Lean Process Development PVC Line

Project Report

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Final Release *January 4th 2011*

Windesheim

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Tiivistelmä

(Summary in Finnish)

Päättötyö projektin päätarkoituksena oli käyttää Lean-valmistamisen apuvälineitä ja metodeja lyhentämään mattojen läpimenoaikaa PVC-osastolla. Yritys halusi parantaa valmistusprosessiaan vähentämällä eri tyyppisiä hukkia prosessista ja lisätäkseen tuotantoa.

Projektin alussa valmistusprosessi analysoitiin määrittelemällä koneiden kapasiteetit ja välivarastojen koot. Tämä nosti esiin muutamia pullonkauloja prosessista. Merkittävin pullonkaula oli viimeistelyleikkaus. Valmistettaessa 40x60 mattoja myös esileikkauksessa oli kapasiteetin puutetta, kun verrataan PVC-linjan kapasiteettiin. Muun kokoisilla tuotteilla pullonkauloja ei esiintynyt.

Varastojen määrittämisen jälkeen kävi selväksi, ettei varastojen koko perustunut koneiden kapasiteetteihin. Sekä trukinkuljettaja, että esileikkausvaihe työnsivät tuotteita seuraavaan vaiheeseen ilman, että he huomioivat vaiheen kulutuksen. Tämä aiheutti paljon negatiivisia sivuvaikutuksia.

Kerätyt tiedot koottiin arvovirtakarttaan. Arvovirtakartta osoitti monia epäkohtia prosessista. Prosessin arvosuhde paljastui todella alhaiseksi: Läpimenoaika oli 155 kertaa pidempi, kuin itse arvoa tuottava valmistusaika. Tämä johtui suurimmaksi osaksi isoista välivarastoista. Myös edellä mainitut pullonkaulat olivat näkyvillä. Arvovirtakartta näytti myös monia parantamisen mahdollisuuksia. Toivottavin muutos olisi siirtää kolmas viimeistelyleikkuri automaattilinjaan. Se poistaisi viimeistelyleikkaus vaiheen pullonkaulan.

Koska kapasiteetit oli nyt määritetty tarkemmalla tavalla, oli selvää, että välivarastoja voisi pienentää. Tämä vähentäisi myös läpimenoaikaa. Pehmeää materiaalivirtaa helpottamaan on tarpeellista määrittää selvä valmistusjärjestys tuotteille, jotka voidaan valmistaa. Trukinkuljettajien täytyy toimittaa rullat määrätyssä järjestyksessä. Käyttämällä FIFO-periaatetta rullille ja kuormalavoille, määrätty valmistusjärjestys virtaa eri vaiheiden läpi.

SMED-menetelmää käytettiin analysoimaan esi- ja viimeistelyleikkausvaiheiden vaihtoja. Parannukset nostivat molempien vaiheiden koneiden työaikoja.

5S-menetelmää käytettiin saavuttamaan tehokkaampi, turvallisempi ja puhtaampi työympäristö.

Kaikki suositukset on koottu tulevaisuuden arvovirtakarttaan. Se esittää, mitä vaikutuksia parannuksilla on prosessiin.

Osa parannuksista pitää tehdä nykyiseen mittausjärjestelmään. Nykyisellä mittausjärjestelmällä ei ole täysin mahdollista arvioida esitettyjen muutosten tehokkuutta.

Summary

The main objective of this project was to use Lean manufacturing tools and methods to reduce lead time for the mats through the PVC department. The company wanted to improve their process by reducing different types of waste from the process and increase production output.

At the start of the project the manufacturing process was analyzed by measuring machine capacities and inventory sizes. This pointed to some bottlenecks within the process. The most noticeable bottleneck was final cutting. When producing 40x60 mats the pre-cutting stage also lacked capacity compared to the PVC line. All other types of products did not create any bottlenecks.

After counting the amount of semi-finished products in inventories it became clear that the amount of products in inventory was not based on machine capacities. Both the forklift driver and the pre-cutting stage pushed products to the next stage without taking its demand into account. This had many negative side-effects.

The gathered measurements were combined into a Value Stream Map. The VSM showed many undesirable aspects within the process. The value ratio of the process turned out to be very low: Lead time was 155 times larger than the actual value adding time. This is mostly due to the large inventories used. Also the aforementioned bottlenecks were visible. The VSM also showed plenty of possible improvements. Very desirable would be moving the 3rd cutter to a position in-line. This would eliminate the final cutting stage as a bottleneck.

Because the capacities were now measured in an accurate way it was clear that the inventories could be reduced significantly. This also reduces lead time. To facilitate smooth material flow it is necessary to start at the beginning and state a clear order in which products can be produced. Forklift drivers need to deliver rolls in this order. By using FIFO systems for rolls and pallets this production order will flow through the stages.

SMED was used to analyze pre-cutting and final cutting changeovers. Improvements were made increasing pre-cutting and final cutting uptime.

5S was used to facilitate in a more efficient, safe and clean work environment.

All the recommended improvements are combined in a future-state VSM. This illustrates the effects the improvements will have on the process.

Some improvements need to be made to the measurement system currently used. In the current state it is not possible to fully judge the effectiveness of the changes suggested.

Introduction

This report has been written to document a project conducted for a company which is located in The Netherlands. Company manufactures different types of non-woven carpets and artificial grass. The project focuses on the PVC department. The PVC department manufactures PVC coated doormats and runners.

The main drive behind this project is reducing department overhead. This was to be achieved by using the different tools that are involved in Lean Manufacturing. Lean Manufacturing, or just “Lean”, is a production philosophy that states that every action taken in the process should actually add value for the customer. All other actions are considered wasteful and should be eliminated. Lean provides a set of tools that helps locate these wasteful operations and hand solutions for these problems.

The report starts with an introduction to Company and their production processes. Next the goals and research questions for the project are defined. In the following chapters data is being gathered and analyzed. During the analysis problems and wasteful actions appear and solutions are being mentioned. Chapter 8 combines all these recommendations.

1. Project Background

This chapter will start by introducing the company, their production facilities and the different types of products that are produced. The main focus of this project, the PVC department, is looked upon more closely. Afterwards the project's goals and research questions are explained.

1.1 The Company

The company specializes in the production of non-woven carpets and artificial grass. Customers for non-woven products are in residential- , commercial- and contract market.

1.1.1 Departments & Facilities

The company has the following production facilities available:

- 3 Needle punching lines
- 7 Tufting lines, 3 for regular carpets and 4 for automotive products
- 2 Backing lines
- 1 PVC line
- 2 Laminating lines

Needle punching and tufting are the two main processes that are used to manufacture carpet rolls. The other departments provide different options of backing materials to these carpet rolls. These processes are explained in more depth in the next chapter.

Figure 1 shows production flow through the different departments.

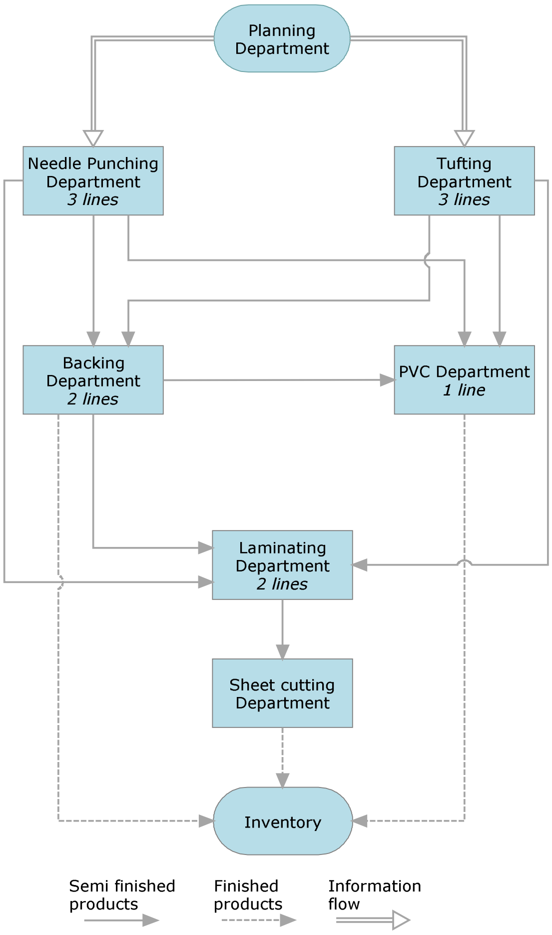


Figure 1: Departments and production flows

1.1.2 Company's Products

The company produces raw carpets rolls using two different methods: Needle punching and tufting. Tufting is split into two departments, one for automotive products and one for regular carpet and mats.

Needle punching is a process that intertwines fibers by layering them and then punching needles through the material, these needles push and pull on the fibers causing them to interlock and form a strong carpet. Multiple patterns are possible by using a different pattern of needles. Figure 2 shows how the fibers are layered, a needle board and the finished product.

In tufting short u-shaped loops of yarn are punched through a primary base material. The tufted yarn forms an array dots on the outside. These dots can be patterned by using different colors and different patterns on the tufting machine. Tufting results in a carpet with a soft top layer. Figure 3 shows a tufted carpet. Note the base material on the right and the looped yarn on the left.

Figure 2: Needle punching; Needles, layered fibers and finished product

Figure 3: Tufted carpet

After the raw carpet rolls are produced they either get stored or sent directly to backing, laminating or PVC. Both departments coat the carpet's backside with a material to provide strength and durability to the carpet. The backing department only produces carpet rolls. The PVC department can either produce square mats or long runners.

1.2 The PVC Department

This project focuses solely on the PVC department. Within the company PVC is the busiest department; production hours are 100% covered and demand is higher than the actual capacity. Production starts Monday morning at 0.30 AM and ends Saturday evening at 11 PM. Due to religious considerations Sundays are not used for production. During a day three different shifts are employed, the fourth shift has the day off. The first shift operates from midnight to 6 AM, the next one runs to 3 PM and the last shift finishes the day to midnight. This results in a total of 141.5 hours of production that is available during a week.

1.2.1 PVC Products

The PVC department is able to produce two different types of products: Mats and runners. Mats consist of a square piece of carpet coated with a flexible layer of PVC. The applied PVC is bigger than the carpet itself, resulting in a black border of PVC around the mat. (Figure 5) Figure 4 shows the most common mat: Lille 60x90cm. Runners are longer rolls of carpets that get coated with a layer of PVC. Runners have a black PVC edge on the short sides. Many different dimensions of mats and runners can be produced. Table 1 lists the most common mat and runner dimensions. Their share in production occupation is expressed as a percentage of the total production surface area.

Table 1: PVC product sizes. % of total product type, (%) of overall production total.

Common PVC Product Dimensions					
Mats (76%)			Runners (24%)		
Length (cm)	**Width (cm)**	**%**	**Width (cm)**	**Length (m)**	**%**
60	90	60% (46%)	200	25	46% (11%)
90	150	16% (12%)	130	25	27% (6%)
40	60	7.5% (6%)	90	25	14% (3%)
90	120	5% (4%)	100	30	7% (2%)
100	150	2% (1%)	120	30	6% (1%)

Figure 4: 60x90 mat, type: Lille

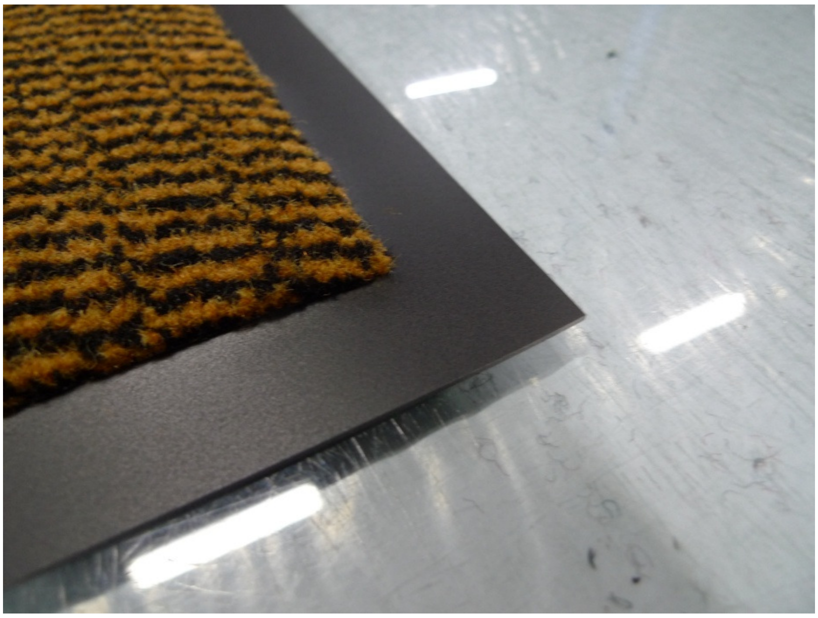


Figure 5: The black PVC border on mats

Figure 6: Finished PVC runner

1.2.2 PVC Mat Production Process & Available Equipment

The mat production process is the most complicated of the two processes. All available machines are being used for mat production. The following machines are available in the PVC department:

- PVC Mixing Station
- 3 Pre-Cutting Machines
- PVC line
- 3 Final cutters
  - 2 Cutters are positioned in-line
  - 1 Cutter is positioned off-line

The first stage in PVC mat production is pre-cutting. Raw carpet rolls are delivered to the pre-cutting machines. These rolls are then cut to rectangular mats and stacked on pallets. The pallets are then moved to a storage area in an adjacent building. Because of the PVC border mats are cut to a smaller size: 55x85cm for 60x90 mats, leaving a 5cm border for the PVC to fill.

There are three different pre-cutting machines. The newest one is able to cut wide rolls, up to 229cm wide. The older one cuts rolls up to 168cm wide. Both these machines cut the roll in length first and then use a moving blade to cut the rows of mats. The third machine is a completely automated hot-wire cutter. This machine is unable to cut rolls in length, so the raw rolls used have to have the right width already. Due to the hot-wire method used it can only cut very soft, non-backed materials and is not used very often.

Next up is applying the mats to the PVC line. The PVC line consists of a Teflon belt, a layer of PVC is spread on the Teflon belt, and then the mats are positioned in the PVC. By heating and then cooling the belt and liquid PVC it solidifies. At the end of the PVC line is a page cutter. This cutter cuts slabs out of the PVC, the PVC used to be one continuous runner.

The last step in mat production is the final cutting stage. Pages are transported to the two in-line cutters using a conveyor system. The page is scanned and the cutter then calculates the path it needs to follow. The cutting step is completely automated. Operators do a quality check on the mats and stack them on pallets.

In certain cases the final cutting machines can't keep up with the PVC line. The excess pages are moved to an overflow device. This machine stacks uncut pages on a pallet. The machine is only able to remove pages from the line, to return pages from the stack an extra operator is needed. These pages can be cut later on the 3rd cutter or on the two in-line cutters when runners are being produced.

Figure 7 and Figure 8 respectively show the floor layout and a flowchart on the process.

Figure 7: PVC overview

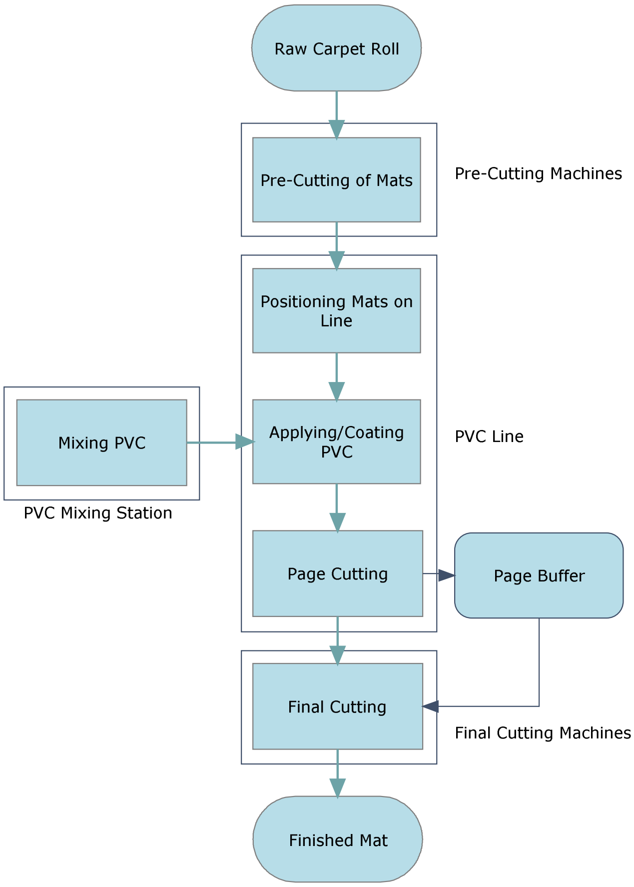


Figure 8: PVC mat production process

1.2.3 PVC Runner Production Process

When producing runners both pre-cutting and final cutting stations are not being used. The runner process is significantly less complicated than the mat process because all operations occur in-line. Figure 9 shows the actions needed when producing runners.

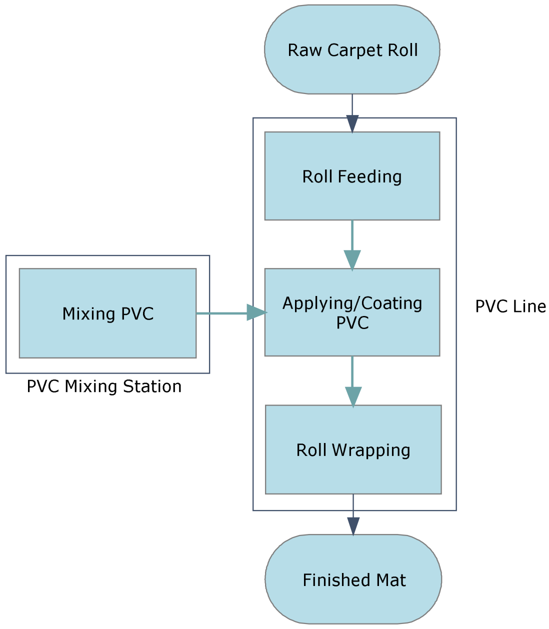


Figure 9: PVC runner process

1.3 Project Origins

To be able to compete in the strong carpet industry continuous improvement of production capacity and facilities is very important. One of company's long term goals is reducing management and production overhead. A way of achieving this goal is by implementing and using different methods from "Lean Manufacturing". Lean Manufacturing focuses on reducing process waste. Attachment 2 contains a short introduction to Lean Manufacturing for those that are unfamiliar with the concept.

1.4 Objective

Currently the weighted lead time in the PVC department is 1 week. This project will focus on reducing that lead time by using and implementing different techniques from Lean Manufacturing. Reducing lead time involves reducing many different kinds of waste within the process.

This project's main objective can be defined as the following:

Reducing lead time in the PVC department for mats by 50% by reducing inventory and changeover times by 20% within one year.

1.5 Goals & Research Questions

To asses which steps need to be taken to achieve this objective it is necessary to define clear goals for this project.

Globally this project focuses on trying to improve the PVC process efficiency, and thus lead time. This can be done on different fronts. Maximizing equipment capacities and reducing waste on one hand and enabling the staff to work more efficiently on the other hand.

To reduce lead time it is important to reduce inventory between the different steps involved in the process. A clear insight in machine capacities is currently not available and a big inventory is maintained to be on the safe side and focused on keeping the PVC line running. By reducing inventory, and thus lead time, it is possible to produce more products on a pull basis instead of the currently used push principle. Reducing inventory will also point to previously hidden problems within the process. Because of the big buffer inventories used, these problems didn’t surface before, but did exist.

Reducing changeover times is a good way to improve machine capacities, especially on the pre-cutting machines. Currently changeover on the pre-cutting machines is relatively long and involves a lot of unnecessary actions in both machine setup and material feed.

Another goal is to start with creating a clean, safe and efficient work environment for the staff to work in. Currently there is a lot of unnecessary clutter in the department. This makes it hard for the staff to find the tools and materials they need to run the production. Having a clean environment helps the staff to see and prioritize tasks needed and consequently have less distraction and more focus on the task at hand.

To clarify the research goals the following sub-questions have been defined:

1. How are the products being produced?
2. What is the current production capacity of the machines?
3. Are these capacities in balance? (I.e. are there any bottlenecks in the process?)
4. How far can the semi-finished product inventory be reduced?
5. Where in the process is value added to the product?
6. What is the impact of moving the 3rd final Cutter in-line with the PVC line?
7. Can the changeover time for the pre-cutting machines be reduced to improve capacity?
8. Can the equipment in the different workstations be modified to improve staff efficiency?
9. Can the effect of the suggested improvements be assessed with the current measurements available?

1.6 Boundaries

When working on a big project it is important to have clear insight in the project's boundaries. These boundaries define a scope:

- The project only involves the PVC department and its process, from the raw material storage to the finished product storage. Other departments within company that supply the PVC department are out of this project's scope and are seen as suppliers to the process.
- Raw material acquisition and delivery to the plant is being judged as 100% efficient.
- The PVC mixing station and the chemistry involved when manufacturing PVC is not part of the project.
- The method used to plan the production for the PVC department is not part of the project.
- Fully implementing 5S is a long process and not feasible within the time available for this project. However, a start with the process will be made.

