A study on the influence of the constraints, variables and objectives that influence scheduling of a balanced production line

CASE: Production of the WUC of the A350 aircraft at Airbus

1 ABSTRACT

This report reflects on the research done on how to balance a production process for the WUC of the A350 at Airbus. Characteristics of the process are that the process is based on a single piece flow concept and that editing is done on the physical cover. This results in mostly sequential work.

In this report an overview of a study on predicting the layout of a balanced production line for future ramp up rates is done. In order to get an overview, working schedules are created based on input and output parameters as shown in Figure 1.

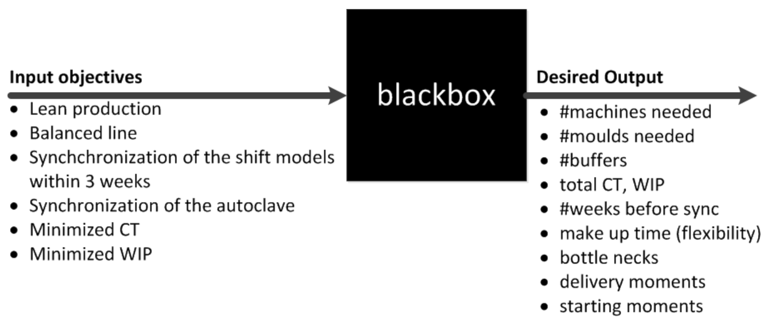

Figure 1: input and output parameters

New relations are found and techniques for the creation of the schedules are designed. And a model is made that point out the factors that influence balancing a line most. The model is explained extensively.

It is advised to follow the point of the checklist in Figure 2, when making the schedules that help to get insight in future rates.

Also the influence of working on Saturdays is studied. It is concluded that scheduling the work in the 2S12 shift model can reduce the total cycle time and therefore the amount of moulds in the process compared to the 2S10 shift model at the production rate of 6,06 ACs/month. Also the amount of available production rates in order to balance is more for the 2S12 model.

Fur the future ramp up scenarios it can be said that the rates that can be reached are 4 5/9, 6, 9 and 12 1/8. And in the 2S12 scenario also the rates 6 5/6 and 13 2/3 can be reached.

For further research it is recommended to:

- Make the model automated
- Gives time schedules for all the ramp up rates
- Business case: What is impact ($) of synchronizing the autoclave VS non-synchronizing
- Study the stringer production
- Take the finishing area into account

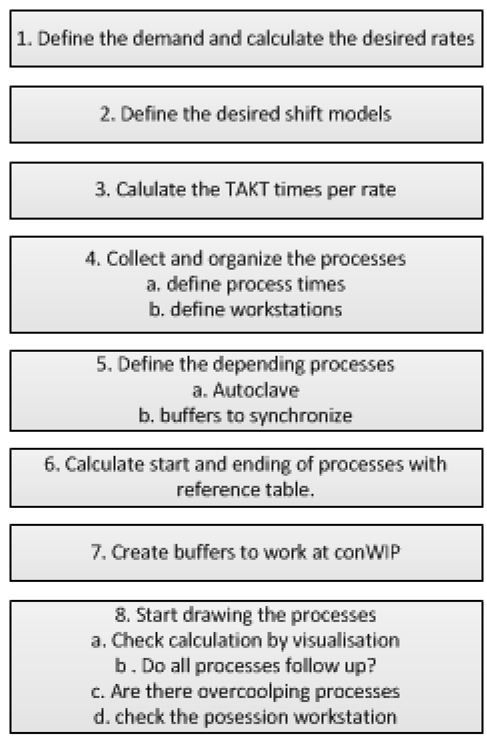

Figure 2: checklist for scheduling

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3 INTRODUCTION TO PROBLEM DESCRIPTION

At the moment the production process of the WUC of the A350 at Airbus is increasing its production in steps; this is called the ramp up phase. Meaning that the process is currently in production, but scale-up plans are designed. There is a possibility that the lay out of the production line should change, to be able to increase the production to the desired rates.

To be able to give a prognosis of the future lay-out, a study on all the influencing parameters need to be done. All is done in order to get a get the grip on the question of ‘what are the implications of producing at future targets?’.

