:00.0000	4:14:40:00.0000	7	14

The calculations of the second simulation highlight the importance of the number of product changes on the production line and its effect on the time resource efficiency of the line.

3.3.3 PVC1 the third simulation

In the third simulation, the quantities in September have doubled compared to the second simulation i.e., instead of 25333 products, 33562 products have to be produced in quarter three. The result of the simulation considering the time resource is [see Table 11].

Month	Working time per month	Setup time	Production + setup time	Setup count	Product line empty time
7_2020	9:11:24:28.8000	3:05:00:00.0000	12:16:24:28.8000	8	6:07:35:31.2000
8_2020	21:22:34:43.2000	4:15:00:00.0000	26:13:34:43.2000	16	2:10:25:16.8000
9_2020	27:07:20:24.0000	3:16:40:00.0000	31:00:00:24.0000	11	-1:00:00:24.0000
10_2020	6:11:24:26.4000	22:00:00.0000	7:09:24:26.4000	3	23:14:35:57.6000

Table 11 Production time usage table

The table of time resources in the simulation shows that the quantity planned for September cannot be produced in one month, which is why the 7-day part of the production resource in October was used. When optimizing the production plan, we take into account the experience gained in the second simulation, the importance of product exchange on time resource efficiency – to gain clean production time, with the aim of producing the specified quantities in the second quarter. We make the following changes to the DeliveryTabel data:

- To reduce the number of product exchanges, products would be produced once a month.
- The production of some products is raised for earlier periods, if the raised product is already produced in the same month, then the quantities are summed up so that there is only one production.

Optimization result compared to the number of products [See Table 12]. Result of production simulation after optimization of raw data
[See Table 13].

Table 12 Product quantities per month

Month	Production quantities per month	Production quantities after optimization	Delta
7_2020	6 672	10 216	3 544
8_2020	10 432	13 044	2 612
9_2020	16 458	10 302	-6 156
Total	33 562	33 562	0

Table 13 Production time usage table

Month	Working time per month	Setup time	Production + setup time	Setup count	Product line empty time
7_2020	13:08:57:02.4000	2:07:10:00.0000	15:16:07:02.4000	7	3:07:52:57.6000
8_2020	26:02:41:00.0000	2:07:30:00.0000	28:10:11:00.0000	8	13:49:00.0000
9_2020	25:17:06:00.0000	1:09:10:00.0000	27:02:16:00.0000	4	2:21:44:00.0000

The optimization of the production plan resulted in the specified quantities being made within three months. The number of product changes decreased to fifteen from thirty-eight. In terms of time, instead of two hundred and ninety-eight hours on product exchanges it takes one hundred and forty-three hours, which makes one hundred and fifty-five hours less.

During the two simulations, the need in raw materials can be changed. Let's have a look at one of the basic raw materials on the PVC1 line marked K67. The raw material need for the first simulation is as follows [See Table 14]. During the optimization of the production plan, the needs in K-67 material also change per month [See Table 15]. Optimizing the production plan will also lead to a change in the quantities of packages moving to the warehouse. For example, an OD160mm 3m compact pipe is taken, the table shows the quantities of the package moving to the warehouse during the first and second course [See Table 16].

Table 14 K67 need and trucks delivery schedule the first simulation

Month	PVC K67 demand	Truck loads	kg	Delta
7_2020	46 000	3	75 000	29 000
8_2020	113 785	4	100 000	15 215
9_2020	140 815	6	150 000	24 400
10_2020	30 919	1	25 000	18 481

Table 15 K67 need and trucks delivery schedule after optimization

Month	PVC K67 demand	Truck loads	kg	Delta
7_2020	65 180	4	100 000	34 820
8_2020	136 084	5	125 000	23 736
9_2020	130 255	5	125 000	18 481

Table 16 OD160mm 3m compact pipe packages units to the warehouse

	70000002_PIPE_160_SN8_3m	
Month	The first simulation	The second simulation
7_2020	88	135
8_2020	47	94
9_2020	94	

3.4 PP2 product line

On the PP2 production line model, we perform a simulation with S&OP data. The time resource table obtained as a result of the simulation illustrates that the given quantities can be made in the given months [See Table 17]. However, looking at the 'Product line empty time' column, we can see that the line occupancy rate is low for several months [See Chart 1]. Such information helps to plan line maintenance, repairs, and it draws attention to the possibility of sales growth during these months.

Month	Working time per month	Setup time	production + setup time	Setup count	Product line empty time
7_2020	12:02:38:46.8000	5:01:00:00.0000	17:03:38:46.8000	7	1:20:21:13.2000
8_2020	15:05:57:43.8000	6:09:30:00.0000	21:15:27:43.8000	12	7:08:32:16.2000
9_2020	13:01:32:57.6000	6:08:00:00.0000	19:09:32:57.6000	9	10:14:27:02.4000
10_2020	14:23:59:43.2000	6:08:30:00.0000	21:08:29:43.2000	10	9:15:30:16.8000
11_2020	8:06:34:22.2000	6:07:30:00.0000	14:14:04:22.2000	8	15:09:55:37.8000
12_2020	5:03:30:52.8000	5:00:30:00.0000	10:04:00:52.8000	5	2:19:59:07.2000
1_2021	6:12:33:00.0000	6:06:30:00.0000	12:19:03:00.0000	6	15:04:57:00.0000

Table 17 Production time usage table

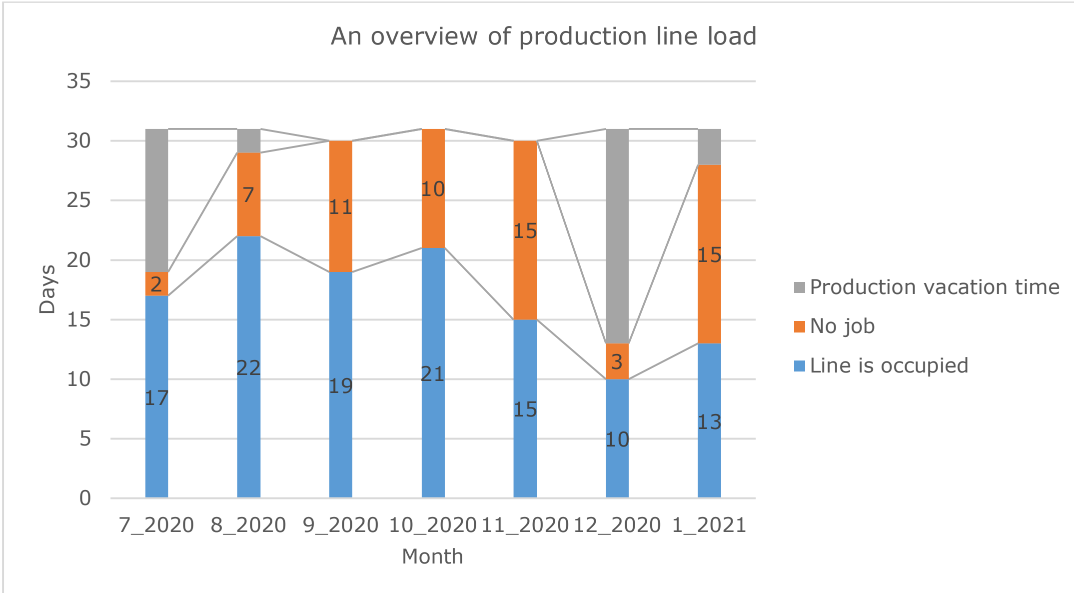


Chart 1 An overview of production line load

The additional information obtained from the simulation provides an overview of the need in raw materials and enables the creation of raw material delivery schedules, which were also completed on the PVC1 production line. The two main granule material needed to produce the pipe on the PP2 production line make 97.7% of the total weight. Compiling an initial delivery schedule will help you better manage the cost of purchasing the material, and look for better deals in the market, knowing your material demand in advance. The needs in the two basic materials are as follows [See Table 18]. Having information about the need in the material, we can plan the initial supply. Given that the stock balance cannot go into the red and the capacity of one container is 26000 kg, the demand for raw material loads would be as follows: [See Chart 2].