1.7 Report Index

Table 2: Research vs. Chapters

#	Research Question	Chapter	Page Number
1	How are the products being produced?	1.2	10
2	What is the current production capacity of the machines?	2	18
3	Are these capacities in balance? (I.e. are there any bottlenecks in the process?)	2.4	24
4	How far can the semi-finished product inventory be reduced?	3, 6 and 8	26, 40, 51
5	Where in the process is value added to the product?	4	31
6	What is the impact of moving the 3rd final Cutter in-line with the PVC line?	5	37
7	Can the changeover time for the pre-cutting machines be reduced to improve capacity?	7	45
8	Can the equipment in the different workstations be modified to improve staff efficiency?	9	60
9	Can the effect of the suggested improvements be assessed with the current measurements available?	10	67

2. Analyzing Machine Capacities

At the start of this project it is important to measure and calculate actual machine capacities. Without accurate baseline performance figures it is impossible to make recommendations. Capacity analysis will also point to possible bottlenecks in the process. This chapter will give more detailed information about the machine capacities in every stage and how the capacities have been calculated or measured.

Capacities have been calculated for 40 cm x 60 cm and 60 cm x 90 cm mats. Because of the high density (pieces per surface area) of these products bottlenecks are most likely to appear. Secondly, the 60 cm x 90 cm size mat is the biggest production volume of all PVC products. Measurements have been made using a stopwatch and have been verified by counting production over a longer period of about 30 to 60 minutes.

2.1 Pre-Cutting Machines

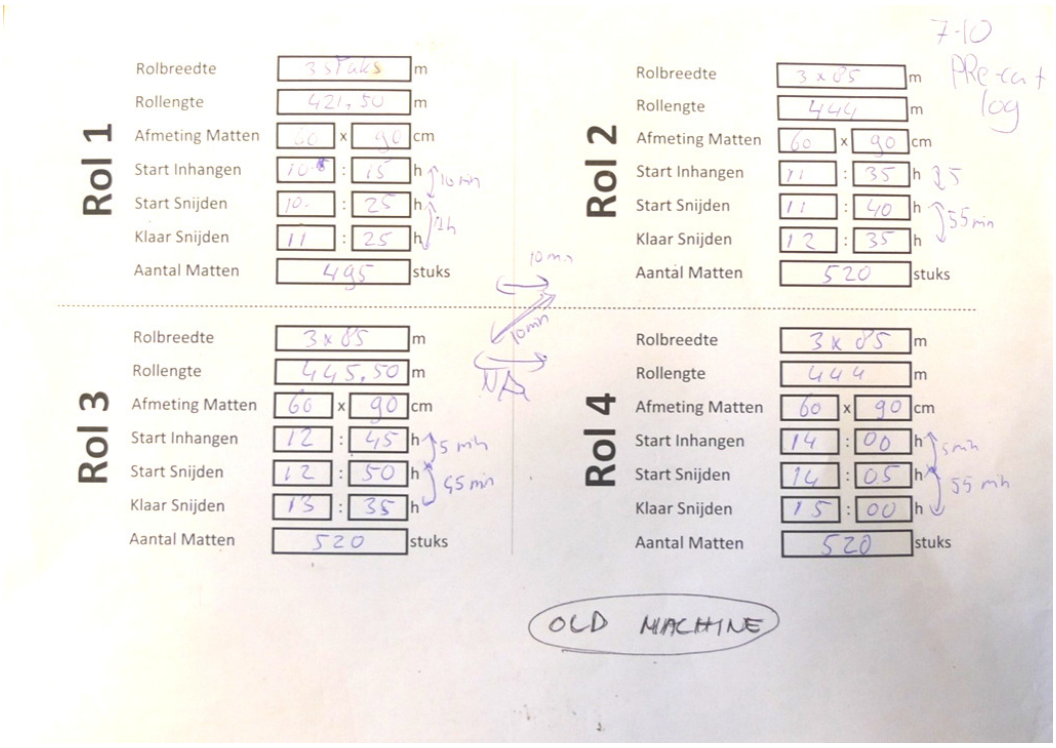
First thing was to find a way to calculate pre-cutting capacities in an accurate way. This was difficult because of the two different machines. The newer machine cuts more mats per row, for 60x90 mats: 4 vs. s mats.

The limiting factor on both machines is the employee. He has to do a quality check on the cut mats and stack them on a pallet. This also equalizes the capacity difference between the older and newer machine; on the old machine the operator only has to check and stack 4 mats per cycle, as opposed to 5 for the newer machine.

Both machines have an adjustable speed that adjusts the speed of roll feed and the moving speed of the cutting blade. Operators fine-tune these settings to suit.

To measure pre-cutting capacities a form (Figure 10) was created on which the operators filled in the following data:

- Number of mats cut per *row*
- Total roll length
- Size of mat
- Setup start time
- Cutting start time
- Cutting end time
- Total amount of mats cut



Rol 1		
Rolbreedte	3 Stuks	m
Rollengte	421,50	m
Afmeting Matten	60 x 90	cm
Start Inhangen	10 : 15	h
Start Snijden	10 : 25	h
Klaar Snijden	11 : 25	h
Aantal Matten	495	stuks

Rol 2		
Rolbreedte	3 x 85	m
Rollengte	444	m
Afmeting Matten	60 x 90	cm
Start Inhangen	11 : 35	h
Start Snijden	11 : 40	h
Klaar Snijden	12 : 35	h
Aantal Matten	520	stuks

Rol 3		
Rolbreedte	3 x 85	m
Rollengte	445,50	m
Afmeting Matten	60 x 90	cm
Start Inhangen	12 : 45	h
Start Snijden	12 : 50	h
Klaar Snijden	13 : 35	h
Aantal Matten	520	stuks

Rol 4		
Rolbreedte	3 x 85	m
Rollengte	444	m
Afmeting Matten	60 x 90	cm
Start Inhangen	14 : 00	h
Start Snijden	14 : 05	h
Klaar Snijden	15 : 00	h
Aantal Matten	520	stuks

Figure 10: Pre-cutting form

From this data changeover times and cutting times could be calculated. The forms were used for the two different machines and with different operators. Differences between operators were very small.

The capacity was calculated in excel sheet like in Table 3. The capacity in m^2 was scaled to finished product size to make it easier to compare it to the PVC line.

Cycle times were recorded using a stopwatch. The speed of the machine was adjusted so that the employee could work without shutting down the machine while stacking and inspecting mats and not having to wait for another row of mats to be ready. Depending on defects in the mats the employee may need to pause the machine for a while to check a mats' conformance.

Changeover times were also measured using a stopwatch. The average changeover time was 12 minutes. One changeover was also recorded by a digital video camera to analyze the changeover operation in more detail. A flowchart of the pre-cutting can be seen in attachment 3 as well as the average changeover time.

Table 3: Pre-cutting capacity calculation sheet (60 cm x 90 cm)

Pre-Cutting Timesheet							
Settings Review							
	MAT DIM		**CUT DIM**				
X	900	*mm*	850	*mm*	Cutting Time	4	*s/row*
Y	600	*mm*	550	*mm*	Movement Speed	65	*mm/s*
		Border:	25	*mm*	Changeover Time	360	*s/roll*
		QTY - X on Width:	362	*pcs/roll*	Roll Width:	2260	*mm*
		QTY - Y on Width:	468	*pcs/roll*	Roll Length:	100	*m*
Calculations							
		Mats/Row:	4	*pcs*	Waste over Width:	60	*mm*
		Mats/Column:	117	*pcs*			
		Total Mats/Roll:	468	*pcs*	Total Waste:	7,21	*m^2/roll*
		Movement Time:	13,1	*s*		3,2	*%*
		Cycle Time:	17,1	*s/row*			
		Total Cutting Time:	33,30	*min*			
		Total Roll Cycle Time:	39,30	*min*			
		Theoretical Capacity:	715	*pcs/h*	@ 100% Uptime		
			385,83	*m^2/h*			
		Actual Capacity:	579	*pcs/h/machine*	@ 81% Uptime		
			312,52	*m^2/h/machine*			

For 60x90 mats one machine has a theoretical production capacity of 715 mats/hour. This theoretical capacity is solely based on cycle time, roll lengths and optimum changeover time. When comparing this theoretical capacity to the actual capacity measured using the forms the machines have an uptime of 81% which can be seen in attachment 4.

The length of the raw roll affects changeover because it determines how often the operator has to feed a new roll. The changeover time also slightly depends on the employee who is working at the moment.

2.2 PVC Line

The PVC line is the most important stage in the process because it is running continuously and it has a significantly higher operating cost compared to pre-cutting and final cutting. Other machines' capacities should be balanced to the PVC line. The PVC line capacity is depending mat dimensions and quality. Quality determines the line speed, the mat dimensions determine the surface area that can be used on the machine.

At the start of the line there is a device that picks a row of mats from a table and positions them on the line. An operator inspects the mats and places them on the table to be picked up. Depending on the page size used for final cutting the machine positions the mats with a gap in between. The gap is bigger where a page is being cut at the end of the line opposed to the gap between mats *on* a page. For example; with 60x90 mats 2 mats are positioned in a row and a page consist of two rows, thus four mats fit on a page. The gap between mats on a page is 7cm while the gap between pages is 9cm. This exact positioning makes it easy to calculate capacity: The average distance between mats (front-to-front) combined with the specified line speed (4.8m/min for 60x90 Lille mats) and the amount of mats in a row result in a consistent output capacity.

Table 4 shows the PVC line capacity calculation sheet and what information was needed to calculate the capacity. For these calculations the PVC line uptime was defined to be 100% because it is a continuous and leading process when compared to the final cutting stage; cutter capacity is best compared with instantaneous PVC line capacity. The actual uptime of the line is 92% and is proven in attachment 5. The actual uptime includes changeover, breakdown, maintenance and rework.

Table 4: PVC line capacity calculation sheet (60 cm x 90 cm)

PVC Line Timesheet										
Settings Review										
DIM			**QTY**		**BORDER**		**MAT GAP**		**PAGE GAP**	
X	900	*mm*	2	*pcs*	25	*mm*	70	*mm*		
Y	600	*mm*	2	pcs	25	*mm*	70	*mm*	90	*mm*
Line Speed:			4,8	*m/min*						
Line Width:			186	*cm*						
Calculations										
Mats/Row:			2	*pcs*						
Average Gap Size			80	*mm*						
Avg. Distance F-F:			630	*mm*						
Cycle Time:			8	*s*						
Theoretical Capacity:			914	*pcs/h*					@ 100% Uptime	
			493,71	*m^2/h*						
Applied PVC:			535,68	*m^2/h*						
Wasted PVC:			41,97	*m^2/h*	8	*%*				
Actual Capacity:			914	*pcs/h*					@ 100% Uptime	
			493,71	*m^2/h*						

2.3 Final Cutting Machines

The final cutting stage cuts the pages into mats. Creating a mathematical model to calculate final cutting capacity is fairly straightforward: Both feeding and cutting speeds for the machines are set, thus cycle time only depends on the total cutting distance needed for a specific type of mat. Table 5 shows the final cutting timesheet used to calculate machine capacity. The resulting capacities have been verified by measuring output for an hour of production.

Initial machine uptime was measured to be 95% and the calculation can be seen in attachment 6.

Table 5: Final cutting capacity calculation sheet (60cm x 90cm)

Final Cutting Timesheet						
Settings Review						
	DIM		**QTY**			
X	900 *mm*	2	*pieces*	Cutting Speed:	580	*mm/s*
Y	600 *mm*	2	*pieces*	Movement Speed:	325	*mm/s*
				Movement Distance:	2110	*mm*
				Extra Waiting Time	3	*s*
Calculations						
Circumference:		3000	*mm*			
QTY/Page:		4	*pieces*			
Total Distance:		12000	*mm*			
Cutting Time:		20,69	*s*		69	% Of Total
Movement Time:		6,49	*s*		22	% Of Total
Total Cycle Time:		30,18	*s*			
Cycle Time/Mat		7,55	*s*			
Theoretical Capacity:		257,64	*m^2/h/machine*	@ 100% Uptime		
		477	*pcs/h/machine*			
Actual Capacity:		244,76	*m^2/h/machine*	@ 95% Uptime		
		453	*pcs/h/machine*			

When producing 40x60cm and 60x90cm mats the final cutting stage poses a bottleneck in the process. Excess pages are moved to the buffer machine and automatically stacked on pallets. With a line speed of 4.8 m/min for 60x90 mats about 1% of total production gets buffered, with 40x60 mats 32% gets buffered.

To finish cutting on the buffered pages two different options are available:

1) When the PCV line is producing runners it is possible to use the two in-line cutting machines to cut pages. For maximum capacity three operators are needed, but the process is possible with one or two operators too:
   a. An operator grabs a page from the stack and puts it on the page transport system. The page gets moved to one of the two cutters where it gets cut and stacked by the other two operators.
   b. Method A is also possible with only one cutter in use, reducing the amount of operators needed.
   c. Sometimes the whole process is done by only one operator. The operator walks between the buffer device and the cutter. The operator is able to put three pages on the line before having to walk back to the cutter to stack the cut mats.

2) During long mat production runs the amount of buffered pages can get too big. In those cases it is not possible to use the two in-line cutters, because they are already occupied. For these cases a 3rd, separate cutter is available.
   Figure 11 shows a pallet of buffered pages waiting for the 3rd cutting machine. As with the in-line cutters it can either be used with one or two operators.
   a. One operator is lifting the page on the table while the second one is stacking the cut mats.
   b. One operator is able to load a single page on the cutter while a second one is being cut. The operator has to remove the cut mats before another page can be loaded. This process involves a lot of walking for the operator.

Figure 11: Overflow pallet and 3rd cutter

2.4 Capacities Summarized

Table 6 summarizes the machine capacities in every stage for both dimensions of mats. There seem to be two bottlenecks in the process when the PVC line speed is 4.8 m/min and producing 40x60 mats. The pre-cutting stage has 113 pieces less capacity per hour than the PVC line and the final cutting machines move 749 pieces to overflow every hour. When producing 60x90 mats the only bottleneck is the final cutting stage.

Table 6: Summary of machines capacities

Machine capacities 40x60	
Pre-Cutting	2191 pieces / hour / 2 machines
PVC Line 4.8m/min	2304 pieces / hour
Final Cutting	1555 pieces / hour / 2 machines
Machine capacities 60x90	
Pre-Cutting	1157 pieces / hour / 2 machines
PVC Line 4.8m/min	914 pieces / hours
Final Cutting	907 pieces / hours / 2 machines

Moving the 3rd available cutter in-line would eliminate the final cutting stage as a bottleneck for both 60x90 and 40x60 mats. It would also create room for a higher PVC line speed if the coating process allows it. Chapter 5 studies the costs and gains of moving the 3rd cutter in-line.

For 40x60 mats the pre-cutting stage lacks capacity. Without any improvements to the machine capacity creating a buffer of semi-finished products (inventory) before the PVC line is the only solution to supply the line. Raising pre-cutting capacity can be done by decreasing the time needed for changeover. Chapter 7 elaborates on ways to achieve this.

3. Analyzing Initial Inventory Sizes

This chapter is using the information gathered in chapter 2 to analyze the amount of semi-finished products in inventories. The initial situation and amount of products in the different inventories have been measured by counting and calculating. This chapter is only dealing with semi-finished products in inventories and not with finished products. Most of the finished products are located in external warehouses and it is too difficult to measure the amount of products and the waiting time before shipping. The amounts of raw rolls waiting on the floor have been counted and their widths have been measured. Lengths were mentioned in the roll's tag, which can be seen in Figure 13. Every roll has its own tag. Listed on the tag are the roll length, mat width and roll type. For mats the length on the tag is not the actual roll length, it needs to be divided by the amount of mats that fit in a row on the pre-cutting machine. For the roll in Figure 13: 596m divided by four mats in a row results in a real length of 149 m. The roll tag in rolls destined for runners is showing real length; the full width is used for a single runner.

Figure 12: Inventory overview

Figure 13: Roll tag

3.1 Raw Rolls for Mats

These semi-finished products are destined for the pre-cutting stage. A lot of rolls are usually waiting to be cut. These rolls are in a random order and Figure 14 illustrates the issues this causes: in this example the operator needs the roll with the pipe in it. It takes time to find the right roll and to move it to the pre-cutter.

Table 7 shows the calculations that have been made and how much production time is buffered.

Table 7: Initial inventory size of raw rolls (60cm x 90cm)

Cut mat size	55	x	85	cm
Roll width (old machine)	1.68	m	8	rolls
Roll width (new machine)	2.29	m	9	rolls
Average roll lenght	100	m		
Total:	**3405**	**m2**	**17**	**rolls**
	7283	**pcs**	*55cm x*	*85cm*
Pre-Cutting capacity	**1157**	**pcs / h**		
Capacity of	**6.3**	**h**		

It can be seen that the size of the semi-finished inventory is too big when aiming for smooth material flow and other lean manufacturing principles. A more sensible amount of product inventory could be estimated by how long a possible breakdown or other delay would take. This would create a small buffer that is safe in case of machine emergencies.

Figure 14: Wrong order of the raw rolls

3.2 Pre-Cut Mats

Pre-cut Mat inventory can be seen in Figure 12 and it contains the pre-cut mats from the pre-cutting machines. After a raw roll has been cut operators write the amount of cut mats and the work order number on the roll's tag. The tag was put between the mats. Figure 13 shows a pallet tag: 696 Pieces and work order W252447.

Table 8 shows the amount of mats in inventory of every color/type.

Table 8: Initial inventory size of pre-cut mats

Mat size	60 X 90	cm
Grey:	12542	pcs
Blue:	4723	pcs
Yellow:	5553	pcs
Brown:	8746	pcs
Total:	**31564**	**pcs**
PVC Line Capacity 4.8m/min	**914**	**pcs/h**
Capacity of	**34.5**	**h**

It is safe to say that the amount of inventory measured is not based on production capacity, over 34 hours of PVC line production is buffered in the inventory. No pre-cutting breakdown or other emergency will take even close to 34 hours. All these semi-finished products are waiting, no value is being added. Waiting is one kind of waste in lean manufacturing and should be reduced.

3.3 Uncut Pages

This inventory consists of the uncut pages that have been moved to overflow buffer in the final cutting stage. With a specified line speed of 4.8 m/min for 60x90 mats, about 1% of total mat production moves to the overflow position. In this example it was estimated that the production length of this kind of mat is 10 hours. The overflow inventory size would be 70 mats in this case (Table 9). In some cases the overflow device is used in emergencies, like when a cutter has broken down or a lot of quality defects appear. Employees need to pause the cutting machines while doing quality checks.

Table 9: Overflow buffer

Production hours	10	h
Average overflow	7	pcs / h
Total overflow	**70**	**pcs**
Final cutting capacity 2 machines	**907**	**pcs / h**
Capacity of	**0.08**	**h**
	4.6	**min**

This is type of semi-finished product inventory is very undesirable. It prevents the order being finished the first time round: The worst scenario is that the whole shipment is late because of overflow and uncut pages in storage.

3.4 Raw Rolls for Runners

When the PVC line is manufacturing runners raw rolls are waiting at the beginning of the PVC line. During the runners production this is the only inventory used inside the PVC department.

Some of the rolls were stacked in high piles and the operator wasn't able to get the right roll down. In this case he needed to ask the forklift driver to fetch the right roll. Figure 15 shows how the raw rolls were put on the ground in random order.

Table 10 shows the amount of rolls in inventory and how many meters in total. The whole inventory was enough for 10.4 hours of PVC line production at 5.5 m/min.

Table 10: Initial size of the Inventory for raw rolls

Amount of raw rolls	40	pieces
Average roll lenght	86	m
Total lenght of rolls	**3440**	**m**
PVC line capacity 5.5m/min	**330**	**m/h**
Capacity of	**10.4**	**h**

Figure 15: Raw rolls waiting for PVC line

3.5 Summary

This chapter was showing the initial size of inventories inside the PVC-department. Inventory sizes were counted and used only 60x90 mats.

Table 11 shows a quick overview about the initial inventories maintained.

Table 11: Summary of inventory sizes

Semi-finished product type	Initial size of inventory		Machine capacities		Total time	
Raw rolls for mats	7283	pcs	1157	pcs/h	**6.3**	**h**
Pre-cut mats	31564	pcs	914	pcs/h	**34.5**	**h**
Uncut pages (overflow)	70	pcs	907	pcs/h	**0.08**	**h**
Raw rolls for runners	3440	m	330	m/h	**10.4**	**h**

4. Process Analysis using Value Stream Mapping

The data gathered in the previous chapter is being used to create an initial state Value Stream Map (VSM). This chapter documents both runner and mat processes.

This chapter also shows what kind of materials are used during the process and how these materials flow inside the department. It gives a good overview about all the transportation that was done inside the department.

4.1 Using & Analyzing VSM

Value Stream Mapping is a widely used tool in Lean Management when aiming to eliminate waste, or muda. A value stream map is a useful tool to visualize every step and flow of products and information in a process. A lot of information can be added to a VSM: cycle times, uptimes and changeover times. The key difference between a VSM and a flowchart used in other systems is that the VSM is based around the process itself, with information flow as a support.

By using a VSM it's easy to see how and where in the process value is added. It helps to visualize material flow between process stages, product inventory and information flow inside the company. Managers are able to find the source of wasteful non-value-added activities in the process.

Normally value stream mapping is used to show the material and information flows from the customer's order through the manufacturing process to the delivery of the finished good to the customer. In this process the primary entity was the manufacturing process inside the PVC department.

Figure 16 contains a legend to the symbols commonly used in a VSM. Table 12 lists a description of the terms used in VSM. VSM was done from both mats and runners.