3.1 OBJECTIVE

This brings us to the **objective** of this assignment**;**

Create insight in the influence of the constraints, variables and objectives on scheduling of a balanced production line of the production of WUC’s of the A350 aircraft at Airbus in order to ***create standards****.*

With a focus on;

- *the amount of weeks before balancing*
- *Rates are calculated in TAKT*
- *sync of shift model 3S18 with 2S10 (and 2S12)*
- *Insight in WIP and CT*
- *#flexibility within process*

Keeping in mind that it is desired to minimize the total investments needed and therefore minimize the CT, WIP, #machines needed, #buffers needed. Also the line must be organized by standards.

3.2 WHY PLANNING, BALANCING AND SYNCHRONIZATION?

In order to be able to get an insight in the future ramp up scenarios, these situation have to be predicted. Planning allows creating an overview for future scenarios. With a good planning it can be shown how big the investment in new machines has to be, how many WIP there will be, at what times the production of the products has to start in order to deliver in time for the customer, and so on.

Next to have a proper plan, there should also be a focus on a balanced line. Balancing a line, and synchronizing the different processes and shift models, results in a **standard planning**. This means that the weekly created schedules, will repeat itself after a specific amount of weeks.

In Figure 3 an overview of the parties involved in the planning, balancing and synchronization is shown, with an indication of their level of involvement.

Customer

For the customer a proper planning is important, since the customer wants to know when he can aspect the product to be delivered. Taking the demand of the customer as a leading constraint for the production line, is called working “Lean”. In order to deliver Lean with a steady predictable output, the production line should work “in TAKT”. The times in between delivery of two following products is defined as 1 TAKT, but this is explained more detailed in the upcoming chapters.

AIRBUS as a company

On order to be able to plan the investments and payments that are needed for future ramp up scenarios, a schedule is needed. By making a well fit schedule, prove for the need of investments can be shown to the budget decision makers. This enables the departments to receive the right amount of budget to be able to buy the necessary new extra machines. Besides new machines, the amount of buffers and WIP can also be demonstrated by a proper schedule. Also to plan an efficient and effective production line, the process should be studied and shown in a schedule.

Employees

Employees are the third party to be concerned about. For the employees standards can be set as a result of a proper planning. By balancing the production line after a specific amount of weeks, standards are set and the once difficult production planning is simplified and understandable. This creates a good overview of the production line for the floorman to, which increases their ability to allocate their workers, also in case of a delay in the line. Also with a proper planning it is possible to give an overview of the flexibility in hours within the line. And as a result of balancing there are repeating weeks where exactly the same processes, with similar starting and ending times, will take place. This gives the workers a good understanding of their weekly schedule, so they can count on standard free time and standard working days.