Month	**923101411_PP NORMAL MODULUS (PP)**	**923100481_PP HIGH MODULUS (PPHM)**
7_2020	59 122	22 531
8_2020	80 802	34 614
9_2020	65 474	21 322
10_2020	69 888	49 507
11_2020	48 728	14 192
12_2020	22 804	15 126
1_2021	30 886	14 192
Total (kg)	377 704	171 484

Table 18 Material needs for two main materials

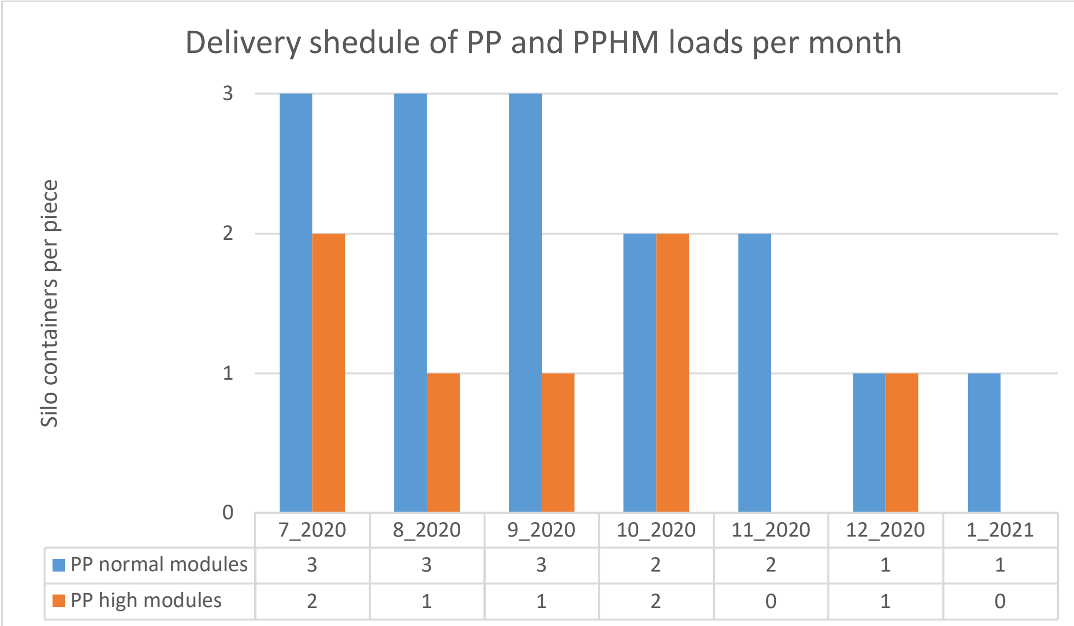


Chart 2 Delivery schedule two main raw materials

The quantities of the package moving to the warehouse are calculated during the simulation and on the PP2 line the author has indicated the OD200 pipe numbers from the report [See Chart 3]. Through the quantities of the packing units, you can make initial storage plans for storing the pipes in the warehouse. E.g., there is no need to leave an area for 100 packages to store 70000259_PRAGMA_200_SN8_6m pipe. Resulting from the fact that 23 packs of pipes come to the warehouse in a month, then you may plan the storage area for 46 packs i.e., a two-month stock, which is a sufficient area for storing the product.

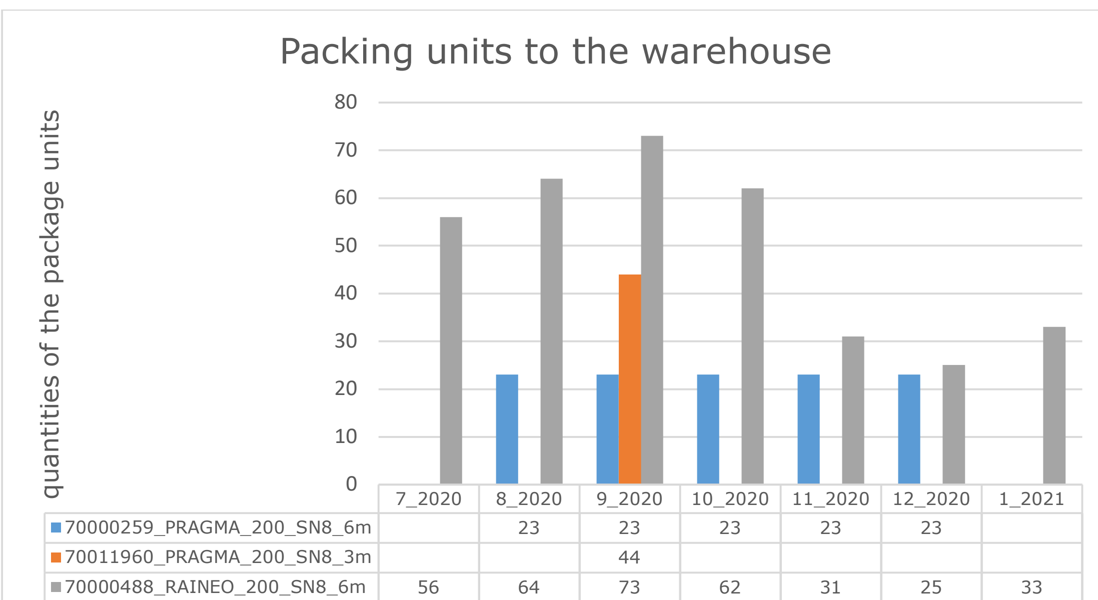


Chart 3 The quantities of the package moving to the warehouse

3.5 Summary of model simulations

The chapter deals with the results of four simulations, three of which are on the PVC1 production line and one on PP2. The purpose of the Master's Thesis was to create a production simulation model, which can be used to assess production capacities on a pipe production line. Production capacity is evaluated through the use of time resources in the production line.

The results of the simulation with the model created in the Tecnomatix Plant Simulation program were analysed in this chapter, where the main emphasis is on the evaluation of the production capacity of the production line through time. The products and quantities determined during the S&OP process, which must be made by a specified period of time, became the raw data for the simulation. In two simulations for the PVC1 line, the original data were modified to better highlight the different results, the lack of production capacity and finding solutions to such situations. In conclusion, the number of product changes is a relevant factor for the efficient use of the time resource of the production line.

When creating the simulation program, functionality was added to the program, as a result of which it is possible to get the quantities of raw material needs on a monthly basis and, besides, identify the number of packages on a basis of products that go to the warehouse monthly. In the analysis of the simulation data, the needs in the main raw materials were reviewed and an initial delivery schedule was created, assuming that the material quantities in stock should not become negative. Package quantity numbers based on the products moving monthly to the warehouse were received resulting from a few examples, without a thorough analysis, as the main purpose of the dissertation was to assess the production capacity of the production line.

As the goal of the author of this Master's Thesis was to create a working simulation model, applying a simulation model to evaluate production capacities and analysing the results, it can be stated in this chapter that the goal of the dissertation is achieved. One solution was proposed to estimate the production capacities on the production line during the S&OP process.

The possibilities of the Tecnomatix Plant Simulation program for the analysis of production activities are much wider than the possibilities that were used in the current dissertation. Seeing the use of this program in the future, you would definitely like to explore and add an opportunity to identify the needs of operators on the production line. Such an approach would mean that the different lines should be brought together in one model. Creating a simulation model for estimating production capacity can go into greater detail, but whether it is plausible requires clarification when setting a user goal.

The simulation model created today provides an answer to the currently set goal. Which is to find an answer to the question – can the production quantities determined during the S&OP process be made within a certain period of time?

SUMMARY

The goal of the Master's Thesis was to get an answer to the question formulated during the S&OP process – is the production resource sufficient to produce predetermined quantities in a certain period of time? According to the author, this was achieved using the Tecnomatix Plant Simulation program.

While learning to use the Tecnomatix Plant Simulation program, the amount of data that can be obtained during the simulation was expanded. Therefore, the following monthly reports were added to the work, such as the production resource table:

- Quantities of raw material required for pipe production and for packaging.
- Number of packages moving to the warehouse by product.

The attached reports show the ability of the Tecnomatix Plant Simulation program to simulate production and the ability to generate data.

In the course of the research, a simulation model was created to estimate the production capacity for two production lines – PVC1 and PP2. The initial data for the simulation model on product quantities came from the S&OP process, but the simulations were also performed on the basis of production scenarios created by the author. During the simulations, the use of the time resource of the production line was reviewed and analysed, the shortest period was one month. The analyses demonstrated that a factor of utmost importance on the production line is the number of product exchanges, as product exchanges on the pipeline are a time-consuming activity. In one of the simulations within the framework of this dissertation, the author had to reduce the number of product changes from thirty-eight product changes to fifteen product changes to perform the given production volumes, which meant releasing one hundred and fifty-five hours on the line for production.

Reports on raw material needs as well as the number of packages moving to the warehouse have been added along with learning the opportunities of the Tecnomatix Plant Simulation program. Expanding the capacity of the simulation model to provide more information that can be used and presented in the S&OP process. Based on the information needs of raw materials, the simulated basic raw material deliveries were obtained to cover the need in materials for the pipe production. The report on packing units moving to the warehouse makes it possible to plan the storage of products in the warehouse, but this topic was not thoroughly addressed in the current Master's Thesis. The main goal of the thesis was to create a simulation model for estimating production capacities.