Value Ratio helps weigh possible future improvements in the process. Value ratio is calculated by using equation 1. The perfect lean operation has a value ratio of 1, which is of course impossible to achieve and normally the value ratio of a manufacturing company is closer to 100. The company's PVC department had a value ratio 155 when producing 60x90 mats. Runner production had a value ratio of 31.1.

$$Value\ Ratio = \frac{Process\ Lead\ Time}{Value\ Added\ Processing\ Time} \quad (1)$$

(Wedgewood, 2007)

Table 12: Lean terms used in Value Stream Mapping

Term	Description
Value-Added Processing Time	Time of those work elements that actually transform the product in a way that customer is willing to pay.
Process Lead Time	The time it takes one piece to move all the way through a process or a value stream, from start to finish. Envision timing a marked part as it moves from beginning to end.
C/T **Cycle Time**	How often a part or product actually is completed by process, as timed by observation. Also, the time it takes an operator to go through all of their work elements before repeating them.

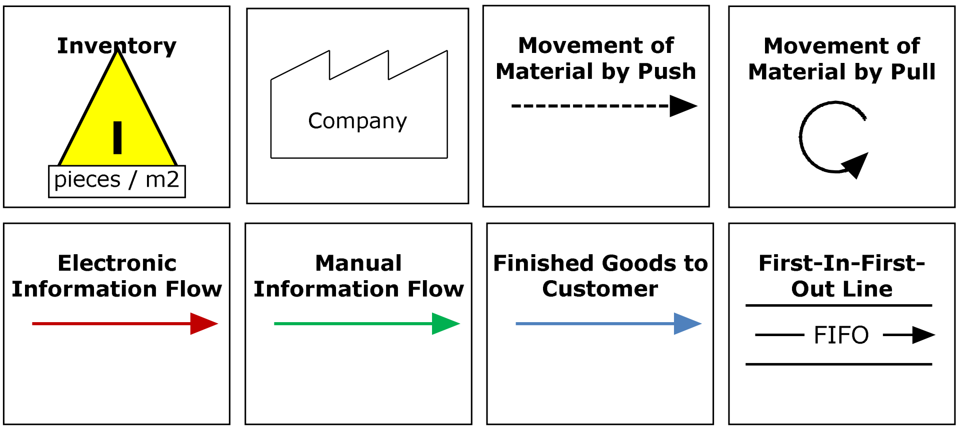


Figure 16: VSM legend

4.2 VSM for the Mat Production Process

The company's highest product volume in the PVC department are mats. In 2009 60x90 mat production was covering 46% of the total production. This is the main reason why the VSM was made for 60x90 mats.

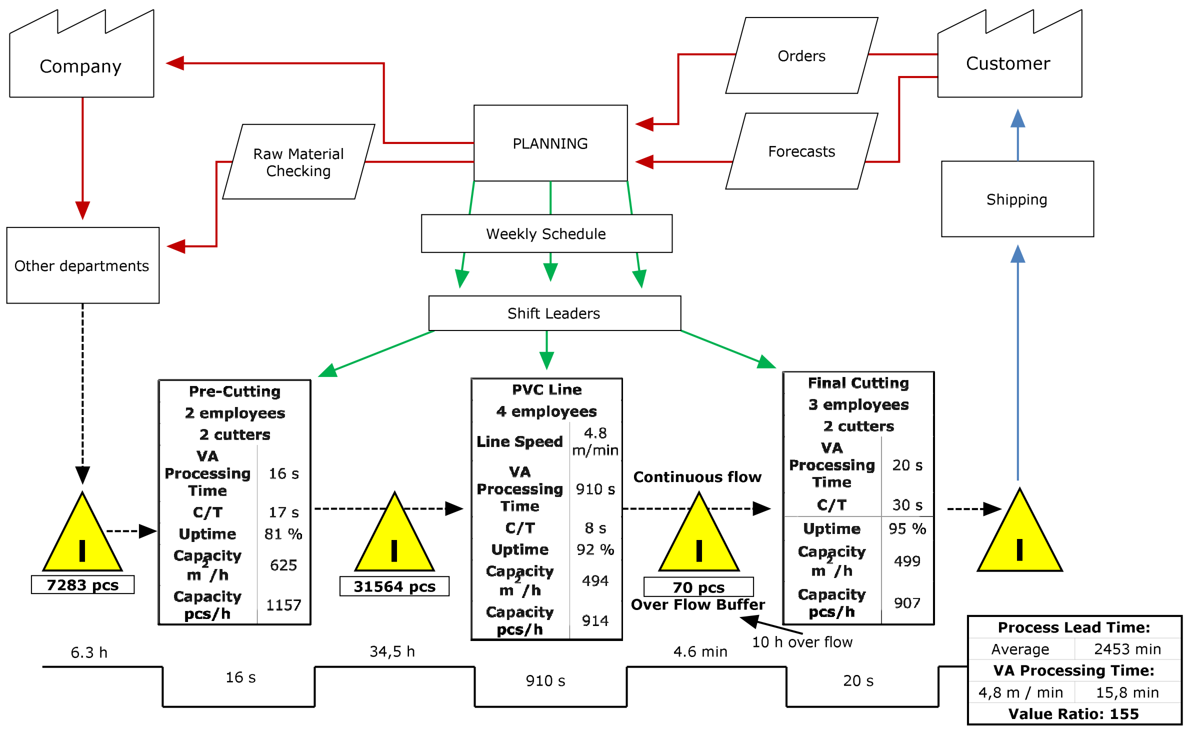


Figure 17: Current state mat VSM

Figure 17 shows the initial situation for the mat manufacturing process. As measured in chapter 3, the company has big semi-finished product inventories in-between stages. Products have a long waiting time in inventories and this has a big impact on lead time. Also the capacities measured in chapter 2 are included.

Even with big batch sizes it is possible to pull orders through. Now there were situations in which they needed to stop manufacturing the current batch and then a rush order got pushed through. The previous batch and semi-finished products were waiting in inventories during that time. If a company has a short lead time it is more flexible, making it easier to react to rush orders because of a smoother product flow.

In the Figure 17 PVC line speed was 4.8 m/min, which was the specified line speed for that size and quality of mat. As shown the capacity of the two pre-cutting machines was higher than the PVC line when producing 60x90 mats. But the capacity of the two final cutting machines wasn't enough to cut all the pages from the PVC line and pages which couldn't be cut went into overflow. In this example they had only ten hours of production in the overflow buffer. The inventory of overflow can be seen in Figure 18. They had to use the overflow buffer and it was increasing the amount of working hours and costs and reduced a batch's profit and lead time.

Possible improvements

Uptime of the cutting machines could be increased by reducing changeover times. Pre-cutting machines uptime was only 81 % (as calculated in attachment 4). By reducing the average changeover time it is possible to increase machine uptime and capacity. Chapter 7 shows how changeover time could be reduced, what kind of improvements are needed and how this would impact capacity. Increasing capacity of final cutting would eliminate having any overflow buffer. Chapter 5 shows a situation where the 3rd final cutting machine is installed in-line like the two others.

After having new capacities for machines it's possible to reduce inventory sizes to a sensible level based on measurements. By reducing inventory sizes and waiting time the lead time will be also shorter. Chapters 8.2 and 8.5 are dealing with these levels.

Figure 18: Overflow inventory

4.3 VSM for the Runner Production Process

Runner production was covering 24% of the total production volume in 2009. The process itself is simpler than that for mats. Only two value-adding steps can be defined: Coating and wrapping.

The first stage was the PVC line where the long raw roll was fed to the PVC line and transported over the line. At the end of the line a rolling machine rolls the runners around a cardboard roll and employees cut it to right length. The length of the roll depends on the quality and thickness of the runners. After the machine is finished rolling, two employees wrap the roll with plastic. An automated conveyor system transports the roll to a roll ramp where the forklift driver picks it up and transports it to the warehouse. Figure 19 shows the situation when producing 30 m long rolls.

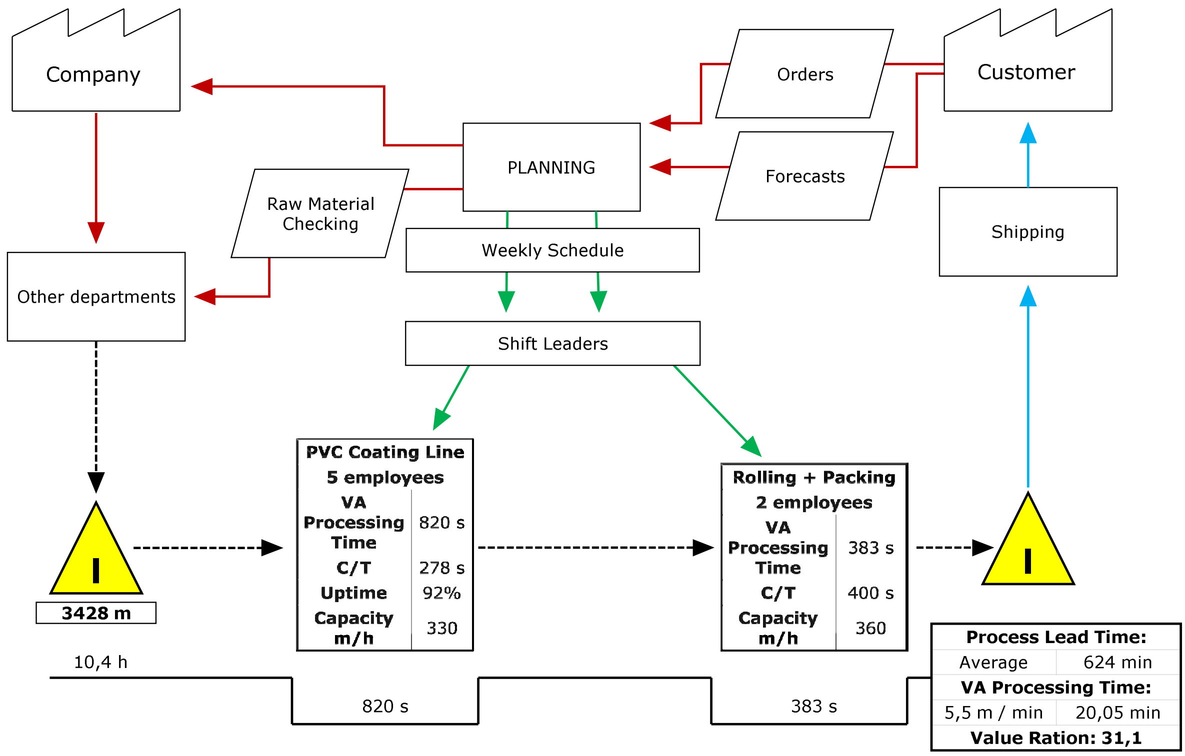


Figure 19: Current state runner VSM

The situation shown above is better than with mat productions. The process is less complicated and the wrapping stage is performed in-line. Lead time is good when compared to mat production. The value ratio of the current process is 31.1. There aren't any unnecessary transport movements between the steps. There was also only one inventory that can increase or reduce the lead time of the process. The line speed is depending on runner quality and type. The initial situation shows that the rolling and packing stage isn't the bottleneck in the process with 5.5 m/min line speed.

Possible improvements

The main objective was reducing the lead time and it could be done by reducing the inventory size. When the raw rolls are in right order it's easier for employees to find the right roll and judge the inventory size. Chapter 8.5 gives more details how it could be done and what would be a reasonable size of inventory.

4.4 Summary & Recommendations

The Value Stream Maps created here are good tools to analyze material and information flow inside the processes. They include important and useful information that can be used during the project. It shows the initial process situation and it helps to visualize the current problems. In this project the VSM was more focused on product flow than information flow. It showed the processing times and the big inventories between the stages.

According to lean methods and different types of waste first thing in this project was trying to reduce lead time through the PVC department. It could be done by reducing inventories after improved machines capacities are known.

5. Final Cutting Capacity & Position

When calculating machine capacities it is important to compare cutting machine capacities to the PVC line capacity. Other stages should keep up the same pace as the PVC line which is the leading stage in this process because of its high operating costs.

Chapter 2.3 shows that the initial capacity of the final cutting stage isn't high enough compared to the PVC line. The problem surfaced especially when producing 60x90 or 40x60 mats. Because the final cutting capacity isn't high enough uncut pages were buffered, thus increasing costs and increasing lead time so it was totally unnecessary inventory. The example in this chapter is calculated by using 40x60 mats because in that case the capacity differences are the biggest.

This chapter presents how the final cutting stage's capacity could be increased by moving the 3rd available cutter to an in-line.

5.1 Capacity Difference

Chapter 2 described the machine capacities in different stages, how the capacities have been calculated and what was affecting these capacities. One of the main problems with capacities in the initial situation was the overflow buffer in final cutting. The problem is best visible with 40x60 sized mats, where the capacity difference is the biggest. As Table 13 shows approximately 749 mats (40x60) were buffered every hour with only two cutting machines.

By installing the third cutter in-line like the two others, regular overflow can be reduced to zero and the buffer will only be used in emergencies. After moving the 3rd cutter there is also the possibility to increase the PVC line speed. Calculations show that when producing 40x60 mats an excess capacity of 29 pieces per hour is available.

Table 13: PVC line and final cutting capacities

Initial capacities 40x60 Uptime 95%		
PVC Line 4.8m /min	**Final cutting machines**	**Difference**
2304 pcs / hour	1555 pcs / hour / 2 machines	**- 749 pcs / hour**
Future capacities 40x60 Uptime 95%		
2304 pcs / hour	2333 pcs / hour / 3 machines	**+ 29 pcs / hour**

5.2 Negative Buffer Side Effects

Besides the need for extra staff and a lower capacity on the 3rd cutter buffering pages have many other negative side effects to both the product and the process.

- Orders are semi-finished. This has more impact on the process because cutting is the final stage before shipping, especially on smaller orders that have one or two pages in the buffer. This means those small orders cannot be shipped, sometimes resulting in missed deadlines.
- The PVC on the pages cools and solidifies more, making the PVC harder to cut and resulting in more blade wear and cutting errors.
- Pages sag on mat borders when stored, this creates wrinkles in the PVC material and this fouls the edge detection on the cutting machines, resulting in extra rework and scrapped products.
- Significant extra work involved. For the pages are cut in-line all the movement is done automatically. However, when the pages are buffered a lot of extra logistics are involved in storing the buffered pallets, retrieving them and putting them back on the line.

5.3 In-Line Placement

It's not possible to install the third cutter next to the two others without modifying the runner conveying system. The company already had a quote dated in 2005 which includes all the modifications and new machines needed to move the 3rd cutter in-line.

The quote featured the following:

- Maintained same gap between machines.
- 3rd cutter is positioned next to current overflow buffer.
- The new layout of the cutters can be seen in the attachment 3.
  - Overflow buffer can be only cut by second and third cutter.
- New equipment needed: Prices from 2005
  - Fourth extra conveyor table 25 395 €
  - Feed to the cutting table 23 740 €
  - Modifications to the transporting belt for runners 2 090 €
  - Roll lift for runners 35 085 €
  - Stock table for runners 6 125 €
  - Modifications for the conveyor system 14 880 €
    - **Total** **107 315 €**
- Compare to initial overflow labor costs:
  - Labor costs when cutting 40x60 and 60x90 mats' overflow away with 3rd cutter not in-line in one year. See attachment 7.
    - **Total** **25 299 €**

5.4 Summary & Recommendations

When aiming to maximize PVC line output and reduce lead time it is necessary to increase the capacity of the final cutting stage. The most sensible and easiest change is to move the already available 3rd cutter to a position in-line like the two others. At the moment the third cutter isn't used all the time and it's far more efficient to keep it working at the same time as the other two cutters.

Having the 3rd cutter in-line only has advantages when producing 40x60 and 60x90 mats. These two types do however, cover 70% of total production volume. When producing 60x90 mats the 3rd cutter's capacity will not be fully covered. This means that the 3rd operator can also do the logistical work needed in final cutting, eliminating the need for an extra operator.

Besides the lowered operating expenses by eliminating the need to manually insert the pages, moving the 3rd cutter in-line has many other advantages that are harder to measure. The biggest advantages can be found in a higher first-time-right production volume: Lesser quality defects and orders get finished on the first try. Another big advantage is that there is significantly less process overhead by not having to manually coordinate the page cutting process.

6. Reducing Inventory: FIFO Storage System

One of the project's goals is to reduce lead time inside the department by reducing inventory. As chapter 3 showed the inventories inside the PVC department were big and semi-finished products weren't stored sensibly. A FIFO storage system will help reduce the amount of inventory needed. The principle of FIFO storage system can be seen in Figure 20: *First product In is the First product Out.*

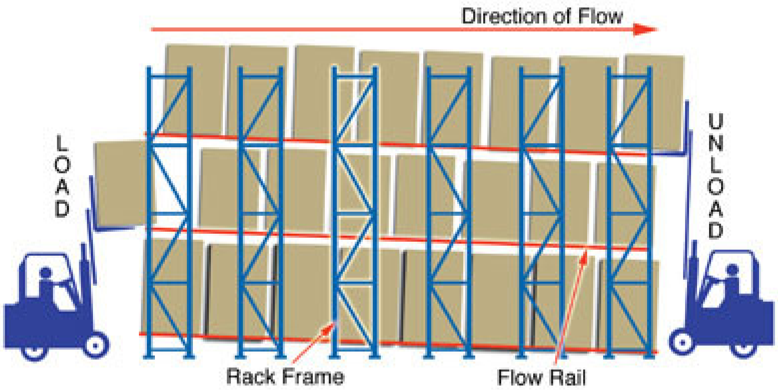


Figure 20: FIFO storage principle

6.1 Considerations & Gains

Storing inventory First In, First Out has many advantages without increasing staff workload. FIFO helps to facilitate the smaller inventory sizes recommended in this project. With FIFO it's important to create a clear order in production: What, when and in which order is it going to be produced. By having a FIFO inventory between the different stages this production order will flow through the whole process.

It starts in the planning department. Currently there is no specific order in production planning. When the order is clear, the forklift driver can deliver the raw rolls in the right order, thus *eliminating searching time* for the pre-cutting operator. Using a FIFO storage for pallets with pre-cut mats will make sure this order flows right through to the PVC line, and therefore eliminating searching time even more.

Having a clear and simple product flow reduces overhead immensely: no more searching for the right pallet or roll and clear insight in the amount (and production time) buffered. This will increase process control and make it easy to reduce inventory and inventory costs.

6.2 Uniform Pallet Size

The first stage in creating a FIFO setup is by choosing a standard pallet size to stack the pre-cut mats. The biggest pallet is a FIN sized pallet: 1200x1000mm. This pallet size will fit 90% of production volume. Figure 21 illustrates loading patterns for common mat sizes. Because these pallets only rotate between the pre-cutting stage and PVC line durable and light plastic pallets can be used. By picking a standard pallet size a lot of industrial pallet handling equipment becomes available; all products are "off the shelf" and do not have to be custom made, reducing investment costs. More on this is shown in chapter 6.3.

Requirements for a type of pallet are:

- Light: Operators have to be able to lift the pallet on their own.
- 3 Slides: The current pallet trolleys need to be able to handle the pallets
- Durable: Pallets are being reused
- Flat top with small gaps to prevent the mats from sagging

Figure 22 shows a pallet that meets all these requirements. It's a polyethylene pallet that is commonly used in the food industry because of hygienic considerations. For the PVC department its lightness and closed top surface are very useful. PE Pallets can carry less weight, but that is not an issue here.

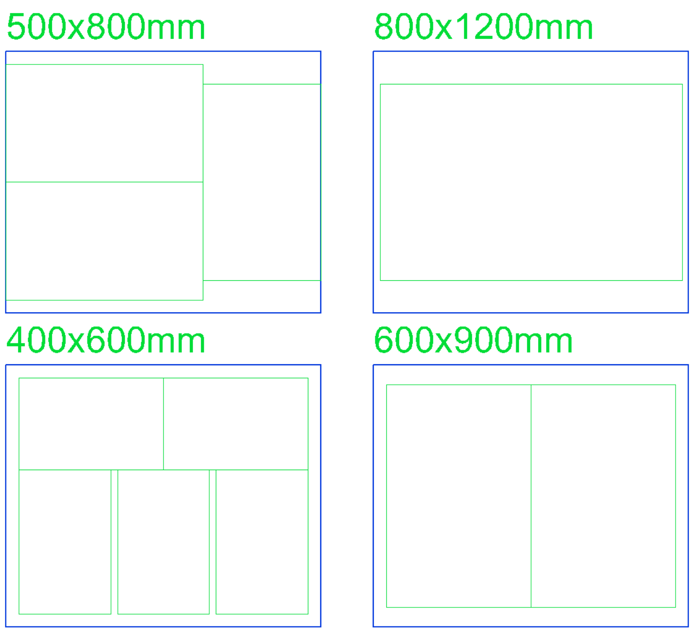


Figure 21: Pallet loading pattern examples

Figure 22: FIN sized PE pallet

6.3 Equipment

Because of the two pre-cutters it is sensible to create 2 FIFO lines for pre-cut mats. This will enable both pre-cutters to work on a different type of product while still maintaining a production order. This is especially useful on smaller production runs.

The necessary equipment for one FIFO line can be seen in Figure 23. This equipment is manufactured by SSI Schaeffer, a leading manufacturer of pallet handling machinery.

A. A pallet lift that lifts the pallet to the right height for the FIFO ramp to work. This lift will be able to pick the pallets up from the trolleys used by the pre-cutters.
B. A motorized transport block to transport the pallet.
C. A rotating platform.
D. The gravity fed FIFO line. Operators are able to use the trolleys again to remove a pallet from the FIFO line.

Detailed product specifications can be found in attachment 9 through 12.

Figure 24 shows a solution for a FIFO system on carpet rolls. This system can be used for both pre-cutters and for runner production. The operator can press a button and the ramp will release a single roll.