Working with the Tecnomatix Plant Simulation program in the course of writing the Master's Thesis not only introduced the program to the author but appeared to provide even wider opportunities for doing job. Implementing the program in the work environment will definitely require more self-learning and the current programs written independently for obtaining Tecnomatix Plant Simulation data should be improved. Anyway, this requires continuous learning and working with the Tecnomatix Plant Simulation program beyond this dissertation.

The goal of finding an answer to the issue of the time resource of the production line was fulfilled and through the Master's Thesis solutions were found that can be considered for implementing in a real work environment.

KOKKUVÕTE

Magistritöö eesmärgiks oli saada vastus S&OP protsessi käigus esitavale küsimusele – kas tootmisressurssi on piisavalt, et toota ära kindlal ajaperioodil ettemääratud kogused? Autori arvates see õnnestus, kasutades Tecnomatix Plant Simulation programmi.

Töö käigus õppides Tecnomatix Plant Simulation programmi kasutama, laines andmete hulk mida simulatsiooni käigus on võimalik saada. Seetõttu lisandusid töösse järgmised raportid, mis on samuti kuupõhised nagu tootmisressurssi tabel:

- Toormaterjali kogused, mida vajatakse toru tootmiseks ja pakkimiseks.
- Lattu liikuvate pakküksuste arv toodete kaupa.

Lisandud raportid näitavad Tecnomatix Plant Simulation programmi võimekust tootmise simuleerimiseks ja andmete genereerimise võimekust.

Töökäigus sai loodud simulatsioonimudel tootmisvõimsuse hindamiseks kahe tootmisliini jaoks – PVC1 ja PP2. Simulatsioonimudeli algandmed tootekoguste kohta tulid S&OP protsessist, kuid sai simulatsioone tehtud ka enda loodud tootmise stsenaariumite põhjal. Simulatsioonide käigus vaadati ja analüüsiti tootmisliini ajalise ressurssi kasutamist, väiksemaks perioodiks oli üks kuu. Analüüsid näitasid, et väga oluliseks faktoriks tootmisliinil on tootevahetuse arv, kuna tootevahetused torutoomiseliinil on ajaressurssi nõudev tegevus. Ühes magistritöös tehtavas simulatsioonis tuli etteantud tootmismahtude ära tegemiseks vähendad tootevahetuste arvu kolmekümne kaheksalt tootevahtuselt viieteistkümne tootevahetusele, mis tähendas ajaliselt saja viiekümne viie tunni vabastamist liinil tootmisejaoks.

Tecnomatix Plant Simulation programmi tundma õppimise käigus lisandunud raportid toormaterjali vajadustest, kui ka pakkeüksuste arvust, mis liiguvad lattu. Laiendades simulatsioonimudeli võimkust anda rohkemat infot, mida saab kasutada ja esitleda S&OP protsessis. Toormaterjalide vajaduste infopõhjal sai simuleeritud põhi toormaterjali tarnete koguseid, katmaks ära materjalide vajadust toru tootmiseks. Lattu liikuvate pakküksuste raport võimaldab planeerida toodete ladustamist lattu, kuid praeguse magistritöös see teema põhjalikku käsitlemist ei leidnud. Magistritöö põhieesmärgiks oli luua simulatsioonimudel tootmisvõimsuste hindamiseks.

Tecnomatix Plant Simulation programmiga töötamine magistritöö käigus, küll tutvustas seda programmi, kuid võin öelda, et see programm saab veelgi paremini enda jaoks tööle panna. Programmi kasutuselevõtt töökeskkonnas nõuab kindlasti rohkemat õppimist enda poolt ja praegused enda poolt kirjutatud programmid Tecnomatix Plant

Simulation andmete kättesaamiseks tuleks viia paremale tasemele. Kuid see nõuab pidevat õppimist ja töötamist Tecnomatix Plant Simulation programmiga edasi peale magistritööd.

Eesmärk, saamaks vastust liini ajaressurssi kasutamise kohta sai täidetud ja läbi magistritöö sai leitud lahendusi, mida saab kaaluda reaalses töökeskkonnas kasutada.

LIST OF REFERENCES

[1] N. Modig ja P. Åhlström, See on Lean, Tallinn: Äripäev, 2016.

[2] D. H. Sheldon, World class sales and operations planning, J. Ross Publishing, 2006.

[3] W. B. Miller ja L. V. Schenk, Tõhus tootmine, Director, 2002.

[4] W. J. Hopp ja M. L. Spearman, Factory Pyhsics, 3nd toim., New York: McGraw-Hill, 2008.

[5] T. E. Vollman, B. L. William ja D. C. Whybark, Manufacturing Planning and Control Systems, 4nd toim., New York: McGraw-Hill, 1997.

[6] S. Chopra ja P. Meindl, Supply Chain Management, 6nd toim., Harlow: Pearson Eduaction Limited, 2016.

[7] TalTech Inseneriteaduskond, "Inseneriteaduskonna Lõputöö Nõuded," 19 6 2019. [Online]. Available: https://www.ttu.ee/public/i/Inseneriteaduskond/dekanaat/Inseneriteaduskonna_loputoode_nouded.pdf. [Accessed 3 2 2020].

[8] TalTech Infotehnloogia teaduskond, „Lõputööde koostamise ja vormindamise juhend," 2018. [Võrgumaterjal]. Available: https://www.ttu.ee/public/i/infotehnoloogia-teaduskond/Tudengile/Vormid/ITT_loputoode_juhend_EST.pdf. [Kasutatud 3 2 2020].

[9] H. E. Kabral, Tootmiskorraldus, Tallinn: TTÜ Kirjastus, 1999.

[10] C. C. Bozarth ja R. B. Handfield, Introduction to Operation and Supply Chain Management, 4nd toim., Harlow: Pearson Education Limited, 2016.

[11] N. Slack ja A. Brandon-Jones, Operation and Process Management, 5nd toim., Harlow: Pearson Education Limited, 2018.

[12] T. Ohno, Toyota Production System, Portland, Oregon: Productivity Press, 1988.

[13] G. Relph ja C. Milner, The Inventory Toolkit, 2nd toim., New York: Kogen Page, 2019.

[14] G. Richards ja S. Grinsted, The Logistics and Supply Chain Toolkit, 2nd toim., London: Kogan Page, 2016.

[15] M. R. Mes, Simulation Modelling using Practical Examples: A Plant Simulation Tutorial, University of Twente, 2017.

[16] D. J. Piasecki, Inventory Management Explained, Ops Publishing, 2009.

[17] P. S. Pande, R. P. Neuman ja R. R. Cavanagh, Kuue Sigma Tee, Tallinn: Pegasus, 2002.

[18] S. N. Chapman, The Fundamentals of Production Planning and Control, Harlow: Pearson Education Limited, 2005.

[19] P. K. Wiseman, Sales Forecasting, CreateSpace Independent Publishing Platform, 2019.

[20] J. Chase, „Practical Sales and Operations Planning," John Chase, 2012.

[21] W. Chee, The Sales Operations Handbook: A Primer on the Sales Operations Function, CreateSpace Independent Publishing Platform, 2017.

[22] Chandana, "www.simplilearn.com," 10 12 2015. [Online]. Available: https://www.simplilearn.com/erp-planning-and-erp-systems-rar102-article. [Accessed 21 03 2020].

[23] W. J. Hopp ja M. L. Spearman, Factory Pyhsics, New York: McGraw-Hill, 1996.

[24] J. B. Clouard, „linkedin,“ 1 06 2017. [Võrgumaterjal]. Available: https://www.linkedin.com/pulse/first-sop-ibp-whats-next-jean-baptiste-clouard/. [Kasutatud 04 04 2020].

[25] R. Antsmäe, „yumpu,“ 2013. [Võrgumaterjal]. Available: https://www.yumpu.com/xx/document/read/10784951/loe-lisa-pdf-05mb-sop. [Kasutatud 04 04 2020].

[26] Rollepaal, „rolleplaanic.com,“ Rollepaal, 2020. [Võrgumaterjal]. Available: https://www.rollepaalinc.com/introduction.html. [Kasutatud 09 4 2020].

APPENDICES

A 1. Products information

Product code	Description	Cycle time per product min	A pack quantity pcs.
70000258	160	2,86	28
70011958	160	1,4	28
70000487	160	2,77	28
70000259	200	3,13	20
70011960	200	1,67	20
70000488	200	3,1	20
70000261	250	3,33	8
70011959	250	1,67	8
70000489	250	3,4	8
70000490	315	3,37	6
70000263	315	3,4	6
70016543	400	4,17	3
70011962	400	4,7	3
70000264	400	4,17	3
70000491	400	4,8	3
70005106	110	0,91	50
70000909	110	1,23	50
70000000	110	2,33	50
70000001	160	1,79	24
70000002	160	2,39	24
70000003	160	4,57	24
70000005	200	2,81	15
70000006	200	3,05	15
70000007	200	6,76	15

A 2. Products description

Product code	Description	Product line	Bar or Roll	Length meter
70000258	PP PRAGMA PIPE 160/139 SN8 6m RB	PP-2	bar	6
70011958	PP PRAGMA PIPE 160x140 SN8 3m RB	PP-2	bar	3
70000487	PP RAINEO PIPE 160/140 SN8 6m BK	PP-2	bar	6
70000259	PP PRAGMA PIPE 200/174 SN8 6m RB	PP-2	bar	6
70011960	PP PRAGMA PIPE 200x175 SN8 3m RB	PP-2	bar	3
70000488	PP RAINEO PIPE 200/175 SN8 6m BK	PP-2	bar	6
70000261	PP PRAGMA PIPE 250/218 SN8 6m RB	PP-2	bar	6
70011959	PP PRAGMA PIPE 250x220 SN8 3m RB	PP-2	bar	3
70000489	PP RAINEO PIPE 250/220 SN8 6m BK	PP-2	bar	6
70000490	PP RAINEO PIPE 315/278 SN8 6m BK	PP-2	bar	6
70000263	PP PRAGMA PIPE 315/276 SN8 6m RB	PP-2	bar	6
70016543	PP PRAGMA RISER PIPE 400x351 SN4 6m BK	PP-2	bar	6
70011962	PP PRAGMA RISER PIPE 400x351 SN8 6m RB	PP-2	bar	6
70000264	PP PRAGMA PIPE 400/348 SN8 6m RB	PP-2	bar	6
70000491	PP RAINEO PIPE 400/351 SN8 6m BK	PP-2	bar	6
70005106	PVC Sewage Pipe 110 SN8 2m	PVC1	bar	2
70000909	PVC SEWAGE PIPE 110x3,2 SN8 3m	PVC1	bar	3

Product code	Description	Product line	Bar or Roll	Length meter
70000000	PVC SEWAGE PIPE 110x3,2 SN8 6m	PVC1	bar	6
70000001	PVC SEWAGE PIPE 160x4,7 SN8 2m	PVC1	bar	2
70000002	PVC SEWAGE PIPE 160x4,7 SN8 3m	PVC1	bar	3
70000003	PVC SEWAGE PIPE 160x4,7 SN8 6m	PVC1	bar	6
70000005	PVC SEWAGE PIPE 200x5,9 SN8 2m	PVC1	bar	2
70000006	PVC SEWAGE PIPE 200x5,9 SN8 3m	PVC1	bar	3
70000007	PVC SEWAGE PIPE 200x5,9 SN8 6m	PVC1	bar	6

A 3. The bill of materials for products

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70005106	50	923200086	PVC MIXTURE RECIPE 801	168.202	KG
70005106	50	923101473	PVC MASTERBATCH RAL8023 BROWN	1.814	KG
70005106	50	923101443	PVC FILLER CHALK HYDROCARB 75T	11.334	KG
70005106	50	70010852	FORSHEDA 605 SEWER-LOCK SEAL 110	50	EA
70005106	50	923101604	PACK.FRAME C 110 NAL/PE 1100x550mm 1,2m	2	EA
70005106	50	923101632	PACKING BLOCK 45x45x45mm	72	EA
70005106	50	923101425	PET STRAP 16,0x0,8 1250m	8	M
70005106	50	923101407	LABEL 102x157 WH	2	EA
70000000	50	923101473	PVC MASTERBATCH RAL8023 BROWN	5.301	KG
70000000	50	923200086	PVC MIXTURE RECIPE 801	491.668	KG
70000000	50	923101443	PVC FILLER CHALK HYDROCARB 75T	33.131	KG
70000000	50	70010852	FORSHEDA 605 SEWER-LOCK SEAL 110	50	EA
70000000	50	923101604	PACK.FRAME C 110 NAL/PE 1100x550mm 1,2m	3	EA
70000000	50	923101632	PACKING BLOCK 45x45x45mm	108	EA
70000000	50	923101405	STEEL TAPE 16x0,5 BYR	12	M
70000000	50	923101407	LABEL 102x157 WH	2	EA

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000001	24	923200086	PVC MIXTURE RECIPE 801	166.214	KG
70000001	24	923101473	PVC MASTERBATCH RAL8023 BROWN	0.687	KG
70000001	24	923101443	PVC FILLER CHALK HYDROCARB 75T	21.979	KG
70000001	24	923101403	REALUBE RL/105 CP PVC	0.24	KG
70000001	24	70010851	FORSHEDA 605 SEWER-LOCK SEAL 160	24	EA
70000001	24	923101605	PACK.FRAME C 160 NAL/PE 960x640mm 1,05m	2	EA
70000001	24	923101633	PACKING BLOCK 70x70x70mm	30	EA
70000001	24	923101425	PET STRAP 16,0x0,8 1250m	8	M
70000001	24	923101407	LABEL 102x157 WH	2	EA
70000002	24	923200086	PVC MIXTURE RECIPE 801	245.356	KG
70000002	24	923101473	PVC MASTERBATCH RAL8023 BROWN	1.014	KG
70000002	24	923101443	PVC FILLER CHALK HYDROCARB 75T	32.444	KG
70000002	24	923101403	REALUBE RL/105 CP PVC	0.355	KG
70000002	24	70010851	FORSHEDA 605 SEWER-LOCK SEAL 160	24	EA
70000002	24	923101605	PACK.FRAME C 160 NAL/PE 960x640mm 1,05m	2	EA
70000002	24	923101633	PACKING BLOCK 70x70x70mm	30	EA
70000002	24	923101425	PET STRAP 16,0x0,8 1250m	8	M

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000002	24	923101407	LABEL 102x157 WH	2	EA
70000003	24	923200086	PVC MIXTURE RECIPE 801	482.822	KG
70000003	24	923101473	PVC MASTERBATCH RAL8023 BROWN	1.995	KG
70000003	24	923101443	PVC FILLER CHALK HYDROCARB 75T	63.844	KG
70000003	24	923101403	REALUBE RL/105 CP PVC	0.698	KG
70000003	24	70010851	FORSHEDA 605 SEWER-LOCK SEAL 160	24	EA
70000003	24	923101605	PACK.FRAME C 160 NAL/PE 960x640mm 1,05m	3	EA
70000003	24	923101633	PACKING BLOCK 70x70x70mm	45	EA
70000003	24	923101405	STEEL TAPE 16x0,5 BYR	12	M
70000003	24	923101407	LABEL 102x157 WH	2	EA
70000005	15	923200086	PVC MIXTURE RECIPE 801	164.922	KG
70000005	15	923101473	PVC MASTERBATCH RAL8023 BROWN	0.585	KG
70000005	15	923101443	PVC FILLER CHALK HYDROCARB 75T	21.28	KG
70000005	15	923101403	REALUBE RL/105 CP PVC	0.532	KG
70000005	15	70010850	FORSHEDA 605 SEWER-LOCK SEAL 200	15	EA
70000005	15	923101417	PACK.FRAME C 200 NAL/PE 1000x600mm 1,1m	2	EA
70000005	15	923101634	PACKING BLOCK 90x90x90mm	16	EA

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000005	15	923101425	PET STRAP 16,0x0,8 1250m	8	M
70000005	15	923101407	LABEL 102x157 WH	2	EA
70000006	15	923200086	PVC MIXTURE RECIPE 801	242.352	KG
70000006	15	923101473	PVC MASTERBATCH RAL8023 BROWN	0.86	KG
70000006	15	923101443	PVC FILLER CHALK HYDROCARB 75T	31.271	KG
70000006	15	923101403	REALUBE RL/105 CP PVC	0.782	KG
70000006	15	70010850	FORSHEDA 605 SEWER-LOCK SEAL 200	15	EA
70000006	15	923101417	PACK.FRAME C 200 NAL/PE 1000x600mm 1,1m	2	EA
70000006	15	923101634	PACKING BLOCK 90x90x90mm	16	EA
70000006	15	923101425	PET STRAP 16,0x0,8 1250m	8	M
70000006	15	923101407	LABEL 102x157 WH	2	EA
70000007	15	923200086	PVC MIXTURE RECIPE 801	474.654	KG
70000007	15	923101473	PVC MASTERBATCH RAL8023 BROWN	1.684	KG
70000007	15	923101443	PVC FILLER CHALK HYDROCARB 75T	61.246	KG
70000007	15	923101403	REALUBE RL/105 CP PVC	1.531	KG
70000007	15	70010850	FORSHEDA 605 SEWER-LOCK SEAL 200	15	EA
70000007	15	923101417	PACK.FRAME C 200 NAL/PE 1000x600mm 1,1m	3	EA