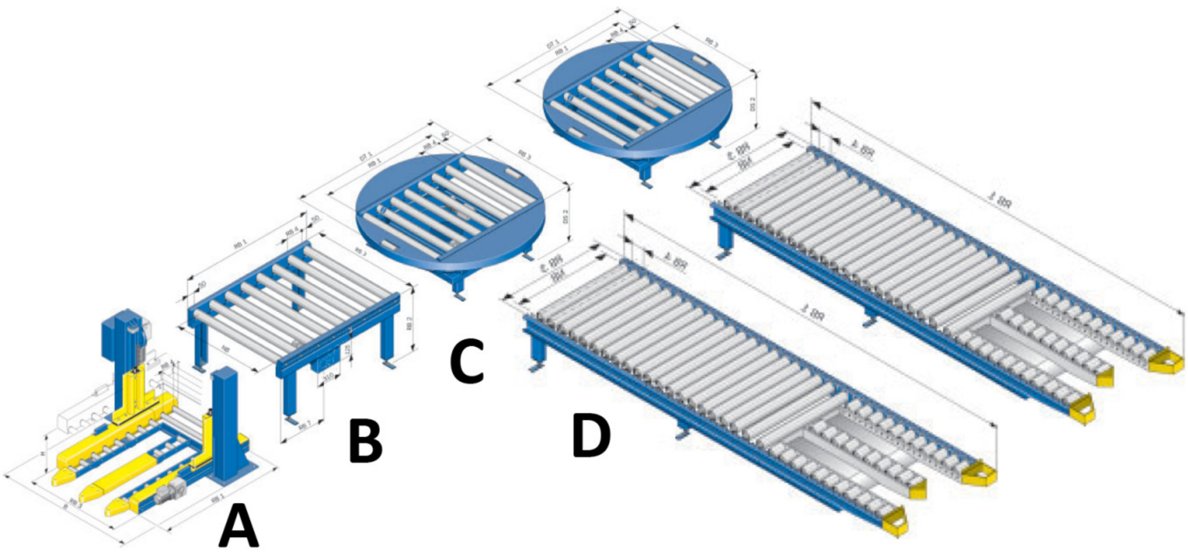


Figure 23: FIFO equipment setup

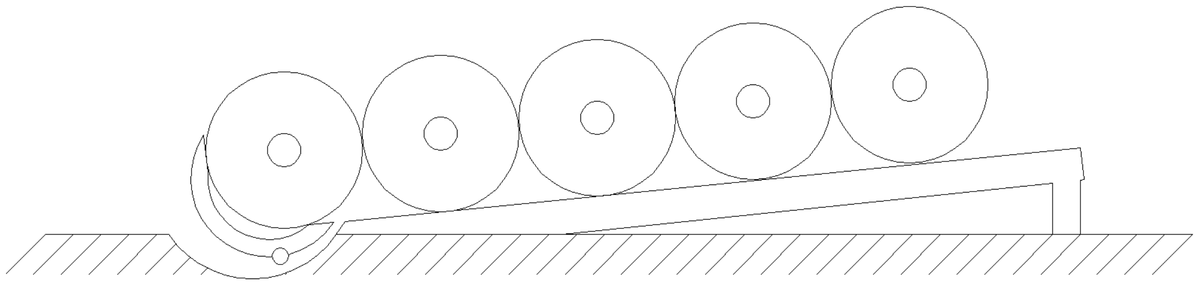


Figure 24: FIFO roll ramp

6.4 Positioning

The FIFO line should be located between the pre-cutting and PVC Line stages. One option for this location is presented in Figure 25 and Figure 26. The start of the FIFO line can be on the other side of the metal wall just next the pre-cutting machines (Figure 26). Creating a passage in the wall will reduce the distance pre-cutting operators need to travel significantly, thus reducing changeover time.

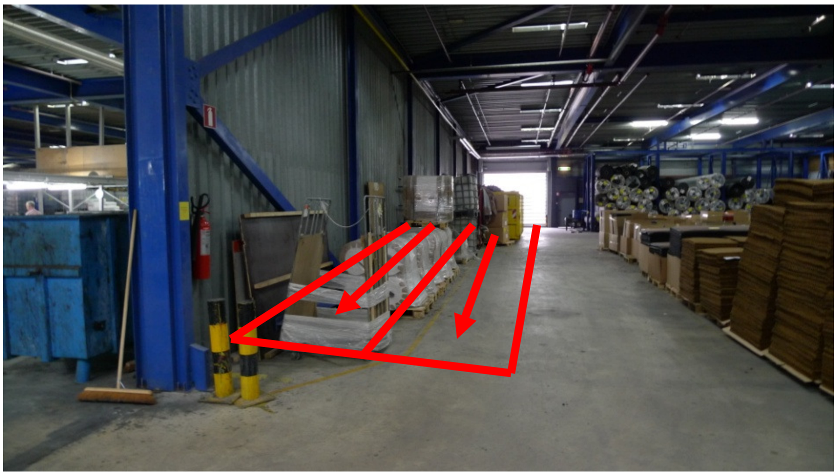


Figure 25: FIFO line positioning

Figure 26: FIFO line positioning

6.5 Summary & Recommendations

The current way of storing semi-finished products between stages doesn’t allow for a smooth, ordered material flow and makes it hard to reduce inventory levels: All the pre-cut mats from different batches and orders are positioned randomly in the storage areas. When using the FIFO principle in every inventory it allows better control over product flow and it always gives a good overview for operators of the inventory sizes.

Simple ramps for the raw rolls and FIFO storage system for the pre-cut mat pallets will make it possible to reduce inventories safely step by step.

7. Changeover Performance

Due to the different product types in the PVC department changeovers are common. For instance if the PVC line is switching from mats to runners, or if the pre-cutters insert a new roll in the machine. This chapter will analyze the current changeover performance and suggest improvements to reduce the time needed.

7.1 Single-Minute Exchange of Dies, SMED

“SMED is short for *Single-Minute Exchange of Die*. The *single* here means a single-digit number of minutes – less than ten. The SMED approach is simple and universal. It works in companies all over the world. Although it was first used in manufacturing with dies, the basic principles of SMED have been used to reduce setup and turnaround time in all types of manufacturing, assembly, and even service industries, from process and packing plants to airlines.”(The Productivity Press Development Team, 1996)

The first step in applying SMED is to differentiate between internal and external setup steps. Internal setup steps can only be performed when the machine is not running. External steps can be performed while the machine is still running. Next up is converting as many of these internal steps to external steps as possible, thus increasing machine uptime. The last phase is to streamline all the setup operations so they take less time to complete.

Changeover operations can be defined in the following categories:

1. Preparation, after-process adjustments, checking of materials and tools.
2. Mounting and removing blades, tools and parts.
3. Measurements, settings and calibrations.
4. Trial runs and adjustments.

7.2 Pre-Cutting Machines

After every cut roll the operator has to perform a changeover to feed the next roll. Average changeover time in that stage was 12 minutes when the operator was cutting equally sized mats; This 12 minutes changeover time does not include any blade adjusting for different size of mats. A flowchart of the pre-cutting and calculations of average changeover time can be seen in attachment 3 and 4. Average roll cutting time was 55 minutes, meaning the changeovers cover 18% of the time that was needed to finish a roll. When cutting different sized mats and adjusting the cutter’s blades to different positions changeover took even more time. The time needed also depends on the operator. Some employees were doing it faster than others. Carpet feeding to the older machine was easier than to the newer one and the operator doesn’t need help.

Because the operator continuously has to stack the mats on the pallet there aren’t many external setups that he can do while the machine is running.

The pre-cutting workstation does not have a barcode reader, the employees need to type the work order numbers by hand. This takes more time and is also prone to errors.

Because of the way the backing department tags and stores the rolls all the rolls need to be rotated 180°. The rotating action takes time because employees are using a crane to lift the roll to rotate it, as shown in Figure 27. By changing the way the rolls are tagged in the backing and laminating departments to a consistent way that suits the pre-cutting machine the operator won't have to use a crane and can use the internal lift in the machine, reducing changeover time. The way the rolls need to be tagged depends on how the rolls are rolled, the rolls need to be unwrapped from the underside.

Figure 27: Roll rotation

A more detailed changeover for pre-cutting machines is shown in attachment 3.

7.2.1 Center Lines & Markings

"In traditional setup operation, center lines and reference planes may not be visible on the machine. This means that the correct position for a tool or work piece must be found by intuition – or by trial and error. Making these center lines and reference planes visible is an effective strategy for eliminating these later adjustments." (The Productivity Press Development Team, 1996)

Both pre-cutting machines have the same type of blades and operators need to adjust these blades' positioning when changing to a different size of mat. Blade adjustment is currently done by using old stickers which can be seen in Figure 28. These stickers aren't clear or accurate enough. The small arrow on the sticker is vaguely indicating the right line on which the blade should be. Employees need to use a tape measure to make sure that blades really are in the right spots.

By replacing the old stickers with one, clear big sticker with all the different spots on it should be easier and faster to adjust blades. Employees can move the blades really close to the proper location and use a tape measure to do the final adjusting.

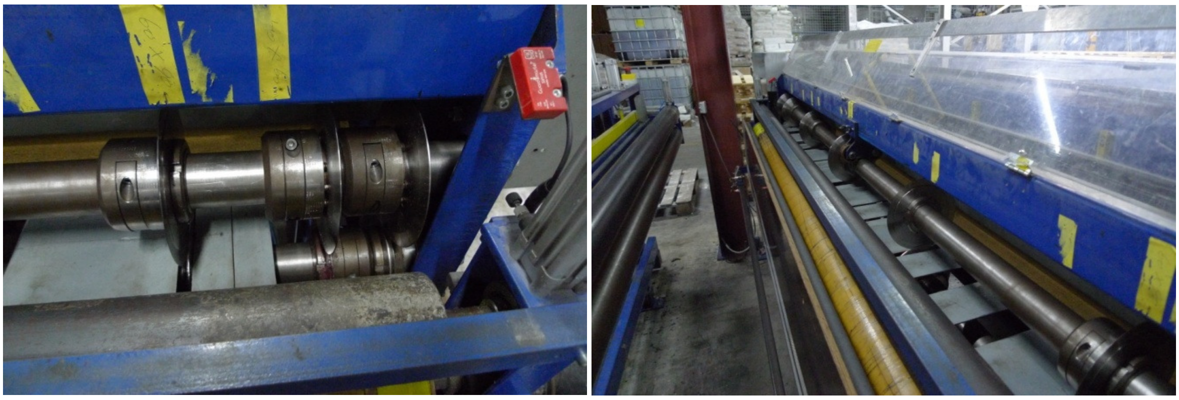


Figure 28: Pre-cutting machine blades settings

The centerline where the mat length sensor is located (Figure 29) should also be mentioned on the big sticker: The detector can't be at the same position as a cutting blade. Otherwise the detector will not recognize the mat properly and this results in mats with the wrong size. Currently the line is only marked behind the blades and it's difficult to see it when adjusting blades.

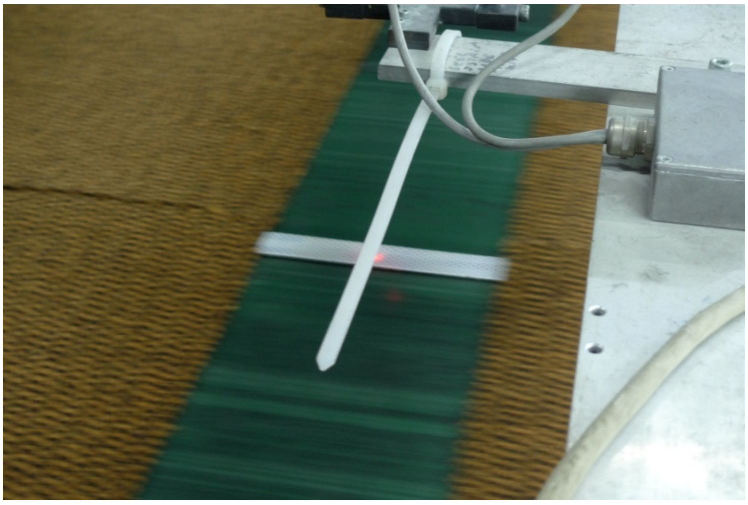


Figure 29: Center line and detector

7.2.2 Least Common Multiple System on Length Measurement

A method for reducing the measurement settings and trial run times is using the Least Common Multiple System LCM. LCM involves modifying the function and not the mechanism of a machine. An example is having multiple tools on a spindle and switching between them by flipping a switch. This significantly reduces adjustment time: automated tool changes and makes trial runs obsolete: settings are already dialed in to the correct values.

By having multiple sensors at a pre-set location instead of one that is moveable eliminates setup adjustments and inaccuracies. This is very applicable to the distance measuring sensor on the older pre-cutting machine. By adding sensors for the 4 most produced product lengths and having one moveable sensor for the other products trial runs can be significantly reduced. These sensors cost around €120.- each, so they do not pose a big investment.

Figure 30 and Figure 31 illustrate the application of LCM on the older pre-cutting machine.

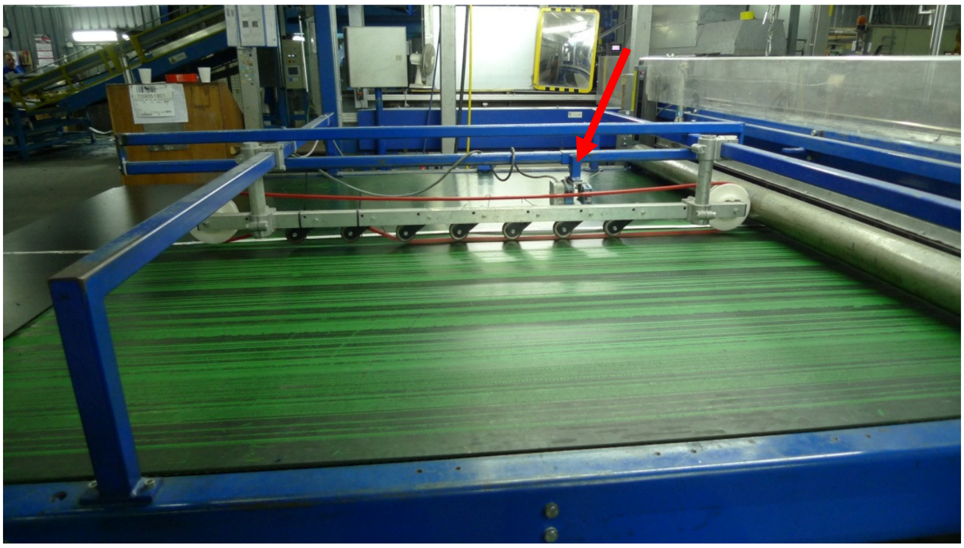


Figure 30: Single adjustable sensor

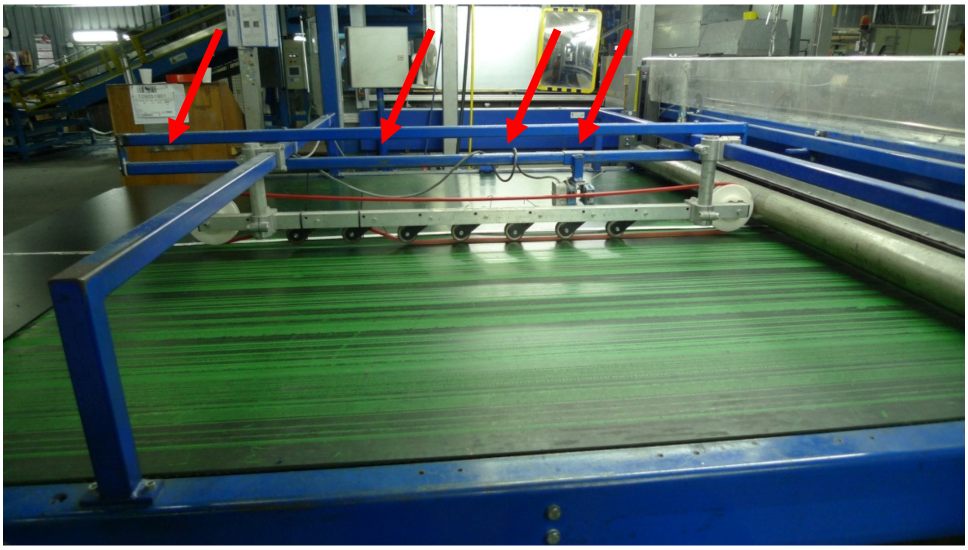


Figure 31: Multiple fixed sensors

Table 42 in attachment 4 shows the impact of reducing changeover time from 12 minutes to 8 minutes. It shouldn't be impossible by removing some unnecessary actions and using FIFO storage in both inventories around the pre-cutting stage. Improved uptime with 8 minute changeovers would be 87%.

7.3 Blade Changes on Final Cutting Machines

In final cutting machines there isn't a pure setup operation to be defined. The only thing they had to change is the blade of the cutter. During that time the machine is paused and the operator is changing the blade. Normally this takes about one minute and twenty seconds and the operation is performed five to twelve times a day.

According to SMED blade changing is an external setup. By replacing the whole tool holder with a new blade instead of replacing the blade in the tool holder machine downtime will be reduced. Only one bolt needs to be undone and tightened up again. When the machine is cutting pages the 3rd operator can replace the blade in the tool holder. A fresh holder with a sharp blade should always be available for a rapid changeover. Equipment needed to perform a blade change can be seen in Figure 32 where the upper picture shows the old equipment and the lower picture shows the new equipment.

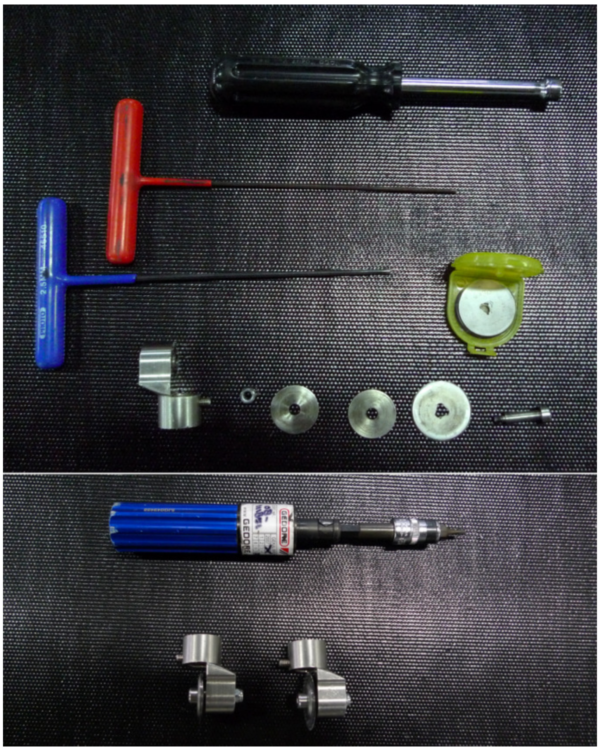


Figure 32: Blade change equipment

Table 14 shows an example of the differences between the old and new method of blade changing. The example uses three cutting machines and estimates that every machine is being used equally and the average blade change frequency to be three hours. The new method takes 80% less time than the old one. During one year this would reduce the downtime by 95 hours. This new method has already been implemented in the process by removing the tools from the cutting machines, posting memos and informing the operators of the advantages.

Table 14: Example of SMED in final cutting

Final cutting machines blade change		
Working hours in a year	7050	h
Mats production time	76 %	
	5358	h
One blade change in every	3	h
Blade changes	1786	times
Total 3 machines	5358	times
Old style takes	80	s
New style takes	16	s
Downtime (old) in one year	119	
Downtime (new) in one year	24	h
Difference	**95**	**h**
	80 %	

7.4 Summary & Recommendations

This chapter shows that by using SMED changeover times in both pre-cutting and final cutting can be reduced.

Pre-cutting had relatively long changeovers, they took 18% of total production time. By reducing the amount of steps necessary and by modifying the tools and machines changeover can be decreased from 12 minutes to 8 minutes.

For the final cutting machines SMED was also used to reduce downtime. Machine uptime was already high, but still some time was saved in the blade change operation. By replacing the whole tool holder the downtime when replacing blades was reduced with 80%.

The PVC line changeover involves many steps and is fairly complicated. Usually it was occurred during evenings or nights so it wasn't possible to review it close enough. Because the line has the highest operating costs changeover should be as short as possible. Using walkie-talkies during production and changeovers would improve the communication between shift leaders and other employees. For the future it would be good idea to analyze the changeover and define all the necessary steps. These steps should be assigned to an employee and can be executed simultaneously.

8. Future Process VSM

The process was already described once using a Value Stream Map but this chapter is going to present the future state drawings for both processes. To achieve a shorter lead time it is obvious that there have to be some improvements to the process. These future state drawings will show the improvements and new inventory sizes, machine uptimes and machine capacities that are proven to be possible in the previous chapters.

8.1 Improved Machine Capacities

Chapters 5 and 7 showed ways to increase machine capacities. This chapter is going to show the new machine capacities which are needed later on to estimate the new inventory sizes.

8.1.1 Pre-Cutting Machines

By reducing changeover time from 12 minutes to 8 minutes in pre-cutting it is possible to increase uptime from 81% to 87%. This was shown and calculated in attachment 4 and explained in chapter 7.2. Table 15 shows the differences between initial and future capacities. Total improvement is 7% for 40x60 and 60x90 mats.