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000007	15	923101634	PACKING BLOCK 90x90x90mm	24	EA
70000007	15	923101405	STEEL TAPE 16x0,5 BYR	12	M
70000007	15	923101407	LABEL 102x157 WH	2	EA
70000258	28	923101411	PP NORMAL MODULUS	154.098	KG
70000258	28	923101478	PP MASTERBATCH RAL8002 BROWN	2.311	KG
70000258	28	923101411	PP NORMAL MODULUS	77.866	KG
70000258	28	923101479	PP MASTERBATCH RAL9010 WHITE	0.545	KG
70000258	28	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.156	KG
70000258	28	70000057	PRAGMA SEALING RING 160	28	EA
70000258	28	70006600	PP DW FRICTION WELDING SOCKET 160 RB	28	EA
70000258	28	923101618	PACK.FRAME C 160 1110x630mm RAIL 1,155m	5.012	EA
70000258	28	923101407	LABEL 102x157 WH	1.999	EA
70000258	28	923101425	PET STRAP 16,0x0,8 1250m	19.992	M
70000259	20	923101411	PP NORMAL MODULUS	136.075	KG
70000259	20	923101478	PP MASTERBATCH RAL8002 BROWN	0.68	KG
70000259	20	923101411	PP NORMAL MODULUS	74.955	KG
70000259	20	923101479	PP MASTERBATCH RAL9010 WHITE	0.525	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000259	20	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.15	KG
70000259	20	70000059	PRAGMA SEALING RING 200	20	EA
70000259	20	70006602	PP DW FRICTION WELDING SOCKET 200 RB	20	EA
70000259	20	923101616	PACK.FRAME B 200 1000x790mm RAIL 1,05m	5	EA
70000259	20	923101407	LABEL 102x157 WH	2	EA
70000259	20	923101425	PET STRAP 16,0x0,8 1250m	20	M
70000261	8	923101411	PP NORMAL MODULUS	96.493	KG
70000261	8	923101478	PP MASTERBATCH RAL8002 BROWN	0.482	KG
70000261	8	923101411	PP NORMAL MODULUS	48.513	KG
70000261	8	923101479	PP MASTERBATCH RAL9010 WHITE	0.34	KG
70000261	8	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.097	KG
70000261	8	70000061	PRAGMA SEALING RING 250	8	EA
70000261	8	70006604	PP DW FRICTION WELDING SOCKET 250 RB	8	EA
70000261	8	923101617	PACKING FRAME C 250 995x498mm RAIL 1,05m	5	EA
70000261	8	923101425	PET STRAP 16,0x0,8 1250m	20	M
70000261	8	923101407	LABEL 102x157 WH	2	EA
70000263	6	923102560	PP HIGH MODULUS	100.154	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
			GRANULATE ALTERNATIVE		
70000263	6	923101478	PP MASTERBATCH RAL8002 BROWN	0.501	KG
70000263	6	923101411	PP NORMAL MODULUS	53.601	KG
70000263	6	923101479	PP MASTERBATCH RAL9010 WHITE	0.375	KG
70000263	6	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.107	KG
70000263	6	70000063	PRAGMA SEALING RING 315	6	EA
70000263	6	70006606	PP DW FRICTION WELDING SOCKET 315 RB	6	EA
70000263	6	923101615	PACKING FRAME C 315 945x626mm RAIL 1,05m	5	EA
70000263	6	923101425	PET STRAP 16,0x0,8 1250m	20	M
70000263	6	923101407	LABEL 102x157 WH	2	EA
70000264	3	923102560	PP HIGH MODULUS GRANULATE ALTERNATIVE	69.093	KG
70000264	3	923101478	PP MASTERBATCH RAL8002 BROWN	0.345	KG
70000264	3	70000065	PRAGMA SEALING RING 400	3	EA
70000264	3	923101411	PP NORMAL MODULUS	38.897	KG
70000264	3	923101479	PP MASTERBATCH RAL9010 WHITE	0.272	KG
70000264	3	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.078	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000264	3	70006878	PP DW FRICTION WELDING SOCKET 400 RB	3	EA
70000264	3	923101623	PACKING BEAM 400 PP 75x75x1000mm	5	EA
70000264	3	923101640	PACKING RAIL PE 0,8m	5	EA
70000264	3	923101425	PET STRAP 16,0x0,8 1250m	20	M
70000264	3	923101407	LABEL 102x157 WH	2	EA
70000487	28	923101411	PP NORMAL MODULUS	149.807	KG
70000487	28	923101481	PE/PP MASTERBATCH RAL9005 BLACK	2.247	KG
70000487	28	923101411	PP NORMAL MODULUS	46844,000	KG
70000487	28	923101480	PE/PP MASTERBATCH RAL5015 BLUE	0.064	KG
70000487	28	923101411	PP NORMAL MODULUS	77.932	KG
70000487	28	923101479	PP MASTERBATCH RAL9010 WHITE	0.545	KG
70000487	28	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.156	KG
70000487	28	70000057	PRAGMA SEALING RING 160	28.056	EA
70000487	28	70006599	PP DW FRICTION WELDING SOCKET 160 BK	28.056	EA
70000487	28	923101618	PACK.FRAME C 160 1110x630mm RAIL 1,155m	5.006	EA
70000487	28	923101425	PET STRAP 16,0x0,8 1250m	20.009	M
70000487	28	923101457	LABEL 102x157 2colors	1.999	EA
70000488	20	923101411	PP NORMAL MODULUS	132.252	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000488	20	923101481	PE/PP MASTERBATCH RAL9005 BLACK	1.984	KG
70000488	20	923101411	PP NORMAL MODULUS	2.035	KG
70000488	20	923101480	PE/PP MASTERBATCH RAL5015 BLUE	0.03	KG
70000488	20	923101411	PP NORMAL MODULUS	74.706	KG
70000488	20	923101434	PE MASTERBATCH RAL9010 WHITE	0.523	KG
70000488	20	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.149	KG
70000488	20	70000059	PRAGMA SEALING RING 200	43941,000	EA
70000488	20	70006601	PP DW FRICTION WELDING SOCKET 200 BK	43941,000	EA
70000488	20	923101616	PACK.FRAME B 200 1000x790mm RAIL 1,05m	43926,000	EA
70000488	20	923101425	PET STRAP 16,0x0,8 1250m	24.96	M
70000488	20	923101457	LABEL 102x157 2colors	2.004	EA
70000489	8	923101411	PP NORMAL MODULUS	91.677	KG
70000489	8	923101481	PE/PP MASTERBATCH RAL9005 BLACK	1.375	KG
70000489	8	923101411	PP NORMAL MODULUS	1.057	KG
70000489	8	923101480	PE/PP MASTERBATCH RAL5015 BLUE	0.016	KG
70000489	8	70000061	PRAGMA SEALING RING 250	8.016	EA
70000489	8	923101411	PP NORMAL MODULUS	50.858	KG
70000489	8	923101479	PP MASTERBATCH RAL9010 WHITE	0.356	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000489	8	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.102	KG
70000489	8	70006603	PP DW FRICTION WELDING SOCKET 250 BK	8.016	EA
70000489	8	923101617	PACKING FRAME C 250 995x498mm RAIL 1,05m	5.002	EA
70000489	8	923101425	PET STRAP 16,0x0,8 1250m	20.016	M
70000489	8	923101457	LABEL 102x157 2colors	2.002	EA
70000490	6	923102560	PP HIGH MODULUS GRANULATE ALTERNATIVE	101.853	KG
70000490	6	923101481	PE/PP MASTERBATCH RAL9005 BLACK	1.528	KG
70000490	6	923101411	PP NORMAL MODULUS	1.308	KG
70000490	6	923101480	PE/PP MASTERBATCH RAL5015 BLUE	0.026	KG
70000490	6	923101411	PP NORMAL MODULUS	49.577	KG
70000490	6	923101479	PP MASTERBATCH RAL9010 WHITE	0.347	KG
70000490	6	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.099	KG
70000490	6	70000063	PRAGMA SEALING RING 315	6	EA
70000490	6	70006605	PP DW FRICTION WELDING SOCKET 315 BK	6	EA
70000490	6	923101615	PACKING FRAME C 315 945x626mm RAIL 1,05m	5	EA
70000490	6	923101425	PET STRAP 16,0x0,8 1250m	20	M

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000490	6	923101457	LABEL 102x157 2colors	2	EA
70000491	3	923102560	PP HIGH MODULUS GRANULATE ALTERNATIVE	67.909	KG
70000491	3	923101481	PE/PP MASTERBATCH RAL9005 BLACK	1.019	KG
70000491	3	923101411	PP NORMAL MODULUS	0.783	KG
70000491	3	923101480	PE/PP MASTERBATCH RAL5015 BLUE	0.016	KG
70000491	3	923101411	PP NORMAL MODULUS	38.611	KG
70000491	3	923101479	PP MASTERBATCH RAL9010 WHITE	0.27	KG
70000491	3	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.077	KG
70000491	3	70000065	PRAGMA SEALING RING 400	3	EA
70000491	3	70006607	PP DW FRICTION WELDING SOCKET 400 BK	3	EA
70000491	3	923101623	PACKING BEAM 400 PP 75x75x1000mm	5	EA
70000491	3	923101640	PACKING RAIL PE 0,8m	5	EA
70000491	3	923101425	PET STRAP 16,0x0,8 1250m	20	M
70000491	3	923101457	LABEL 102x157 2colors	2	EA
70000909	50	923200086	PVC MIXTURE RECIPE 801	249.08	KG
70000909	50	923101473	PVC MASTERBATCH RAL8023 BROWN	2.686	KG
70000909	50	923101443	PVC FILLER CHALK HYDROCARB 75T	16.784	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70000909	50	70010852	FORSHEDA 605 SEWER-LOCK SEAL 110	50	EA
70000909	50	923101604	PACK.FRAME C 110 NAL/PE 1100x550mm 1,2m	2	EA
70000909	50	923101632	PACKING BLOCK 45x45x45mm	72	EA
70000909	50	923101425	PET STRAP 16,0x0,8 1250m	8	M
70000909	50	923101407	LABEL 102x157 WH	2	EA
70011958	28	923101411	PP NORMAL MODULUS	77.306	KG
70011958	28	923101478	PP MASTERBATCH RAL8002 BROWN	42370,000	KG
70011958	28	923101411	PP NORMAL MODULUS	39.063	KG
70011958	28	923101479	PP MASTERBATCH RAL9010 WHITE	0.273	KG
70011958	28	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.078	KG
70011958	28	70000057	PRAGMA SEALING RING 160	28	EA
70011958	28	70006600	PP DW FRICTION WELDING SOCKET 160 RB	28	EA
70011958	28	923101618	PACK.FRAME C 160 1110x630mm RAIL 1,155m	2.996	EA
70011958	28	923101425	PET STRAP 16,0x0,8 1250m	11.984	M
70011958	28	923101407	LABEL 102x157 WH	1.999	EA
70011959	8	923101411	PP NORMAL MODULUS	48.407	KG
70011959	8	923101478	PP MASTERBATCH RAL8002 BROWN	0.242	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70011959	8	923101411	PP NORMAL MODULUS	24.337	KG
70011959	8	923101479	PP MASTERBATCH RAL9010 WHITE	0.17	KG
70011959	8	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.049	KG
70011959	8	70000061	PRAGMA SEALING RING 250	8	EA
70011959	8	70006604	PP DW FRICTION WELDING SOCKET 250 RB	8	EA
70011959	8	923101617	PACKING FRAME C 250 995x498mm RAIL 1,05m	3	EA
70011959	8	923101425	PET STRAP 16,0x0,8 1250m	12	M
70011959	8	923101407	LABEL 102x157 WH	2	EA
70011960	20	923101411	PP NORMAL MODULUS	68.264	KG
70011960	20	923101478	PP MASTERBATCH RAL8002 BROWN	0.341	KG
70011960	20	923101411	PP NORMAL MODULUS	37.602	KG
70011960	20	923101479	PP MASTERBATCH RAL9010 WHITE	0.263	KG
70011960	20	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.075	KG
70011960	20	70000059	PRAGMA SEALING RING 200	20	EA
70011960	20	70006602	PP DW FRICTION WELDING SOCKET 200 RB	20	EA
70011960	20	923101616	PACK.FRAME B 200 1000x790mm RAIL 1,05m	3	EA

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70011960	20	923101407	LABEL 102x157 WH	2	EA
70011960	20	923101425	PET STRAP 16,0x0,8 1250m	20	M
70011962	3	923102560	PP HIGH MODULUS GRANULATE ALTERNATIVE	69.093	KG
70011962	3	923101478	PP MASTERBATCH RAL8002 BROWN	0.345	KG
70011962	3	923101411	PP NORMAL MODULUS	38.897	KG
70011962	3	923101479	PP MASTERBATCH RAL9010 WHITE	0.272	KG
70011962	3	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.078	KG
70011962	3	923101623	PACKING BEAM 400 PP 75x75x1000mm	5	EA
70011962	3	923101640	PACKING RAIL PE 0,8m	5	EA
70011962	3	923101425	PET STRAP 16,0x0,8 1250m	20	M
70011962	3	923101407	LABEL 102x157 WH	4	EA
70016543	3	923101411	PP NORMAL MODULUS	63.098	KG
70016543	3	923101481	PE/PP MASTERBATCH RAL9005 BLACK	0.946	KG
70016543	3	923101411	PP NORMAL MODULUS	33.825	KG
70016543	3	923101479	PP MASTERBATCH RAL9010 WHITE	0.237	KG
70016543	3	923101435	PE/PP MASTERBATCH RAL7001 GREY	0.068	KG
70016543	3	923101623	PACKING BEAM 400 PP 75x75x1000mm	5.004	EA
70016543	3	923101640	PACKING RAIL PE 0,8m	5.004	EA

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
70016543	3	923101425	PET STRAP 16,0x0,8 1250m	19.998	M
70016543	3	923101407	LABEL 102x157 WH	2	EA
70001163	48	923200061	PVC MIXTURE RECIPE 402	370.886	KG
70001163	48	923200041	PVC1 POWDER SCRAP	41.21	KG
70001163	48	923101430	PVC MASTERBATCH RAL7037 GREY	2.071	KG
70001163	48	70009993	SEWAGE SEALING RING 100 PVC cable BK	48	EA
70001163	48	923101416	PACKING FRAME C 100 OPTO 1000x450mm 1,1m	3	EA
70001163	48	923101405	STEEL TAPE 16x0,5 BYR	8	M
70001163	48	923101407	LABEL 102x157 WH	2	EA
70001164	48	923200061	PVC MIXTURE RECIPE 402	645.855	KG
70001164	48	923101403	REALUBE RL/105 CP PVC	2.702	KG
70001164	48	923101430	PVC MASTERBATCH RAL7037 GREY	2.702	KG
70001164	48	70009993	SEWAGE SEALING RING 100 PVC cable BK	48	EA
70001164	48	923101416	PACKING FRAME C 100 OPTO 1000x450mm 1,1m	3	EA
70001164	48	923101405	STEEL TAPE 16x0,5 BYR	12	M
70001164	48	923101407	LABEL 102x157 WH	2	EA
923200086	195	923100599	PVC K67	165.535	KG
923200086	195	923101402	STABILOX G-TU/1113/5 XO PVC	4.635	KG
923200086	195	923101443	PVC FILLER CHALK	24.83	KG

Product code	Base quantity pcs.	Component	Description	Quantity	Unit
			HYDROCARB 75T		
923200061	195	923100599	PVC K67	164.975	KG
923200061	195	923101402	STABILOX G-TU/1113/5 XO PVC	4.619	KG
923200061	195	923101443	PVC FILLER CHALK HYDROCARB 75T	24.746	KG
923200061	195	923101464	BAEROSTAB SMS 9907 R/1 PVC COLOR BOOSTER	0.66	KG

A 4. Products forecast per month

Year	**2020**						**2021**
Month	**7**	**8**	**9**	**10**	**11**	**12**	**1**
Product code	**pcs.**	**pcs.**	**pcs.**	**pcs.**	**pcs.**	**pcs.**	**pcs.**
70000000			650				
70000909	2400		1300	1200		1200	
70005106		1600			1600		1600
70000001		816					816
70000002	2112	1128	1128	1032	720	720	816
70000003		2664	1896	1704	1200	1224	1344
70000005							525
70000006		480			480		
70000007		720	375	345	240	255	270
70001163	1440	2304	2064	2016	1056	1536	1488
70001164	720	720	816	864	528	528	576
70000258	1092	532	532	532		532	532
70011958		1036					
70000487	1064	560	672	756	532		532
70000259		460	460	460	460	460	
70011960			880				
70000488	1120	1280	1460	1240	620	500	660
70000261			432		432		
70011959		872					
70000489	968	712	656	800	424		424
70000263		426		426		426	
70000490	504	744	852	666	432		432
70000264		348		348		348	
70000491	303	303	303	705	303		303
70011962	309			309			
70016543		309			309		