Table 15: New pre-cutting capacity

Pre-Cutting Capacity					
	INITIAL		**FUTURE**		
Uptime **81 %**	Changeover time **12 min**	Uptime **87 %**	Changeover time **8 min**		
Mat size	Capacity pcs / h	Mat size	Capacity pcs / h	Difference	
40x60	**2191**	40x60	**2353**	**+ 162**	**7 %**
60x90	**1157**	60x90	**1243**	**+ 86**	**7 %**

8.1.2 PVC Line

When pre-cutting and final cutting machine capacities have been increased it may also be possible to increase the PVC line capacity. This can be achieved by using a higher line speed to get more output from the line. Initially the line speed was 4.8 m/min and after improvements it can be raised to 5.5 m/min for 60x90 mats. With this higher speed the PVC output can be increased by 15%.

Table 16: New PVC line capacity

PVC Line Capacity					
	INITIAL		**FUTURE**		
Line speed	**4.8 m / min**	Line speed	**5.5 m /min**		
Mat size	Capacity pcs / h	Mat size	Capacity pcs / h		Difference
40x60	**2304**	40x60	**2640**	**+ 336**	**15 %**
60x90	**914**	60x90	**1048**	**+ 134**	**15 %**

8.1.3 Final Cutting Machines

The biggest change here is moving the 3rd cutter in-line, as described in chapter 5. Machine uptime is also improved by reducing the blade change time from 80 s to 16 s. These modifications improve instantaneous capacity by 55%.

Table 17: New final cutting capacity

Final Cutting Capacity					
INITIAL		FUTURE			
Uptime **95 %**	Changeover time **80 s**	Uptime **98 %**	Changeover time **16 s**		
2 cutting machines			**3** cutting machines		
Mat size	Capacity pcs / h	Mat size	Capacity pcs / h		Difference
40x60	**1555**	40x60	**2407**	**+ 852**	**55 %**
60x90	**907**	60x90	**1403**	**+ 496**	**55 %**

For a quick overview of stage capacities and how they compare to each other Table 18 lists the future state capacities. As can be seen, 40x60 production has two bottlenecks in the process if the PVC line is using a new higher line speed (5.5m/min). These bottlenecks can be avoided by not having an increased line speed and running the specified 4.8m/min. This can be verified by using the capacity calculation sheet. 60x90 production doesn't have any bottlenecks after the improvements, even if the PVC line speed is higher than in the initial situation.

Table 18: Summary of new machine capacities

Machines New Capacities				
PVC Line Speed	**Mat size**	**Pre-Cutting**	**PVC Line**	**Final Cutting**
5.5 m/min	40x60	2353	2640	2407
5.5 m/min	60x90	1243	1048	1403
4.8 m/min	40x60	2353	2304	2407

8.2 New Inventory Sizes in Mat Production

With these higher machine capacities it's possible to define a new amount of semi-finished products for every inventory. New inventory size should be estimated by how long a possible delay would take in the previous stage. It is important to reduce inventory in steps to see if any problems surface, like transporting delays if the forklift driver is too busy to deliver rolls.

8.2.1 Raw Rolls for Mats

In the initial situation there were 17 rolls in total waiting in two high piles, enough for 6.3 hours of production. This example estimates that possible breakdown or other delay will not take longer than three hours: The buffer should be three hours of pre-cutting capacity.

Reducing inventory should be done by reducing one roll for each machine in every week to reach the proposed amount in Table 19.

Table 19: Proposal future inventory size of raw rolls (60cm x 90cm)

Cut mat size	55	x	85	cm
Roll width (old machine)	1.68	m	5	rolls
Roll width (new machine)	2.29	m	4	rolls
Average roll lenght	100	m		
Total:	1756	m2	9	rolls
	3756	pcs		
New pre-cutting capacity	1243	pcs / h		
Capacity of	**3**	**h**		

8.2.2 Pre-Cut Mats

The proposed future example in Table 20 estimates that a possible breakdown will not take longer than three hours. The chance that both pre-cutting machines break down at the same time is very slim. Achieving this level of inventory can be achieved by planning pre-cutting closer to the PVC line and in a specific order, as suggested in chapter 6. For pre-cutting it is wise to gradually reduce inventory too. Temporarily reducing pre-cutting capacity by slowing down the machines should achieve this.

Using a FIFO storage system between pre-cutting and the PVC line would help create a clear insight in the current inventory level. This helps the machine operators to judge their pace and adjust correspondently.

Table 20: Proposed future inventory size for pre-cut mats

Mat size	60 X 90	cm
Total:	3144	pcs
PVC Line Capacity 5.5m/min	1048	pcs/h
Capacity of	**3**	**h**

8.2.3 Un-Cut Pages

As described in chapter 5 it is very desirable to move the 3rd cutter in-line. It also proves that it is possible to reduce page inventory to zero.

8.3 Inventory Costs

By reducing inventory size it is possible to save money which is invested in semi-finished products. An easy way to calculate the money saved is to compare inventory sizes between the initial situation and the proposed future situation. Table 21 shows details on the final product and its price. The costs include labor and material costs. It does not include heating, electricity or storage costs in inventories. This example hasn't been used to calculate inventory costs for runners because there was only one inventory for semi-finished runners in the department.

In this example the product is going through tufting, backing, roll cutting, pre-cutting, PVC line and final cutting stages. In every step there is the same amount of money added to the product, which is shown as percentages.

Table 21: Product information

Final Product Price			
3.50 €	60 x 90	0.54	m²

Table 22 is showing an example of a similar situation as in Figure 17 and how much money has been invested in semi-finished products inside the department during the initial situation.

Table 23 shows how much money there would be invested in semi-finished products in the proposed future situation with new inventory sizes. If The company could save the same percentage of money in every product type and in every department inside the plant the saved amount of money would be very notable.

Table 22: Inventory costs in initial situation

INITIAL									
Production Stages							**Product's Value**	**Pieces**	**Costs**
Tufting	**17 %**						0.58 €		
Backing	17 %	**33 %**					1.17 €		
Roll Cutting	17 %		**50 %**				1.75 €	7283	12 745 €
Pre-Cutting	17 %			**67 %**			2.33 €	31564	73 544 €
PVC Line Overflow	17 %				**83 %**		2.92 €	70	240 €
Final Cutting	17 %					**100 %**	3.50 €		- €
							Inventory costs		**86 559 €**

Table 23: Inventory costs in proposed future situation

FUTURE					
Production Stages			**Product's Value**	**Pieces**	**Costs**
Tufting	**17 %**		0.58 €		
Backing	17 %	**33 %**	1.17 €		
Roll cutting	17 %	**50 %**	1.75 €	3756	6 802 €
Pre-Cutting	17 %	**67 %**	2.33 €	3144	7 336 €
PVC Line Overflow	17 %	**83 %**	2.92 €	0	- €
Final Cutting	17 %	**100 %**	3.50 €		- €
			Inventory costs		**13 909 €**

8.4 Proposed Future-State VSM for Mats

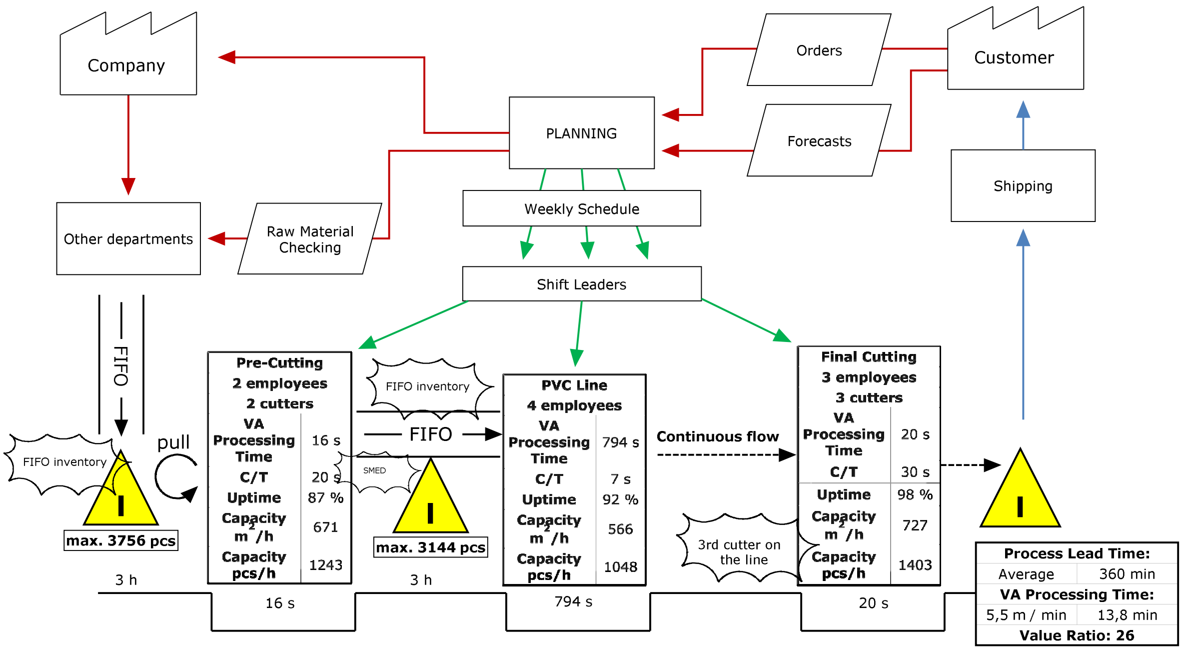


Figure 33: Future state mat VSM

The future state VSM in Figure 33 includes all the changes that can be made to the process. These changes can be summarized as following:

- First-In-First-Out inventories with a pull movement where possible (chapter 6).

- Reduced changeover times by using Single-Minute Exchange of Dies (chapter 7).
- Move the 3rd final cutter in-line (chapter 5).
- Reduce the amount of products in both inventories (chapter 8.5).
- No more overflow buffer when producing mats.
- Higher line speed for PVC line.

To achieve this proposed situation the first thing is to start using FIFO inventories which will help to create a smooth material flow inside the department. Before pre-cutting the FIFO inventory should be restricted to maximum amount of rolls. FIFO inventories also help to see how the current batch is flowing through the process.

The FIFO inventory for the rolls can be a simple ramp (Figure 24) which is using gravity to feed rolls. The forklift driver needs to bring the right amount of rolls to the inventory in the proper order. The right amount of raw rolls could be defined by using the machines capacity for different size of mats. The pull-symbol is expressing that pre-cutting machines work just as fast as they need to keep the next inventory balanced. Sometimes the cutters have to work faster like when producing 40x60 mats than when producing bigger mats.

Before the PVC line there is another FIFO inventory. This is the most important inventory inside the department because PVC line is the stage which should have enough semi-finished products all the time. The difference between the current situation and future situation is the FIFO inventory and the size of the inventory. In the future they have two different ground level FIFO lines for cut mats.

In the current situation the pre-cutting machine uptime was quite low compared to cutting time. Changeovers were covering 18% of the total production time. By using The Single-Minute Exchange of Die, SMED it is possible to reduce the time needed to perform changeovers. Changeover time can be reduced by doing some improvements like reducing transporting distances and eliminating unnecessary tasks during the changeover. When reducing changeover time the machine’s uptime increases as well.

In the final stage the 3rd cutter is positioned in-line and that’s why the capacity is higher. After that there isn’t going to be any overflow when producing mats. The employee who is using the third cutter still has time to move full pallets and make new cardboard boxes for the finished mats because of the capacity reserve. One employee can be responsible also for replacing blades in every cutting machine’s waiting tool holder as mentioned in chapter 7.3.

Having the 3rd cutting machine in-line makes it possible to use a higher line speed on the PVC line and increasing its output. That’s why the value-added processing time is shorter in the future situation than in the initial situation.

Table 24: Lead time summary for mat production

Initial situation	Future situation	Improvement
Process Lead Time		
2453 min	360 min	85 %
Value-Added Processing Time		
15.8 min	13.8 min	12 %
Value Ratio		
155	26	83 %

Table 24 summarizes differences in times and value ratios between initial and future situations. The total improvement in value ratio is 83%.

Inventory costs

Table 25 describes how much money the company had waiting in inventories inside the PVC department. Reducing the initial inventory sizes as proposed earlier would help to reduce the amount of money inside inventories by 84%.

Table 25: Summary of inventory costs

Summary of inventory costs	
INITIAL costs	86 559 €
FUTURE costs	13 909 €
DIFFERENCE	**72 690 €**
SAVE	**84 %**

8.5 New Inventory Size for Runner Production

During runner production there was only one inventory used. The lead time in initial situation wasn't that long as in mat production but it still can be improved by reducing the amount of rolls in inventory.

8.5.1 Raw Rolls for Runners

Table 26 lists an example of the proposed future inventory size. PVC line capacity for four hours should be enough to overcome difficulties if something happens in a previous stage in another department.

An easy way to see the inventory level is to use a simple ramp like the one used for raw rolls in pre-cutting. This keeps the rolls in the right order and operators and forklift drivers are able to see when new rolls have to be delivered.

It would be a good idea to reduce the amount of rolls every time when they do the changeover from mats to runners. During every changeover they could reduce the size of inventory by ten rolls. The last five rolls from twenty to fifteen could be done by reducing only one roll each time. Then they are still able to act if any new problems surface between the previous stage and PVC line and solve those.

Table 26: Proposed future size of raw roll inventory

Amount of raw rolls	15	pieces
Average roll lenght	86	m
Total lenght of rolls	1320	m
PVC line capacity 5,5m/min	330	m/h
Capacity of	**4**	**h**

Table 27 summarizes all inventory sizes inside the department in initial and future situations. The biggest difference is in pre-cut mats' inventory where the amount of mats is reduced by 28,420 pieces.

Table 27: Inventory summary

INITIAL inventory sizes		FUTURE inventory sizes	Difference
Raw Rolls for Mats	7283	3756	- 3527
Pre-Cut Mats	31564	3144	- 28420
Uncut Pages	70	0	- 70
Raw Rolls for Runners	3440	1320	- 2120

8.6 Proposed Future-State VSM for Runners

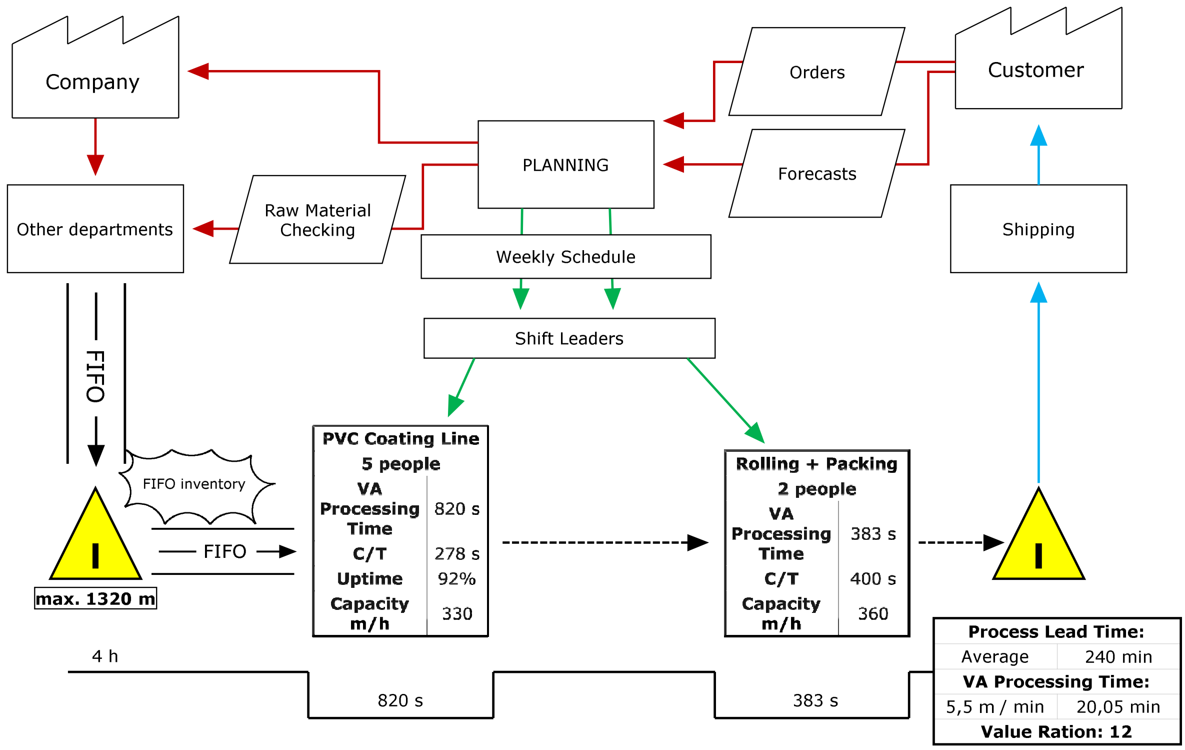


Figure 34: Future-state runner VSM

Because runner production is quite simple and there are only two steps and one inventory it's harder to reduce process lead time as much as in the process for mats. The only change in the future state drawing was the FIFO inventory with a roll ramp before the PVC line. The maximum amount of rolls can be the capacity of the PVC line for four hours.

Table 28: Lead time summary for runners

Current situation	Future situation	Improvement
Process Lead Time		
624 min	240 min	62 %
Value-Added Processing Time		
20.05 min	20.05 min	0 %
Value Ratio		
31.1	12	62 %

Table 28 summarizes the runner manufacturing process and its process times. After the inventory has been reduced the value ratio will drop from 31.1 to 12. Total improvement is 62% only by reducing one inventory's size.

8.7 Summary & Recommendations

This chapter summarizes all the improvements in the manufacturing process and illustrates them in a proposed future state VSM. Machines capacities have increased by reducing changeover times or using a higher line speed. Also the inventory levels are balanced to work with the new machine capacities to achieve a shorter lead time through the process. At the same time reducing inventories saves money in inventory costs and is also shown in this chapter.

Most of the improvements and changes are made to the mat production process because the initial lead time and value ratio were worse than with runners. Total improvement for the mat process is 83% and in runner process is 62%.

9. Work Environment Improvement Using 5S

Usually when a company wants to implement lean tools to their manufacturing process, they also need to improve the work environment. The most common lean tool to do that is 5S. Originally 5S term comes from Japanese words *seiri, seiton, seiso, seiketsu,* and *shitsuke.* English terms for those five words and definitions are shown in Table 29. The main idea in 5S is to reduce unneeded tasks, activities and materials on the shop floor. At the same time it leads to lowered costs, improved on-time delivery and productivity, higher production quality, better use of floor space, and a safer working environment. This chapter is explaining how the 5S methods were used in this project.

Table 29: 5S Defined

5S Term	Definition
1. Sort	Separate needed items from unneeded items (including tools, parts, materials and paperwork), and discard the unneeded.
2. Straighten	Neatly arrange what is left with a place for everything and everything in its place. Organize the work area so that it is easy to find what is needed.
3. Shine	Clean and wash the work area and make it shine
4. Standardize	Establish schedules and methods of performing the cleaning and sorting. Formalize the cleanliness that results from regularly doing the first three S practices so that perpetual cleanliness and a state of readiness are maintained.
5. Sustain	Create discipline to perform the first four S practices, whereby everyone understands, obeys, and practices the rules when in the plant. Implementing mechanisms to sustain the gains by involving people and recognizing them through a performance measurement system.

(Krajewksi, Ritzman, & Malhotra, Operations Management: Processes and Supply Chains, 2009)

9.1 Initial Situation & Issues

The company had already performed some 5S steps in their backing department and wanted to achieve the same results. The situation at the beginning of the project included some problems:

- There were many different types of materials in the wrong. Like Figure 35 shows there were uncut PVC pages stored in the waiting area of raw rolls before pre-cutting machines.
- There isn’t a specific place defined for the tools needed in every work station.
- Raw materials weren’t in the right order before the stages.
- Lots of unnecessary items were collected in the drawers and closets.
- There were also situations where finished products, B-choice products and other items were in the same place like in Figure 36. It didn’t only look messy but it also made the forklift driver’s work harder to pick up the right products.

- While PVC line is manufacturing runners they don't need to cut so many mats to the inventory with pre-cutting machines. One or two employees from the pre-cutting stage could do 5S things inside PVC department like sorting etc.

Figure 35: Semi-finished products and cardboard rolls

Figure 36: The pick-up area of the finished rolls

The current conveyor in Figure 38 which conveys the cutting waste away after PVC line's edge cutters could be rotated to point to the outside. This would make it possible to use bigger containers like the one in Figure 37. It would save space next to the first final cutter and remove some transporting inside the department.

Figure 37: A big waste container

Figure 38: PVC waste conveyor

9.2 Lean Team

To implement 5S and gain staff support a lean team was set up. Gaining staff support is very important to succeed with 5S. Letting the people on the floor help in the process and by listening to them helps immensely with this.

The lean team includes the following staff members:

- Shift Leader
- Forklift driver
- PVC Mixer
- Final cutting employee
- Pre-cutting employee

The PVC department's manager is acting as the team manager. Project members are helping with 5S implementation after a introduction of the 5S principles.

The PVC department was divided to different sections and every team member got his own section to sort. Unnecessary items were moved to a red tag area. The red tag area was a big cardboard box, as can be seen in Figure 39. Right after lean team got their red tags they started to collect unnecessary items in the box. Figure 40 shows that there were lots of tools which were not necessary in the different workstations. Employees who are working in those workstations know best what tools and materials are needed to perform the tasks. Mentioned was that they are only taking care of the equipment, they are not the owners; If they don't need something, tag it. Lean team manager has the responsibly to sort through the tagged items and dispose of them. Employees also got brochures to search for example tool boards for their workstation which will help to organize tools and equipments.

Figure 39: Red tag area

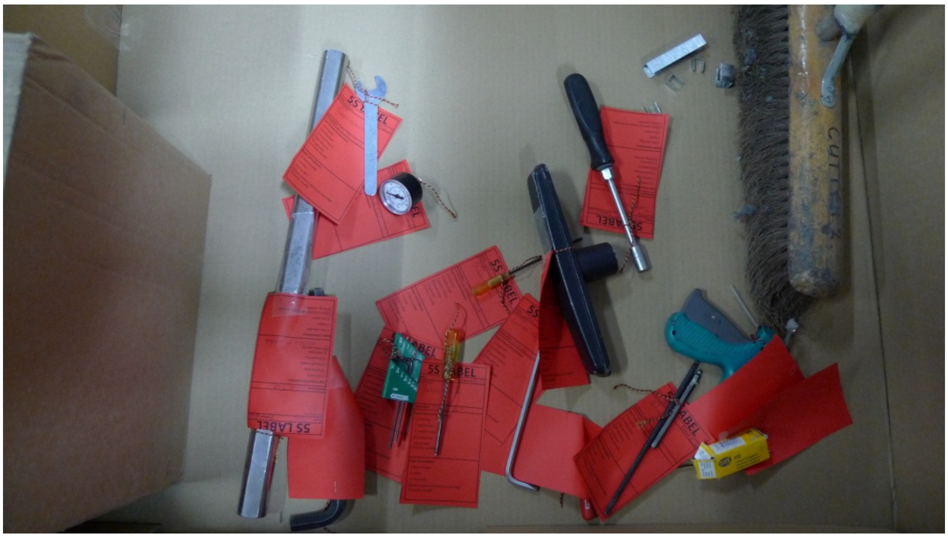


Figure 40: Tools in red tag area

9.2.1 Workstations

In conjunction with the lean team the following workstations were defined and each one was assigned to a member in the team:

- General department floor: Department manager and forklift driver
- Storage areas: Department manager and shift leader
- PVC mixing station: PVC mixer
- PVC line: Shift leader and PVC mixer
- Pre-cutters: Pre-cutter
- Final cutters: Final cutter
- Roll wrapping: Final cutter

Figure 41 is showing one of the final cutting work stations. There is too much paper on the white board and someone already crashed into it. Old work orders are waiting under the table in plastic box and new ones are lying on the table. There should be a folder for the work orders to store them properly.

The workstation of roll wrapping can be seen in Figure 43. There are lots of unnecessary items lying on the tables and compressed air hoses are on the floor. Papers aren’t stored properly. All the necessary tools and stuff should put on the specific place on the wall.

Figure 41: Final cutting workstation

Figure 42: Roll wrapping workstation

9.3 Future Improvements

As of the deadline for this report the 5S process has been initiated as described above. The Sort and Straighten phases have almost been completed. To facilitate future improvements the lean team will keep having meetings to keep the process going forward. Products like boards to hang tools, prober waste bins, and smaller baskets will be picked in cooperation with the team members.

Standardization is achieved by defining a specific spot for each item. Tools will be hung at a tool board, where each tools' spot is labeled. Different raw materials, like the cardboard end caps shown in Figure 42, will have a large container in a specified spot in the storage area and a small basket at the workstation. The baskets will be filled using a two-bin stock system; one basket is in use and the other is being refilled.

On shift changes a "Shift Transfer Form" will make sure that each shift leaves the workstation in a proper way on a shift change. The old and new shift leaders do a quick review of every station and tick the correspondent box. When the review is finished they both sign the form. This makes sure the stations always have the required tools and raw materials available.

10. Measurement System Analysis

For this project certain measurements are important. However, before these measurements can be used it is wise to judge the quality of the current measurements. In this chapter the measurement system and data gathering methods are being analyzed for usability and reliability. Within the production process various variables are being logged. For this project production figures are the most important to analyze the current process and judge the effectivity of the improvements suggested.

10.1 Production Planning & Control

When an order for a type of product is placed a default turnaround time of three weeks is maintained. During these weeks the product has to pass through all the different stages involved, for instance: Tufting → Backing → PVC.

The raw carpet rolls are requested from other departments. Due to the big batch sizes used in the supplying departments it is possible that a raw roll is in stock and does not have to be manufactured. When the raw materials become available for the PVC department, production is planned into a specific block as a work order. A work order contains the product type, raw material roll identification and the amount of the product to be produced (either pieces for mats or meters for runners). Block lengths vary from 1 to 3 days and contain the products needed in alphabetic order. Process capacity during a block is being deduced from the AS400 ERP system used.

The weekly block schedule is handed to the shift leaders. Blocks have to be produced in order, the order in which the different products within the block are produced is completely up to the shift leader. All steps needed to produce a finished product are coordinated by the shift leader:

- Raw Material Delivery
- Pre-cutting
- PVC Line
- Final Cutting
- Delivery of the finished product to the expedition department

Incidentally a rush order has to be produced. Causes for a rush order can differ: a failed production run has to be a rushed as a re-run has, the planning department makes mistakes and sometimes the customer is willing to pay extra for a shorter turnover time.

During production the completion of the different steps aforementioned are being registered in the AS400 system. Pre-cutting operators register the amount of mats cut from a specific roll. When these mats are inserted in the PVC line the amount of mats is not being recounted, the pre-cut amount is re-used. When the mats have passed the final cutting stage the last registration of the mats is being made.

Besides the work order data registered in the AS400 system a couple of other measurements are being made.

Continuous Line Speed Logging: Line speed is being logged as data points with a one-minute interval. This is completely independent from the AS400 system. Figure 43 and Table 30 were created by using a php script to parse the values. While absolute downtime (Line Speed = 0) can be calculated from these data points changeover times and efficiency can't be calculated from these figures.

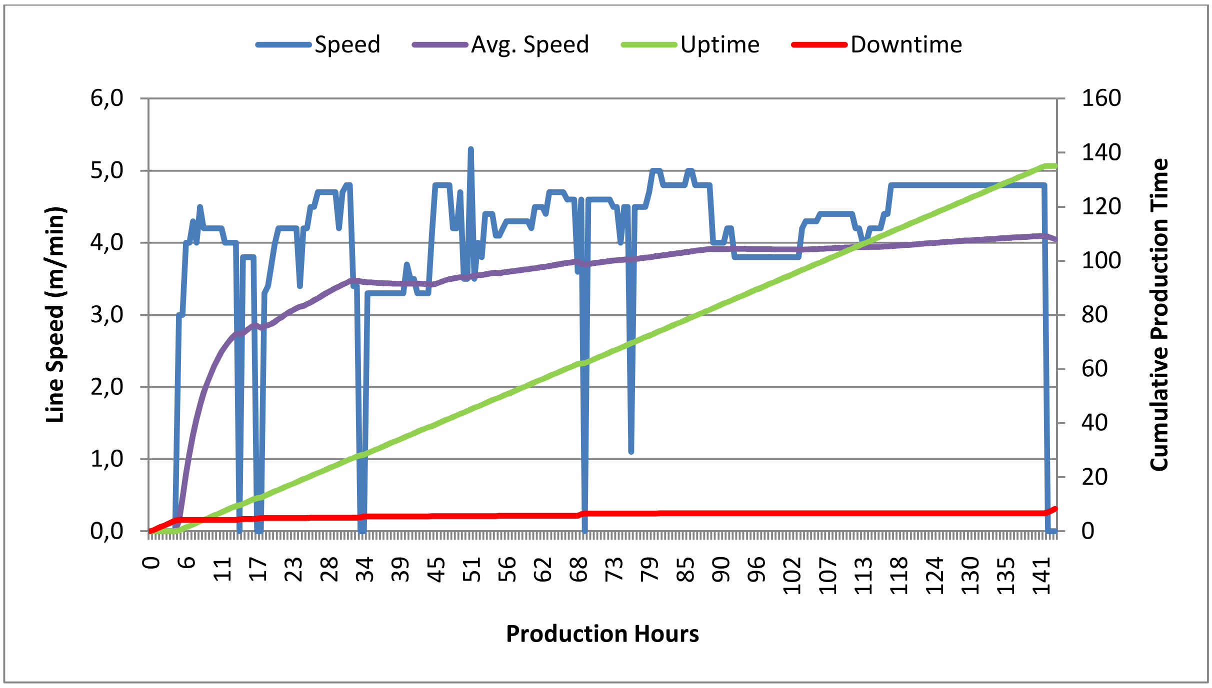


Figure 43: Line speed (Wk 43, 2010)

Averages		
Total Production Time	143.97	*h*
Uptime	135.1	*h*
Downtime	8.87	*h*
% Downtime	7	*%*
Average Line Speed	4.04	*m/min*
Average Production Block	0.86	*h*

Table 30: Weekly averages (Wk43, 2010)

Uptime Logging: During production the different machine states (Startup, changeover rework and production) are being logged in to an Excel file. This log is only being used in the department itself, not for upper management analysis.

10.2 Process Performance Monitoring for Management

Most of the aforementioned logged data is being merged into a weekly performance report. This report is the only data the management uses to judge the PVC department's performance.

The report contains the following variables:

Mat and Runner Production

- Quantities in square meters
  - Material Origin:
    - Tufting
    - Needle punching
    - 3rd Party Materials
- Machine Production Hours for each machine
- Machine Operation Costs
- PVC Line Efficiency

10.3 Incorrect Data Logging

Within this process a couple of problems can be determined:

Inaccurate counting of pre-cut mats: The amount of pre-cut mats from a roll is only registered at the pre-cutting station. The operator has to subtract faulty mats from the total count the machine has. Sometimes the machine count gets lost or the operator fails to correctly count the faulty products. Because the mats are not re-counted when being inserted on the PVC a possible error will be detected when the mats are packed and sent out to shipping.

Overflow buffer registration: Currently the amount that didn't make it through the final cutting stage, and thus were sent into overflow, are not registered in the AS400 system. The only way of determining the amount of uncut pages in the overflow buffer is subtracting the amount of finished mats with the mats that were put on the PVC line. This is obviously an incorrect figure because the aforementioned error in mat counting and because faulty products because of the PVC-coating line that have not yet been counted.

Machine State Logging: Machine states aren't consistently defined into classes. The data is being logged but not being used in the performance logging.

Production Hours of pre-cutters and final cutters: Production hours for the pre- and final cutters are calculated by their output: By dividing the amount of products by a set amount of time needed to produce a product. This makes it impossible to judge machine efficiencies over time; downtime does not have any effect on the reported machine hours.

Overall Efficiency of the PVC Line: While line output and line speed are already taken into account in the efficiency factor of the PVC line, product conformance does not impact the factor directly. The amount of time it takes to do rework on those products is taken in to account, but the loss of capacity due to the production of faulty products is not. This does make it impossible to judge product quality by using the efficiency factor. For example it is possible to produce a lot of faulty products while still having a high efficiency factor.

10.4 Data Acquisition Improvements

Many of these issues can be solved. Some additional Output Variables are recommended as well.

10.4.1 Order/Production Lead Time

The AS400 system already contains enough information to query the time it takes for a product to pass through the PVC department. Lead time would be a valuable addition to the weekly performance report to be able to judge inventory sizes and process efficiency.

10.4.2 Product Conformance & Fault Registration

In the current registration system only unrecoverable faults are registered in the system. These products are called “B-Choice” and the still useable ones are still sold.

Even though the amount of B-Products is a decent indicator in-line performance, recoverable faults are not registered at the moment. These recoverable faults do cost time, and thus money and stall the process. This lack of logging makes it impossible to judge the amount of defects, and thus impossible to judge machine performance.

10.4.3 Overall Equipment Effectiveness (OEE)

A solid improvement to the currently used efficiency number would be using the OEE number. OEE is used extensively throughout the industry to examine machine reliability and effectiveness.

OEE consists of three factors:
Machine Uptime: Uptime can be defined as only the time the machine is doing work that adds value. Other activities, such as setup, changeover, breakdown, etc are considered downtime.
Processing Speed (Pace): Sometimes the machine is not completely down but operating at a lower speed.
Product Quality: Quality defects have a negative impact on machine effectiveness too. When a non-conforming product is produced this product cannot be sold and thus the production of the product has not been value-adding.

$$OEE = \frac{Actual\ Capacity}{Potential\ Capacity} * 100\% = \%Uptime * \%Pace * \%Quality \quad (2)$$

$$\%Uptime = \frac{Value\ Added\ Time}{Operating\ Time} * 100\% \quad (3)$$

$$\%Pace = \frac{Current\ Processing\ Rate}{Ideal\ Processing\ Rate} * 100\% \quad (4)$$

$$\%Quality = \frac{Processed\ Ammount - Defect\ Ammount}{Processed\ Ammount} * 100\% \quad (5)$$

(Wedgewood, 2007)

Applying OEE is not possible with the current data that is being logged. %Uptime can be calculated from the machine production hour sheet. %Pace is already being logged in the machine speed log. The problem lies in the %Quality. By having a clear measurement of both recoverable and unrecoverable quality defects OEE would be able to be calculated accurately.

10.5 Summary & Recommendations

For the current data logging system used certain issues can be found. Some have a bigger impact than others. The line efficiency factor has the biggest problems, implementing a way to add the amount of rework and scrap to an order's statistics would make the figure more useful. Fully implementing OEE will have the most accurate result.

Also the way pre-cutting is monitored is not sufficient enough. Any improvements in overall efficiency will not show in the figures currently used. By measuring the amount of time the machine is *actually* running instead of deducting it from the amount of mats cut will make it possible to judge output versus the actual production time. In this stage it is sensible to log rework and scrap separately when the operator enters the data in the AS300 system. This will also reduce counting errors because the operators don't have to perform mathematical operations.

Adding the average lead time to the department performance will help achieve and maintain a shorter lead time, not having this measurement will lead back to increased lead time.

These suggested improvements are necessary to judge the suggested improvements in this report on their effect. The changes will not be hard to implement in the ERP software currently used.

11. Conclusion

The recommendations made in this report will have many positive effects on the process. The overall department value ratio will be reduced from 155 to 26. This is a 83% improvement, more than the goal set at the start of this project. Many different aspects contribute to this improvement:

- Lower inventory levels, based on actual machine capacities and the likeliness of breakdowns.
- Moving the 3rd cutter in-line will eliminate the final cutting stage as a bottleneck and create room for a higher PVC line speed.
- FIFO storage for both pre-cut mats and roll inventories will reduce product transporting and searching. It also has a positive effect on changeover, because the operators perform the transportation.
- Pre-cutter uptime will be increased from 81% to 87% using a more efficient changeover procedure.
- Final cutter uptime will increase from 95% to 98% using a different method to replace cutting blades.
- 5S has increased staff efficiency by reducing unnecessary actions.

Most suggested changes do not require big investments. A part of the investment is being regained from the lower amount of money invested in the semi-finished product inventories.

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Attachments

1. Plan Of Approach

2. Introduction to Lean management

Lean Manufacturing is a set of tools that help to improve process efficiency and product quality. It emerged in Japan during the 70s. Toyota played a big part in the development and can be seen as a pioneer in the area. Toyota also has its own manufacturing system (TPS) which is a collection of advanced manufacturing methods pioneered in the 1950s. Toyota aimed to minimize the resources which will need to produce one product in the production process. The main idea in lean manufacturing is to reduce waste from the production and after that the problems will be seen better and it's possible to fix the problems.

Shortening lead time by eliminating waste in each step of process leads to best quality and lower cost, while improving safety and morale. (Liker, 2004)

Process Waste

In short lean systems focuses on the continuous elimination of waste. In Lean Systems waste involves more than just excess materials or garbage. Table 31: 8 types of waste lists the different types of waste and gives a small description. Reducing these kinds of waste will maximize the value added by each step and reduce delays.

Table 31: 8 types of waste

	Waste	Description
1.	Overproduction	Manufacturing an item before it is needed, making it difficult to detect defects and creating excessive lead times and inventory.
2.	Inappropriate Processing	Using expensive high precision equipment when simpler machines would suffice. It leads to overutilization of expensive capital assets. Investment in smaller flexible equipment, immaculately maintained older machines and combining process steps where appropriate reduce the waste associated with inappropriate processing.
3.	Waiting	Wasteful time incurred when product is not being moved or processed. Long production runs, poor material flows, and processes that are not tightly linked to another can cause over 90% of a product's lead time to be spent waiting.
4.	Transportation	Excessive movement and material handling of product between processes, which can cause damage and deterioration of product quality without adding any significant customer value.
5.	Motion	Unnecessary effort related to the ergonomics of bending, stretching, reaching, lifting, and walking. Jobs with excessive motion should be redesigned.
6.	Inventory	Excess inventory hides problems on the shop floor, consumes space, increases lead times, and inhibits communication. Work-in-process inventory is a direct result of overproduction and waiting.
7.	Defects	Quality defects result in rework and scrap, and add wasteful

		costs to the system in the form of lost capacity, rescheduling effort, increased inspection, and loss of customer goodwill.
8.	Underutilization of Employees	Failure of the firm to learn from and capitalize on its employees' knowledge and creativity impedes long term efforts to eliminate waste.

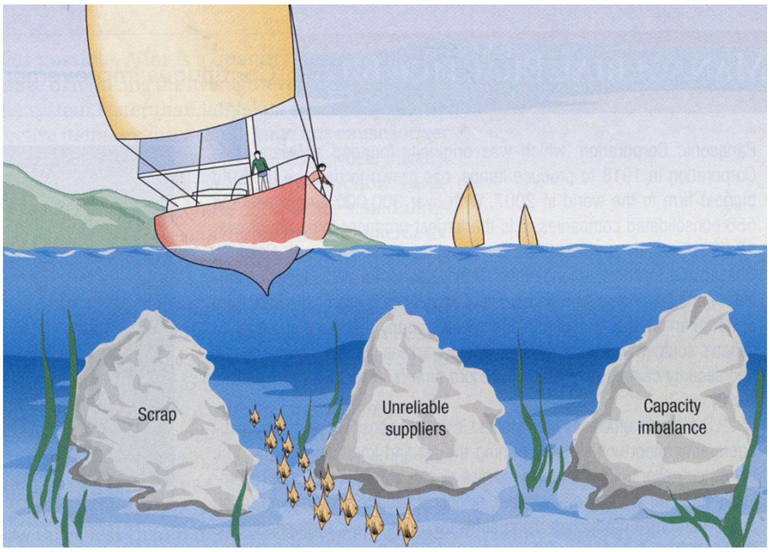


Figure 44: Waste and inventories

Figure 44 illustrates a common metaphor to show that having a large inventory hides the problems these different forms of waste cause. By reducing inventory (the waterline) these problems will surface and the production (the ship) will suffer.

Although this is just a fairly simple representation, it proves that having excess inventory is not preferable. Only by reducing inventory the real problems will surface and can be solved effectively.

This paragraph from "Learning to See" succeeds in summarizing the need to reduce inventory

"The most significant source of waste is overproduction, which means producing more, sooner or faster than is required by the nest process. Overproduction causes all kinds of waste, not just excess inventory and money tied up in that inventory. Batches of parts must be stored requiring storage space; handled, requiring people and equipment; sorted; and reworked. Overproduction results in shortages, because processes are busy making the wrong things. It means that you need extra operators and equipment capacity, because you are using some of your labor and equipment to produce parts that are not yet needed. It also lengthens the lead time, which impairs your flexibility to respond to customer requirements" (Rother & Shook, 2003)

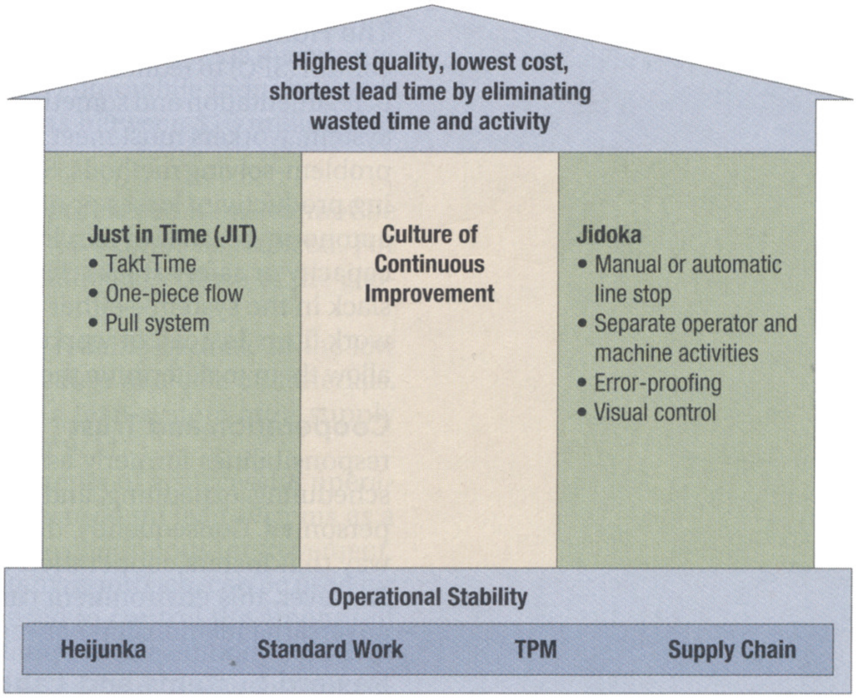


Figure 45: The House of Toyota

The House of Toyota

Taiichi Ohno and Eij Toyoda created the *House of Toyota* to explain the Toyota Production System to their employees and suppliers. There are all the four principles of the TPS described in the opening description and it represents all the essential elements of the lean systems that makes TPS work. The roof represents the primary goals of high quality, low costs, waste elimination and short lead-times. The roof is supported by twin pillars of *Just in Time* (JIT) and jidoka.