A 5. A Program for MonthTimeUsageReport

```
 --make a month string
var
month_string:string:=to_str(month(eventController.abssimTime))+"_"+to_str(year(eventController.abssimTime)+1900)
if MonthTimeUsageReport.getRowNo(month_string) = -1
--insert into index
MonthTimeUsageReport[0,MonthTimeUsageReport.yDimIndex+1]:=month_string
MonthTimeUsageReport[1,MonthTimeUsageReport.yDim+1]:=?.statWorkingTime
MonthTimeUsageReport[3,MonthTimeUsageReport.yDim]:=?.statSetupTim
MonthTimeUsageReport[6,MonthTimeUsageReport.yDim]:=?.statSetUpCount-1
MonthTimeUsageReport[10,MonthTimeUsageReport.yDim]:=?.statSetUpCount
MonthTimeUsageReport[8,MonthTimeUsageReport.yDim]:=?.statEmptyTime
	--calculate working time
	if MonthTimeUsageReport.yDim > 1
	--production time
	MonthTimeUsageReport[2,MonthTimeUsageReport.yDim1]:=MonthTimeUsageReport[1,MonthTimeUsageReport.y
	Dim]-MonthTimeUsageReport[1,MonthTimeUsageReport.yDim-1]
	--setup time
	MonthTimeUsageReport[4,MonthTimeUsageReport.yDim1]:=MonthTimeUsageReport[3,MonthTimeUsageReport.y
	Dim]-MonthTimeUsageReport[3,MonthTimeUsageReport.yDim-1]
	--total usage time per month = production time + setup time
	MonthTimeUsageReport[5,MonthTimeUsageReport.yDim1]:=MonthTimeUsageReport[2,MonthTimeUsageReport.y
	Dim-1]+MonthTimeUsageReport[4,MonthTimeUsageReport.yDim-1]
	--setup count per month
	MonthTimeUsageReport[7,MonthTimeUsageReport.yDim1]:=MonthTimeUsageReport[6,MonthTimeUsageReport.y
	Dim]-MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1]
	--parameters to count setup  per month
	If MonthTimeUsageReport[7,MonthTimeUsageReport.yDim-1] < 0
		MonthTimeUsageReport[7,MonthTimeUsageReport.yDim-1] := 0
	end
	if MonthTimeUsageReport[7,MonthTimeUsageReport.yDim-1] = 0 and
	MonthTimeUsageReport[4,MonthTimeUsageReport.yDim-1] > 00:00:00.0000
	MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1]
	:=MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1] +
	(MonthTimeUsageReport[10,MonthTimeUsageReport.yDim-1] -
	MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1])
		MonthTimeUsageReport[7,MonthTimeUsageReport.yDim-1] := ?.statSetUpCount - (?.statSetUpCount-
		1)
	end
	if MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1]
	MonthTimeUsageReport[10,MonthTimeUsageReport.yDim-1] and
	MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1] =
	MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1]
		MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1] := ?.statSetUpCount
		MonthTimeUsageReport[6,MonthTimeUsageReport.yDim] := ?.statSetUpCount
	end
	if  MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1] <
	MonthTimeUsageReport[6,MonthTimeUsageReport.yDim] and
	MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1] =
	MonthTimeUsageReport[10,MonthTimeUsageReport.yDim-1]
	MonthTimeUsageReport[6,MonthTimeUsageReport.yDim-1] := ?.statSetUpCount-1
	end
--idle time on the production line per month
MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=MonthTimeUsageReport[8,MonthTimeUsageReport.yDim-1]-
MonthTimeUsageReport[5,MonthTimeUsageReport.yDim-1]
	if MonthTimeUsageReport.yDim = 3
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]
		MonthTimeUsageReport[11,1] := 12:00:00:00.0000 -- 7_2020
	elseif MonthTimeUsageReport.yDim = 4
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
		(MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]  +
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-3])
		MonthTimeUsageReport[11,2] := 02:00:00:00.0000 -- 8_2020
	elseif MonthTimeUsageReport.yDim = 5
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
		(MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]  +
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-3] +
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-4])
		MonthTimeUsageReport[11,3] := 00:00:00:00.0000 -- 9_2020
	elseif MonthTimeUsageReport.yDim = 6
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
		(MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]  +
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-3] +
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-4] +
		MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-5])
```

```
            MonthTimeUsageReport[11,4] := 00:00:00:00.0000 -- 10_2020
      elseif MonthTimeUsageReport.yDim = 7
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
            (MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]  +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-3] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-4] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-5]+
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-6])
            MonthTimeUsageReport[11,5] := 00:00:00:00.0000 -- 11_2020
      elseif MonthTimeUsageReport.yDim = 8
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
            (MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]  +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-3] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-4] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-5]+
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-6]+
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-7])
            MonthTimeUsageReport[11,6] := 18:00:00:00.0000 -- 12_2020
            MonthTimeUsageReport[11,7] := 03:00:00:00.0000 -- 1_2021
      -- Planned stop time is taken down
            MonthTimeUsageReport[9,1] := MonthTimeUsageReport[9,1] - MonthTimeUsageReport[11,1]
            MonthTimeUsageReport[9,2] := MonthTimeUsageReport[9,2] - MonthTimeUsageReport[11,2]
            MonthTimeUsageReport[9,3] := MonthTimeUsageReport[9,3] - MonthTimeUsageReport[11,3]
            MonthTimeUsageReport[9,4] := MonthTimeUsageReport[9,4] - MonthTimeUsageReport[11,4]
            MonthTimeUsageReport[9,5] := MonthTimeUsageReport[9,5] - MonthTimeUsageReport[11,5]
            MonthTimeUsageReport[9,6] := MonthTimeUsageReport[9,6] - MonthTimeUsageReport[11,6]
            MonthTimeUsageReport[9,7] := MonthTimeUsageReport[9,7] - MonthTimeUsageReport[11,7]
      elseif MonthTimeUsageReport.yDim = 9
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
            (MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]  +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-3] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-4] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-5]+
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-6]+
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-7] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-8])
      elseif MonthTimeUsageReport.yDim = 10
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1]:=
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-1] -
            (MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-2]  +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-3] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-4] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-5]+
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-6]+
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-7] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-8] +
            MonthTimeUsageReport[9,MonthTimeUsageReport.yDim-9])
      end
      end
end
```

A 6. A Method for distribution products to assemble stations in the PVC1 simulation

```
--distribution of products between assembly stations
	if @.Name = "PVC1_70000000"
		@.move(PIPE_110_SN8_6m)
	elseif @.Name = "PVC1_70000001"
		@.move(PIPE_160_SN8_2m)
	elseif @.Name = "PVC1_70000002"
		@.move(PIPE_160_SN8_3m)
	elseif @.Name = "PVC1_70000003"
		@.move(PIPE_160_SN8_6m)
	elseif @.Name = "PVC1_70000005"
		@.move(PIPE_200_SN8_2m)
	elseif @.Name = "PVC1_70000006"
		@.move(PIPE_200_SN8_3m)
	elseif @.Name = "PVC1_70000007"
		@.move(PIPE_200_SN8_6m)
	elseif @.Name = "PVC1_70000909"
		@.move(PIPE_110_SN8_3m)
	elseif @.Name = "PVC1_70005106"
		@.move(PIPE_110_SN8_2m)
	elseif @.Name = "PVC1_70001163"
		@.move(OPTO_100_3_6m)
	elseif @.Name = "PVC1_70001164"
		@.move(OPTO_100_4_6m)
	end
```

A 7. The assembly station program for 110mm pipe 3m to forward data the MonthProducedPackingUnits report

```
--make a month string
var
month_string:string:=to_str(month(eventController.abssimTime))+"_"+to_str(year(eventController.abssimTime)+1900)
--produced quantity divided in table by month
	if PIPE_110_SN8_3m.statNumOut = 0
	elseif month_string = "7_2020"
		MonthProducedPackingUnits[3,0]:=MonthProducedPackingUnits[3,0] + 1
		MonthProducedPackingUnits[4,0]:=MonthProducedPackingUnits[3,0] * (5.371 * 50)
	elseif month_string = "8_2020"
		MonthProducedPackingUnits[3,1]:=MonthProducedPackingUnits[3,1] + 1
		MonthProducedPackingUnits[4,1]:=MonthProducedPackingUnits[3,1] * (5.371 * 50)
	elseif month_string = "9_2020"
		MonthProducedPackingUnits[3,2]:=MonthProducedPackingUnits[3,2] + 1
		MonthProducedPackingUnits[4,2]:=MonthProducedPackingUnits[3,2] * (5.371 * 50)
	elseif month_string = "10_2020"
		MonthProducedPackingUnits[3,3]:=MonthProducedPackingUnits[3,3] + 1
		MonthProducedPackingUnits[4,3]:=MonthProducedPackingUnits[3,3] * (5.371 * 50)
	elseif month_string = "11_2020"
		MonthProducedPackingUnits[3,4]:=MonthProducedPackingUnits[3,4] + 1
		MonthProducedPackingUnits[4,4]:=MonthProducedPackingUnits[3,4] * (5.371 * 50)
	elseif month_string = "12_2020"
		MonthProducedPackingUnits[3,5]:=MonthProducedPackingUnits[3,5] + 1
		MonthProducedPackingUnits[4,5]:=MonthProducedPackingUnits[3,5] * (5.371 * 50)
	elseif month_string = "1_2021"
		MonthProducedPackingUnits[3,6]:=MonthProducedPackingUnits[3,6] + 1
		MonthProducedPackingUnits[4,6]:=MonthProducedPackingUnits[3,6] * (5.371 * 50)
	elseif month_string = "2_2021"
		MonthProducedPackingUnits[3,7]:=MonthProducedPackingUnits[3,7] + 1
		MonthProducedPackingUnits[4,7]:=MonthProducedPackingUnits[3,7] * (5.371 * 50)
	elseif month_string = "3_2021"
		MonthProducedPackingUnits[3,8]:=MonthProducedPackingUnits[3,8] + 1
		MonthProducedPackingUnits[4,8]:=MonthProducedPackingUnits[3,8] * (5.371 * 50)
	elseif month_string = "4_2021"
		MonthProducedPackingUnits[3,9]:=MonthProducedPackingUnits[3,9] + 1
		MonthProducedPackingUnits[4,9]:=MonthProducedPackingUnits[3,9] * (5.371 * 50)
	elseif month_string = "5_2021"
		MonthProducedPackingUnits[3,10]:=MonthProducedPackingUnits[3,10] + 1
		MonthProducedPackingUnits[4,10]:=MonthProducedPackingUnits[3,10] * (5.371 * 50)
	elseif month_string = "6_2021"
		MonthProducedPackingUnits[3,11]:=MonthProducedPackingUnits[3,11] + 1
		MonthProducedPackingUnits[4,11]:=MonthProducedPackingUnits[3,11] * (5.371 * 50)
	end
		MonthProducedPackingUnits[3,13]:=PIPE_110_SN8_3m.statNumOut
		MonthProducedPackingUnits[4,13]:=PIPE_110_SN8_3m.statNumOut * (5.371 * 50)
```

A8. The program to provide info to MaterialUsage report

```
--make a month string
        var
month_string:string:=to_str(month(eventController.abssimTime))+"_"+to_str(year(eventController.abssimTime)+1900)
--BOMs

        if P70005106.statNumOut = 0

        elseif month_string = "7_2020"
                        --70005106 PVC Sewage Pipe 110 SN8 2m
                if @.name = "P70005106"
                        --PVC mix 801
                        MaterialUsage[1,0]:= MaterialUsage[1,0] + (168.202*0.85)
                        MaterialUsage[2,0]:= MaterialUsage[2,0] + (168.202*0.02)
                        MaterialUsage[3,0]:= MaterialUsage[3,0] + (168.202*0.13)
                        --brown colour
                        MaterialUsage[7,0]:= MaterialUsage[7,0] + (1.814)
                        --PVC filler
                        MaterialUsage[3,0]:= MaterialUsage[3,0] + (11.334)
                        --seal 110
                        MaterialUsage[10,0]:= MaterialUsage[10,0] + (50)
                        --packing frame
                        MaterialUsage[14,0]:= MaterialUsage[14,0] + (2)
                        --packing block
                        MaterialUsage[18,0]:= MaterialUsage[18,0] + (72)
                        --pet strap
                        MaterialUsage[21,0]:= MaterialUsage[21,0] + (8)
                        --label
                        MaterialUsage[23,0]:= MaterialUsage[23,0] + (2)
                --70000009 PVC SEWAGE PIPE 110x3,0 SN8 3m
                        elseif @.name = "P70000909"
                        --PVC mix 801
                        MaterialUsage[1,0]:= MaterialUsage[1,0] + (249.09*0.85)
                        MaterialUsage[2,0]:= MaterialUsage[2,0] + (249.09*0.02)
                        MaterialUsage[3,0]:= MaterialUsage[3,0] + (249.09*0.13)
                        --brown colour
                        MaterialUsage[7,0]:= MaterialUsage[7,0] + (2.686)
                        --PVC filler
                        MaterialUsage[3,0]:= MaterialUsage[3,0] + (16.784)
                        --seal 110
                        MaterialUsage[10,0]:= MaterialUsage[10,0] + (50)
                        --packing frame
                        MaterialUsage[14,0]:= MaterialUsage[14,0] + (2)
                        --packing block
                        MaterialUsage[18,0]:= MaterialUsage[18,0] + (72)
                        --pet strap
                        MaterialUsage[21,0]:= MaterialUsage[21,0] + (8)
                        --label
                        MaterialUsage[23,0]:= MaterialUsage[23,0] + (2)

……
        -- 70001164 PVC-U OPTO PIPE 100x4,11 SN16/A 6m GE
                elseif @.name = "P70001164"
                        MaterialUsage[1,11]:= MaterialUsage[1,11] + (645.855*0.84)
                        MaterialUsage[4,11]:= MaterialUsage[4,11] + (645.855*0.02)
                        MaterialUsage[3,11]:= MaterialUsage[3,11] + (645.855*0.11)
                        MaterialUsage[6,11]:= MaterialUsage[6,11] + (645.855*0.03)
                        --grey colour
                        MaterialUsage[8,11]:= MaterialUsage[8,11] + (2.702)
                        -- REALUBE RL/105 CP PVC
                        MaterialUsage[5,11]:= MaterialUsage[5,11] + (2.702)
                        --seal 100
                        MaterialUsage[13,11]:= MaterialUsage[13,11] + (48)
                        --packing frame
                        MaterialUsage[17,11]:= MaterialUsage[17,11] + (3)
                        --steel strap
                        MaterialUsage[22,11]:= MaterialUsage[22,11] + (8)
                        --label
                        MaterialUsage[23,11]:= MaterialUsage[23,11] + (2)
                end

        end

-- summing the material usage per column
MaterialUsage[22,13] := MaterialUsage[22,1] + MaterialUsage[22,2] + MaterialUsage[22,3] + MaterialUsage[22,4] +
MaterialUsage[22,5] + MaterialUsage[22,6] + MaterialUsage[22,7] + MaterialUsage[22,8] + MaterialUsage[22,9] +
MaterialUsage[22,10] + MaterialUsage[22,11] + MaterialUsage[22,12]
MaterialUsage[23,13] := MaterialUsage[23,1] + MaterialUsage[23,2] + MaterialUsage[23,3] + MaterialUsage[23,4] +
MaterialUsage[23,5] + MaterialUsage[23,6] + MaterialUsage[23,7] + MaterialUsage[23,8] + MaterialUsage[23,9] +
MaterialUsage[23,10] + MaterialUsage[23,11] + MaterialUsage[23,12]
```

A 9. The Init method to delete old data in reports and add monthly info to reports

```
--deleting data from reports
MonthTimeUsageReport.delete({0,1}..{*,*})
MonthProducedPackingUnits.delete({0,1}..{*,*})
MaterialUsage.delete({0,1}..{*,*})
--the starting period for MonthTimeUsageReport
MonthTimeUsageReport[0,1]:="7_2020"
--the months periods for MonthProducedPackingUnits
MonthProducedPackingUnits[0,1]:="7_2020"
MonthProducedPackingUnits[0,2]:="8_2020"
MonthProducedPackingUnits[0,3]:="9_2020"
MonthProducedPackingUnits[0,4]:="10_2020"
MonthProducedPackingUnits[0,5]:="11_2020"
MonthProducedPackingUnits[0,6]:="12_2020"
MonthProducedPackingUnits[0,7]:="1_2021"
MonthProducedPackingUnits[0,8]:="2_2021"
MonthProducedPackingUnits[0,9]:="3_2021"
MonthProducedPackingUnits[0,10]:="4_2021"
MonthProducedPackingUnits[0,11]:="5_2021"
MonthProducedPackingUnits[0,12]:="6_2021"
MonthProducedPackingUnits[0,13]:="Total"
--the month periods for MaterialUsage period
MaterialUsage[0,1]:="7_2020"
MaterialUsage[0,2]:="8_2020"
MaterialUsage[0,3]:="9_2020"
MaterialUsage[0,4]:="10_2020"
MaterialUsage[0,5]:="11_2020"
MaterialUsage[0,6]:="12_2020"
MaterialUsage[0,7]:="1_2021"
MaterialUsage[0,8]:="2_2021"
MaterialUsage[0,9]:="3_2021"
MaterialUsage[0,10]:="4_2021"
MaterialUsage[0,11]:="5_2021"
MaterialUsage[0,12]:="6_2021"
MaterialUsage[0,13]:="Total"
```

A 10. The PVC1 model view in the Tecnomatix Plant Simulation