Continuous Improvement

Continuous improvement is the philosophy of seeking ways to improve processes and it's based on Japanese concept called kaizen. Continuous improvement philosophy beliefs that there are always things that can be improved inside the process and normally the people who are working closely with the process have the best knowledge of what should be changed in the process. The idea is to act before a massive problem occurs in the process. When the employees are working with the problem-solving activities they also get the feeling that they have some control over their workplace and tasks. After that they are even more willing to find out more things what could be improve and they also feel a responsibility for the process and products.

The heart of the continuous improvement is shown in the Figure 3. The Plan-Do-Study-Act Cycle is widely used and trained in many companies for problem solving. After World War II statistician W. Edward Deming taught quality improvement techniques to the Japanese and the cycle is also known as Deming Wheel. The main idea of continuous improvement is to reduce or eliminate activities that that do not add value and thus are wasteful.

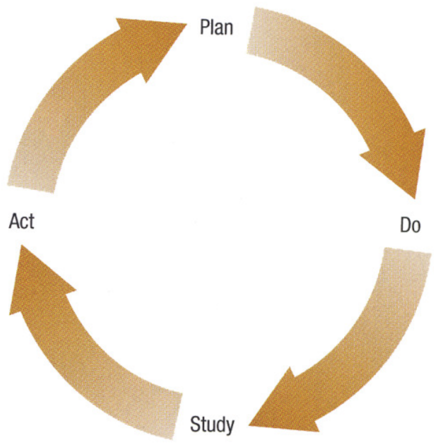


Figure 46: Continuous improvement

Plan: First the team has to select a process that needs improvement. It can be an activity, method, machine or policy. They gather information about the process and current situation and documents that. Team sets goals for improvement and finds out different ways to reach the goals and also thinks benefits and costs of alternatives. At the end the team develops a plan with quantifiable measures for improvement.

Do: The team implements the plan and monitors progress. They collect data continuously to measure the improvements in the process. If there are any changes in the process those should be documented if needed to revision further.

Study: The team analyzes collected data at the same time with *do* step. That way they can see how closely the results correspond to the goals set in the *plan* step. If major shortcomings exist, the team reevaluates the plan or stops the project.

Act: If results are successful the team documents the revised process so that it becomes the standard procedure for all who may use it. The team may instruct other employees in the use of the revised process.

3. Pre-Cutting Flowchart

Having clear insight in the pre-cutting stage and the different tasks involved was important. A digital video camera was used to record one changeover. This made it easy to separate the different task during the changeover and measure how long they took. A flowchart was made by using this information.

The video also showed some unnecessary steps and transport movements which could be removed or reduced. Future situation's flowchart uses bolded text to show the possible improvements in the process to achieve shorter changeover time.

Process: Pre-cutting 60 cm x 90 cm mats

Start: Employee lifts empty pallet up

End: After the employee has come back from the storage to the machine

Table 32 shows the pre-cutting setup for cutting. These setting are the same for initial and future situations. Roll length was estimated at 150 meters and machine cycle time was used to calculate total cutting time. Theoretical cutting took 50 minutes and average cutting ten percentages more which was totally 55 minutes.

Table 32: Pre-cutting machine flowchart setup

Roll lenght	150	m
Mat width	0,55	m
mats in a row	4	pcs
Mat lenght	0,85	m
Cut times	176	times
Amount of mats	706	pcs
Cycle time	17	s
Theoritical cutting time	50	min
Average cutting time +10%	55	min

Initial situation

Table 33 shows the different activities and how many steps are needed, including every activity and total time per activity.

Table 33: Pre-cutting machine activities summary, initial

Activity	Number of Steps	Time (sec)
Operation ●	18	3428
Transport ➡	13	191
Inspect ■	2	37
Delay D	0	0
Store ▼	0	0

Table 34 describes every step in pre-cutting and shows the duration of each step. Every step was categorized into operations, transports, inspections, delays and storages.

Table 34: Pre-cutting machine flowchart, initial

#	T	○	⇨	□	D	▽	Step Description
1	15		X				E lifts palette up
2	20		X				E walks to find the next roll from rolls waiting area
3	7		X				E walks back to machine
4	17			X			E checks the roll tag and machine setups
5	35	X					E takes right work order from folder
6	6	X					E fills the work order
7	18	X					E looses crane from lifting bar
8	10	X					E takes the empty cardboard roll from the lifting bar
9	18		X				E takes the empty roll to the trash bin
10	22	X					E takes the metal lifting bar and puts it inside the roll and tights it
11	20	X					E fastens the crane
12	6		X				E lifts and rotates roll
13	9	X					E puts the roll on the stand
14	6	X					E loosens the crane
15	15		X				E takes plastic wrapper off and takes it to trash bin
16	17	X					E opens the roll
17	75	X					E and other cutting employee puts the beginning of the roll to machine
18	10	X					E takes previous roll's cutting waste from the cutter
19	20			X			E checks the first cut
20	5	X					E starts the machine
21	0	X					Machine cutting mats while E is stacking and inspecting mats
22	5	X					E shutdown the machine
23	10		X				E puts faulty products to waste container
24	15		X				E empty waste bins to container
25	20	X					E counts the amount of cut mats
26	3000	X					E types the work order to computer
27	110	X					E uses the compressed air to clean mats and the workplace
28	10	X					E puts the roll tag between cut mats
29	3		X				E pumps trolley up
30	40		X				E transfers the palette to the storage
31	20		X				E walks to get a empty pallet
32	2		X				E pumps trolley and empty pallet up
33	20		X				E walks back to pre-cutting machine
	Total Time 61 min						

The total duration in the initial situation was 61 minutes, including changeover and cutting. Table 35 shows summary of the initial situation.

Table 35: Pre-cutting machine flowchart summary, initial

Example's cutting time	50	min
Average cutting time + 10%	55	min
Example's changeover time	11	min
Average changeover time + 10%	12	min

Future situation

A flowchart was used to estimate a possible future changeover time. Table 36 summarizes future activities, steps and durations. The only difference between initial and future situations is that Table 36 has one separate transport step extra. Operations take 129 seconds less time transportation takes 82 seconds less time in the future than in initial situation. Inspection time was equal in both cases.

Table 36: Pre-cutting machine activities summary, future

Activity		Number of Steps	Time (sec)
Operation	●	18	3299
Transport	➡	14	109
Inspect	■	2	37
Delay	D	0	0
Store	▼	0	0

Table 38 describes every action in the future situation and shows how long those would take. Bolded actions are different from the initial situation. Table 37 explains the differences between initial and future changeover.

Table 37: Future flowchart's changes

#	Description
2	When using a ramp like in Figure 24 employee doesn't need to find the next roll. Next roll is already waiting first on the ramp.
3	Employee needs to release the first roll from the ramp and it will roll next to pre-cutting machine. The release mechanism is described also in Figure 24.
5	Both cutting machines have their own trolley for empty rolls next to machine. Employee doesn't need to walk far away to put the roll to trolley.
7	Both pre-cutting machines have a lift for the roll. It's integrated to roll stand but in initial situation they don't use those lifts because they need to rotate the roll anyway with a crane. Employee can lower the lift by pushing a button and they don't need to use the crane to lift the roll to the stand.
9	Employee pushes the button and roll lift lifts roll up.
10	Employee puts plastic wrap to trash bin which is next to machine. Employee doesn't need to walk far away to put the plastic to trash bin.

11	Employee can open the roll faster with a sharp knife.
12	In initial situation they had problems to feed the new carpet to machine. They needed to ask some other employee to help with that. Problem was that they had device which was on a way when feeding new carpet. The device was a part of the machine but was used only couple times in a year. Maybe it's possible to replace the device to help feeding the new carpet and maybe the employee could do that alone after that.
15	Folder with the work orders was located far away and in the future it would be better to give both machines their own folder with work orders. Folder would be next to machine's control panel where employee needs it.
29	Employee transports full pallet to new FIFO storage system's lift which is showed in chapter 6. Distance between FIFO line and cutting machines would be shorter than in initial situation.
30	At the beginning of the FIFO line there would be pallet lift which lifts full pallet on the FIFO line which works with gravity. Employee puts the pallet on the lift.
31	Employee pushes button and pallet goes to FIFO line.
32	Empty pallets are waiting next to cutting machines so employees don't need to find empty ones somewhere else.
34	Walking distance back to machine is shorter than in initial situation.

Table 38: Pre-cutting machine flowchart, future

#	T	○	⇨	□	D	▽	Step Description
1	15		X				E pumps palette up
2	**10**		**X**				**E walks to get a roll tag from next roll**
3	**3**	**X**					**E releases next roll from the ramp**
4	10	X					E takes the empty cardboard roll from the lifting bar
5	**5**		**X**				**E puts the empty roll to the trash bin**
6	22	X					E takes the metal lifting bar and puts it inside the roll and tights it
7	**5**		**X**				**E lowers roll lift**
8	5		X				E puts the roll on the stand
9	**5**		**X**				**E lifts roll up with a roll lift**
10	**8**	**X**					**E takes plastic wrapper off and puts it to trash bin**
11	**10**	**X**					**E opens the roll**
12	**40**	**X**					**E puts the beginning of the roll to the machine**
13	7		X				E walks back to machine
14	17			X			E checks the roll tag and machine setups
15	**15**	**X**					**E takes right work order from folder**
16	6	X					E fills the work order
17	10	X					E takes previous roll's cutting waste from the cutter
18	20			X			E checks the first cut
19	5	X					E starts the machine
20	3000	X					Machine cutting mats while E is stacking and inspecting mats
21	5	X					E shutdown the machine
22	10		X				E puts faulty products to waste container
23	15		X				E empty waste bins to container

24	20	X		E counts the amount of cut mats
25	25	X		E uses bar code reader to put the work order to computer
26	110	X		E uses the compressed air to clean mats and the workplace
27	10	X		E puts the roll tag between cut mats
28	3		X	E pumps trolley up
29	**10**		**X**	**E transfers the palette to the FIFO line**
30	**5**	**X**		**E leaves pallet on the lift**
31	**3**	**X**		**E push a button to move pallet to inventory**
32	**10**		**X**	**E walks to get a empty pallet next to cutting machine**
33	2		X	E pumps trolley and empty pallet up
34	**7**		X	**E walks back to pre-cutting machine**
Total Time 58 min				

Table 39 summarize the future situation's times and shows new changeover time which is drop from 12 minutes to eight minutes.

Table 39: Pre-cutting machine flowchart summary, future

Example's cutting time	50	min
Average cutting time + 10%	55	min
Example's changeover time	8	min
Average changeover time + 10%	8	min

4. Pre-Cutting Machines Uptime Calculations

Pre-cutting machine uptimes were calculated for both machines. The biggest difference between the two machines wasis with blades change time. Usually they perform it one time in changes. Blade changes are usually done once a month. On the newer machine it takes 5 hours and 3 on the older one.

Table 40 is showing the uptime calculation sheet for newer cutting machine. Blades change take five hours each a month, which results in one hour each week. Initial roll changeover time was 12 minutes and it this was calculated in attachment 3 using a flowchart. Future flowchart shows that it would be possible to reduce changeover time to eight minutes if some improvements would be made. By reducing the changeover time from 12 minutes to eight minutes total changeover time during one week could be reduced by 504 minutes. Calculations estimate that cutting machines are able to cut 21 rolls in each day.

Table 40: Newer pre-cutting machine's uptimes

	INITIAL		FUTURE	
Working hours per week	140	h	140	h
minutes	8400	min	8400	min
How often change blades	1	time a month	1	time a month
How much time it takes	5	h	5	h
per day	0,17	h	0,17	h
per week	1	h	1	h
Average C/O time	**12**	**min**	**8**	**min**
How many rolls per a day	21	pcs	21	pcs
rolls per week	126		126	
Total C/O time in a week	**1512**	**min**	**1008**	**min**
Total cutting time in a week	**6828**	**min**	**7332**	**min**

Table 41 shows the older machine's uptime calculations. The only difference between the old and new machine is the blade change time. Roll changeover times are the same for both machines.

Table 41: Older pre-cutting machine's uptimes

	INITIAL		FUTURE	
Working hours per week	140	h	140	h
	8400	min	8400	min
How often change blades	1	time a month	1	time a month
How much time it takes	3	h	3	h

per day	0,1	h	0,1	h
per week	0,6	h	0,6	h
Average C/O time	**12**	**min**	**8**	**min**
How many rolls per a day	21	pcs	21	pcs
per week	126		126	
Total C/O time in a week	**1512**	**min**	**1008**	**min**
Total cutting time in a week	**6852**	**min**	**7356**	**min**

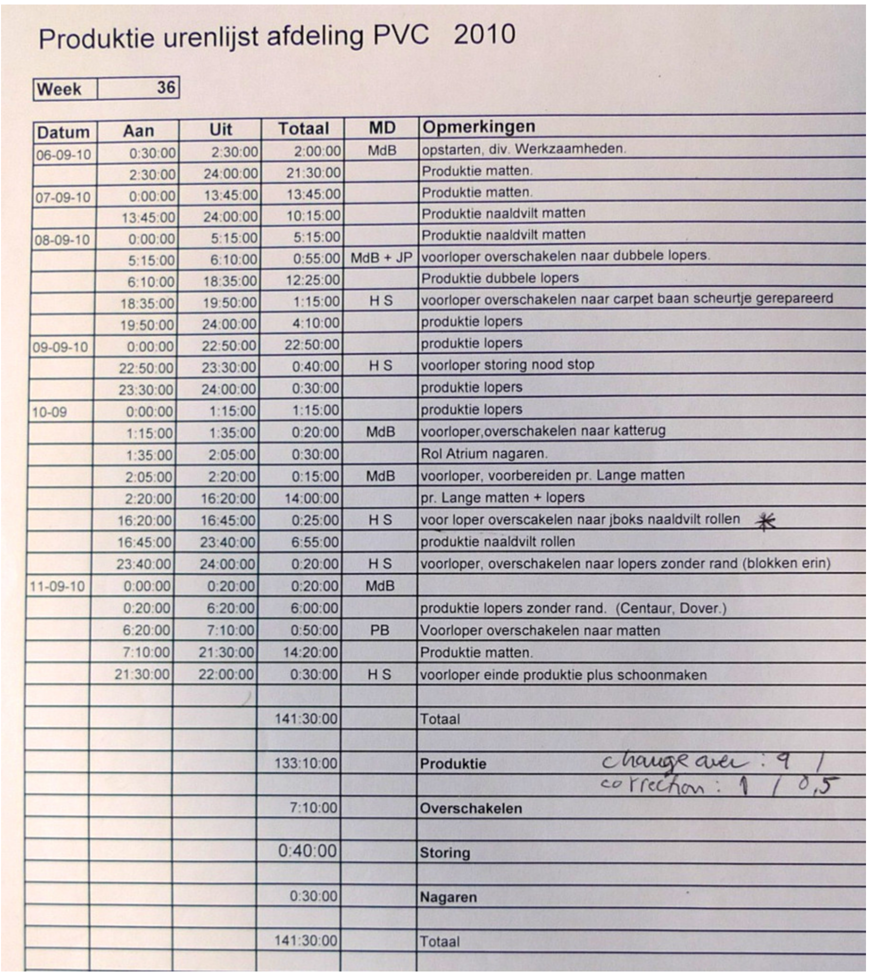
Table 42 shows a summary of the pre-cutting machine uptimes. Initial uptime with 12 minutes changeover was 81%. Future uptime would be 87% by reducing roll changeover time to eight minutes for both machines.

Table 42: Summary of pre-cutting machine' uptimes

Summary of uptimes	INITIAL		FUTURE	
Newer machine cutting time in a week	6828	min	7332	min
Older machine cutting time in a week	6852	min	7356	min
Total working time in a week	8400	min	8400	min
UPTIME	**81**	**%**	**87**	**%**

5. PVC Line Uptimes

All the times to table below have been acquired from the weekly production list. Shift leaders log state changes, ie. startup, changeover, breakdowns, etc to a excel-sheet during the week. The table can be seen in Figure 47.



Produktie urenlijst afdeling PVC 2010

Week	36

Datum	Aan	Uit	Totaal	MD	Opmerkingen
06-09-10	0:30:00	2:30:00	2:00:00	MdB	opstarten, div. Werkzaamheden.
	2:30:00	24:00:00	21:30:00		Produktie matten.
07-09-10	0:00:00	13:45:00	13:45:00		Produktie matten.
	13:45:00	24:00:00	10:15:00		Produktie naaldvilt matten
08-09-10	0:00:00	5:15:00	5:15:00		Produktie naaldvilt matten
	5:15:00	6:10:00	0:55:00	MdB + JP	voorloper overschakelen naar dubbele lopers.
	6:10:00	18:35:00	12:25:00		Produktie dubbele lopers
	18:35:00	19:50:00	1:15:00	H S	voorloper overschakelen naar carpet baan scheurtje gerepareerd
	19:50:00	24:00:00	4:10:00		produktie lopers
09-09-10	0:00:00	22:50:00	22:50:00		produktie lopers
	22:50:00	23:30:00	0:40:00	H S	voorloper storing nood stop
	23:30:00	24:00:00	0:30:00		produktie lopers
10-09	0:00:00	1:15:00	1:15:00		produktie lopers
	1:15:00	1:35:00	0:20:00	MdB	voorloper,overschakelen naar katterug
	1:35:00	2:05:00	0:30:00		Rol Atrium nagaren.
	2:05:00	2:20:00	0:15:00	MdB	voorloper, voorbereiden pr. Lange matten
	2:20:00	16:20:00	14:00:00		pr. Lange matten + lopers
	16:20:00	16:45:00	0:25:00	H S	voor loper overscakelen naar jboks naaldvilt rollen *
	16:45:00	23:40:00	6:55:00		produktie naaldvilt rollen
	23:40:00	24:00:00	0:20:00	H S	voorloper, overschakelen naar lopers zonder rand (blokken erin)
11-09-10	0:00:00	0:20:00	0:20:00	MdB	
	0:20:00	6:20:00	6:00:00		produktie lopers zonder rand. (Centaur, Dover.)
	6:20:00	7:10:00	0:50:00	PB	Voorloper overschakelen naar matten
	7:10:00	21:30:00	14:20:00		Produktie matten.
	21:30:00	22:00:00	0:30:00	H S	voorloper einde produktie plus schoonmaken
			141:30:00		Totaal
			133:10:00		**Produktie** change over : 9 / correction : 1 / 0,5
			7:10:00		**Overschakelen**
			0:40:00		**Storing**
			0:30:00		**Nagaren**
			141:30:00		Totaal

Figure 47: PVC-coating line's weekly log

In Table 43 data has been collected from the weekly logs PVC line log during 15 weeks.

Table 43: PVC line's summary

Week Number	Production Hours	Working Hours	Changeover Hours	Rework Hours	Breakdown / Repair Hours
21	97:00:00	112:00:00	0:55:00	4:35:00	7:45:00
22	125:45:00	134:30:00	5:10:00	0:35:00	0:00:00
23	134:55:00	141:30:00	2:15:00	2:00:00	0:25:00
24	132:10:00	141:30:00	4:15:00	1:10:00	2:15:00
35	137:05:00	141:30:00	2:20:00	0:00:00	0:00:00
36	133:10:00	141:30:00	4:40:00	0:30:00	0:40:00
37	129:05:00	141:30:00	0:20:00	8:30:00	0:00:00
38	134:20:00	141:30:00	2:30:00	1:50:00	1:50:00

39	136:20:00	141:30:00	1:00:00	1:55:00	0:00:00
40	122:25:00	141:30:00	5:05:00	10:05:00	0:00:00
41	129:25:00	141:20:00	4:05:00	4:30:00	0:00:00
42	116:55:00	141:30:00	3:20:00	7:25:00	11:35:00
43	122:05:00	141:30:00	1:30:00	12:25:00	3:00:00
44	138:15:00	141:30:00	0:10:00	1:15:00	0:00:00
45	134:55:00	141:30:00	3:25:00	0:50:00	0:00:00
Total	**1923:50:00**	**2085:50:00**	**41:00:00**	**57:35:00**	**27:30:00**

Table 44 shows a summary of the PVC line's production. Total uptime of the line was 92 % during these weeks and the average changeover time was 38.50 minutes. Rework took 3% of the whole production time and breakdown and repair time 1.3%.

Table 44: PVC line's summary for 15 weeks

PVC Line's Summary for 15 weeks			
Uptime	**Rework**	**Average C/O time**	**Breakdowns + Repair**
92%	**3.0%**	**0:38:50**	**1.3%**

Figure 48 illustrates the different forms of downtimes and it's share. It shows that rework has the biggest impact on downtime. Changeover was 32% and breakdowns and repairs 22% of the downtimes.

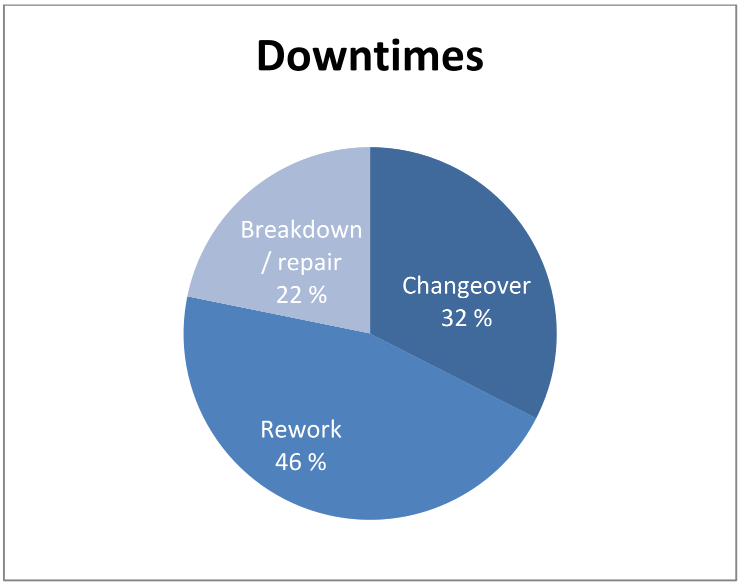


Figure 48: PVC line's downtimes

Figure 49 gives a quick overview of the PVC line's production hours and working hours. There can be seen some variation between different weeks. In week 21 and 22 they had holidays and that's why there were less working hours than normally.

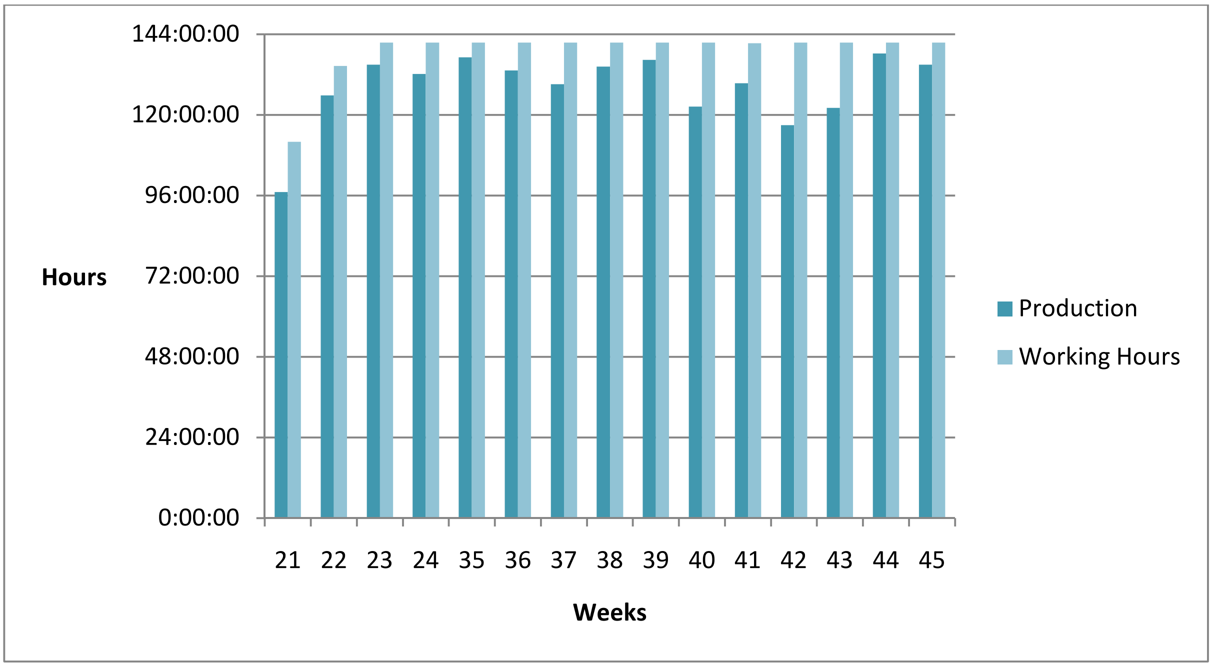


Figure 49: PVC line's working and production hours

6. Final Cutting Machines Uptimes Calculations

The final cutting machines have a set speed that cannot be changed. In final cutting there aren't clear changeovers to be defined. Changing blades is the biggest cause of downtime. Sometimes when the type of mat changes the operator has to change some settings in the machine. This to make sure the scanners have the correct edge detection. During these two actions the cutter is being paused.

Table 45 shows how the uptime has been calculated. There were two things that affected uptime. Blade changes took more time than the other delays like scanner adjusting or checking for quality defects.

In the initial situation a blade change took 1.20 minutes. The blade was changed in the tool holder. Blade change interval is highly dependent on mat quality, the blade wears faster if the PVC mixture contains more chalk. The interval can vary from once every hour to twice per shift. The average interval was estimated to be once every two hours. This calculation estimates other delays at two minutes each hour. Initial uptime for cutters was 95%.

In the future example blade changes take only 16 seconds. This is achieved by replacing the tool holder as one piece. Chapter 7.3 describes the changes.

Also the delay time can be reduced to one minute each hour. This could be achieved by installing the 3rd cutter in-line to eliminate any overflow during production. When pages move to the overflow buffer the PVC hardens more and the borders sag. This causes increased quality defects and more blade changes, thus increasing machine downtime.

After improvements the future uptime would be 98%.

Table 45: Final cutting machines' uptime

	INITIAL		FUTURE	
Working hours per week	140	h	140	h
	8400	min	8400	min
How often change blades	12	times a day	12	times a day
How much time it takes	**1,33**	**min**	**16**	**s**
per week	96	min	19	min
Other delays per hour	**2**	**min in a hour**	**1**	**min in a hour**
per week	283	min	142	min
	8021	**min**	**8239**	**min**
UPTIME	**95 %**		**98 %**	

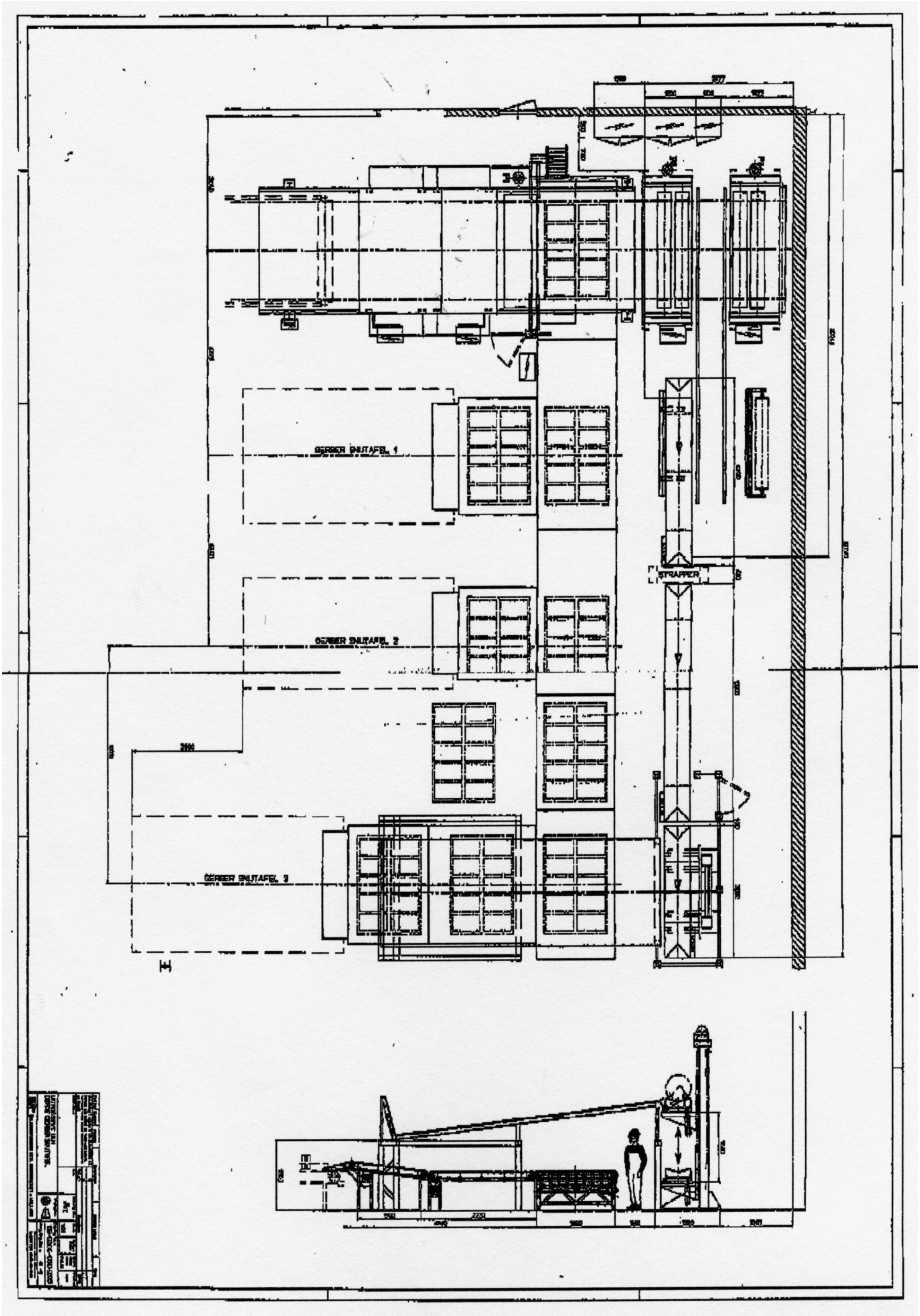
7. Extra Salary Costs from Overflow in one Year

The example in Table 46 shows how much it would cost to use the 3rd cutter, positioned off-line, to cut away one year production overflow of 40x60 and 60x90 mats with one employee. PVC line's speed is in both situations 4.8 m/min. Machine costs have been acquired from production logs where every machine's expenses are stated.

Table 46: Overflow buffer costs

Example: Cutting of overflow buffer			
Machine costs including employee		48,89 €	/h
Working hours a week		141	h
Working weeks in a year		50	
Hours in a year		7050	h
PVC line's speed		4,8	m/min
Production time 40 x 60		6 %	
Production time		423	h
Overflow		749	pcs/h
Overflow total		316827	pcs
Hand feeded cutter capacity		700	pcs/h
Time needed 1 cutter		453	h
Costs	**22 128 €**		
Production time 60 x 90		46 %	
Production time		3243	
Overflow		8	pcs/h
Overflow total		25944	pcs
Hand feeded cutter capacity		400	pcs/h
Time needed 1 cutter		65	h
Costs	**3 171 €**		
Total Costs in one year	**25 299 €**		

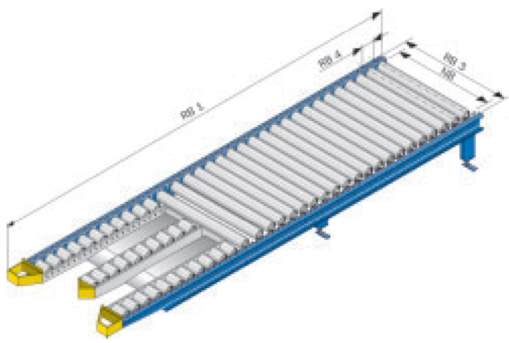
8. 3rd Cutter New Layout



9. SSI Schäfer Pallet Gravity Fed Line

ROLLENFÖRDERTECHNIK

Schwerkraftrollenbahn (SRB)



Kurzbeschreibung

Schwerkraftrollenbahnen werden hauptsächlich an Förderanlagen-Endstellen und in Palettendurchlaufregalen eingesetzt.

Die Schwerkraftrollenbahn hat ein Gefälle von ca. 4%. Durch den Einsatz von Bremsrollen kann die Ablaufgeschwindigkeit des Fördergutes gebremst werden.
Am Ende der Rollenbahnen kann das Fördergut mit Handhubwagen oder Gabelstapler abgenommen werden.

Die Schwerkraftrollenbahn kann mit oder ohne dreigeteilten Auslaufrollen in Abhängigkeit der Flurförderzeuge eingesetzt werden. Bei langen Schwerkraftrollenbahnen werden eine oder mehrere Bremsrollen eingesetzt.

Zubehör

- Spurkränze
- Führungsrollen
- Sensorhalter
- Bremsrollen/Bremstragrollen
- Zwei-/dreiteilige Ein- und Ausgabe
- Palettentrennvorrichtung am Abnahmeplatz
- Einsetztrichter
- Rollenschutzprofil
- Elektro-Handhubwagenentnahme

Technische Daten

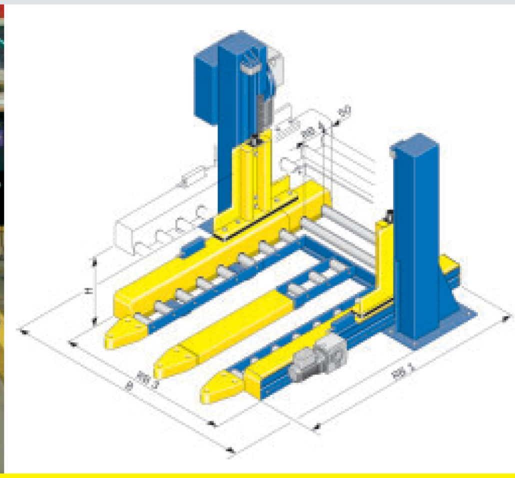
Antrieb:	Schwerkraft		
Notwendiges Gefälle:	ca. 4 %		
Rollenbahnlänge (RB1):	min.	720	mm
	max.	ca. 10.000	mm
Förderhöhe (RB2):	min.	350	mm
	max.	1.000	mm
Nennbreite (NB):	min.	880	mm
	max.	1.280	mm
Fördererbreite (RB3):	NB	+ 70	mm
Rollendurchmesser:		60	mm
Rollenwanddicke:		2	mm
Rollenteilung (RB4):		156	mm

14 technische Änderungen auf Anfrage

10. SSI Schäfer Pallet Lift

AUFGABEFÖRDERTECHNIK

Ebenerdige Rollenbahn mit Hub (EAS-RBmH)



Kurzbeschreibung

Mit der ebenerdigen Aufgabestation mit Hub können Transporteinheiten mit einem Handhubwagen aufgegeben bzw. abgenommen werden.

Zum Aufgeben der Transporteinheiten steht die Aufgabestation in unterer Stellung mit einem Förderniveau von +75 mm zum Bodenniveau. Der Hub wird über einen Kettentrieb mit Elektromotor realisiert.

Von den 3 Rollenleisten sind die beiden Äußeren angetrieben. Die mittlere, nichtgetriebene Rollenleiste dient zum Abstützen der Palette.

Sicherheitseinrichtung

- Eine Lichtschranke mit Auswerteeinheit, die bei Bedämpfung den Hubmotor stoppt.
- Rutschkupplung
- Stabile Einführhilfe zum Schutz der Rollenbahn

Zubehör

- Sensorhalter

Technische Daten

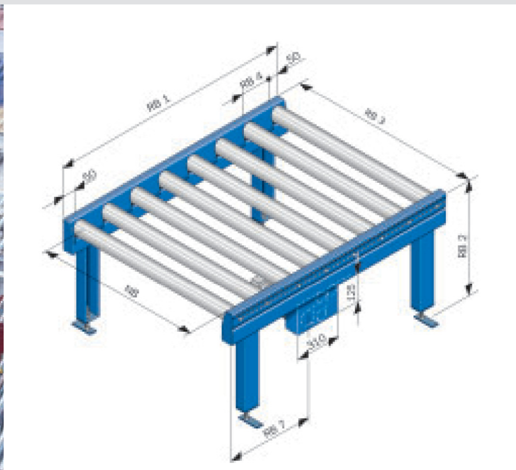
Hubgeschwindigkeit:	max.	0,07	m/s
Fördergeschwindigkeit:	max.	0,3	m/s
Antriebsleistung Hub:	max.	1,5	kW
Antriebsleistung RB:	max.	0,37	kW
Förderleistung:	max.	120	Pal/h
Motor Rollenbahn:	- Drehstrommotor - Movimot - Moviswitch - polumschaltbarer Motor		
Motor Hub:	- Drehstromantrieb mit externen Frequenzumrichter - Movimot		
Rollenbahnlänge (RB1):		1.750	mm
Fördererbreite (RB3):	min. max.	1.250 1.650	mm mm
Gesamtbreite (B):	RB3	+ 800	mm
Nennbreite (NB):	min. max.	880 1.280	mm mm
Hub (H)	max.	600	mm
Rollendurchmesser:		60	mm
Rollenwanddicke:		3	mm
Rollenteilung (RB4):		160	mm

8 technische Änderungen auf Anfrage

11. SSI Schäfer Pallet Roller

ROLLENFÖRDERTECHNIK

Rollenbahn (RB)



Kurzbeschreibung

Die Rollenbahn wird zum horizontalen Transport von Ladeeinheiten eingesetzt.

Der Ladungsträger wird auf angetriebenen Tragrollen gefördert, die durch einen tangential wirkenden Kettentrieb bewegt werden.

Kette, Kettenräder und Umlenkrollen sind vor unbeabsichtigtem Eingriff durch Schutzbleche verkleidet.

Zum Ausgleich von Bodenunebenheiten sind die Stützenfüße über Gewindestangen (± 40mm) höhenverstellbar. Die Stützen und die Antriebseinheit sind verschiebbar.

Zubehör

- Spurkränze
- Führungsrollen
- Sensorhalter
- Endanschlag

Technische Daten

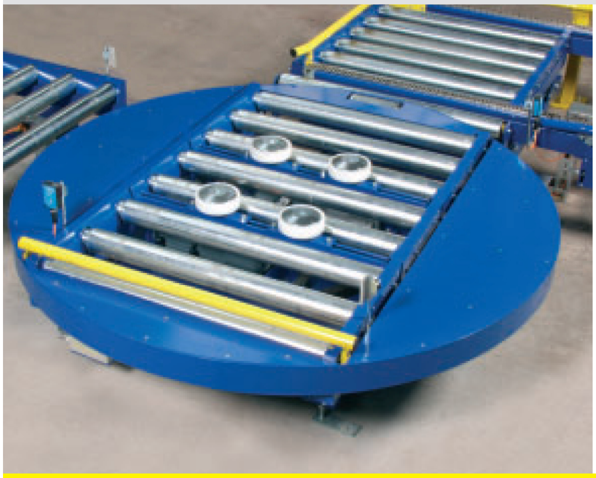
Fördergeschwindigkeit:	max.	0,3	m/s
Antriebskette:	10B-1 (5/8" x 3/8" Simplex) DIN 8187		
Antriebsleistung:	max.	0,55	kW
Antrieb:	- Drehstrommotor - Movimot - Moviswitch - polumschaltbarer Motor		
Rollenbahnlänge (RB1):	min.	720	mm
	max.	4.500	mm
Fördererhöhe (RB2):	min.	350 (± 40	mm)
	max.	2.000 (± 40	mm)
Nennbreite (NB):	min.	880	mm
	max.	1.280	mm
Fördererbreite (RB3):	NB	+ 200	mm
Lage Antrieb (RB7):	min.	370	mm
Rollendurchmesser:		80	mm
Rollenwanddicke:		3	mm
Rollenteilung (RB4):		120 – 200	mm (in 20 mm Schritten)

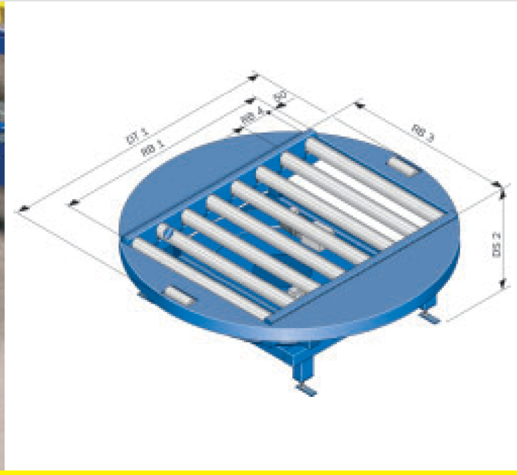
12 technische Änderungen auf Anfrage

12. SSI Schäfer Pallet Turning Station

UMSETZFÖRDERTECHNIK

Drehstation mit Rollenbahn (DRB)





Kurzbeschreibung

Die Drehstation mit Rollenbahn dient zum Richtungswechsel bzw. zur Wendung von Ladeeinheiten im Längstransport.

Die Drehung beträgt im Standardfall 90° bzw. 180°.

Die Drehbewegung erfolgt über ein direkt auf die Motorwelle gesetztes Ritzel, das über den Zahnkranz der Kugeldrehverbindung den stufenlos einstellbaren Drehwinkel ausführt.
Die Drehlagerung erfolgt über eine Kugeldrehverbindung.

Die Stromzuführung zum drehenden Oberteil erfolgt mit einer Energiekette.

Zubehör

- Sensorhalter
- Spurkränze
- Führungsrollen
- Endanschlag

Technische Daten

Dreh- und Positionierzeit 90°:	5 s	
Drehwinkel:	max. 270° (+90°; –180°)	
Antriebsleistung:	max. 0,37 kW	
Förderleistung 90°:	max. 180 Pal/h	
Energiezufuhr:	Kabelkette	
Antrieb Drehtisch:	- Movimot - polumschaltbarer Motor	
Antrieb Rollenbahn:	- Drehstrommotor - Movimot - Moviswitch - polumschaltbarer Motor	
Rollenbahnlänge (RB1):		1.500 mm
Fördererhöhe (DS2):	min.	450 mm (± 40 mm)
	max.	1.000 mm (± 40 mm)
Nennbreite (NB):	min.	880 mm
	max.	1.280 mm
Fördererbreite (RB3):	NB	+ 200 mm
Drehtischdurchmesser (DT1):		1.800 mm
Rollendurchmesser:		80 mm
Rollenwanddicke:		3 mm
Rollenteilung (RB4):		120 – 200 mm (in 20 mm Schritten)

 technische Änderungen auf Anfrage