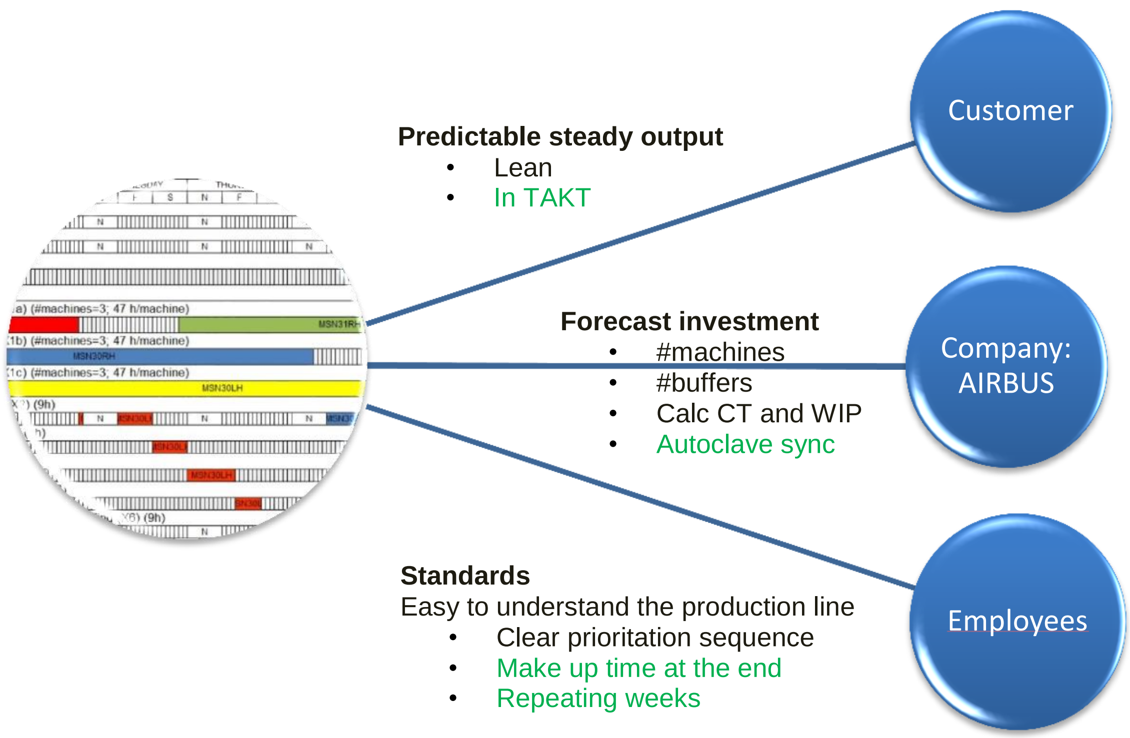


Figure 3: parties involving line balancing

4 DESCRIPTION OF THE SITUATION

4.1 CURRENT STATE

At the moment the production line is producing wing upper covers. The production line is working in a specific layout and is using the current available resources. These resources are influencing and determining the optimal rate. For now the current state has a rate that is too low to meet the future demand of the customer; Airbus has to ramp up. In order to be able to ramp up, which has to take place step by step, the schedules at different production rates need to be calculated. The layout of these schedules can vary in a great amount because there are a lot of variables that influence the scheduling.

4.2 SCOPE

Airbus SAS is an aircraft manufacturing division of Airbus Group (formerly European Aeronautic Defense and Space Company). Based in Blagnac, France, a suburb of Toulouse with production and manufacturing facilities mainly in France, Germany, Spain and the United Kingdom, the company produced 626 airliners in 2013 and planned to produce over 800 airplanes in 2014. Airbus began as a consortium of aerospace manufacturers, Airbus Industrie. The company produces and markets the first commercially viable fly-by-wire airliner, the Airbus A320, and the world's largest passenger airliner, the A380. In 2004 the design on the A350 XWB (extra wide body) started. Airbus stated that it will be more fuel-efficient and have operating costs up to 8% lower than the competing Boeing 787 Dreamliner.

In Stade, one of the world's leading centers in the use of carbon fiber reinforced plastic (CFRP), parts are produced as well. Mostly Stade produces components from CFRP, like the vertical tail planes for all Airbus aircraft, flaps for single-aisle A320 aircraft, spoilers for the wide body A330 and A340. The pressure bulkheads for the A330, A340 and A380 are also part of Stade's production responsibilities. Most important for this study, is the production line that produces the components of the A350 XWB like the upper wing cover – which represents the largest integrated carbon fiber component ever made by Airbus.

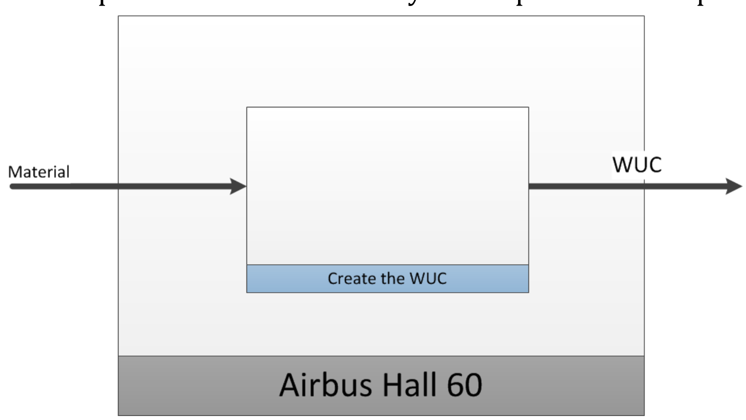


Figure 4: production process level 1

The topic of this research is the production line in Stade that produces these Wing Upper Covers for the A350 XWB. At the production line the parts for these aircrafts are produced (2 parts for each aircraft; left and right). These A350 XWB wing covers are 32 meters long by 6 meters wide, making them the biggest single civil aviation parts made from carbon fiber composite material.

As shown in **Error! Reference source not found.**, the covers are produced in Hall 60 which is the hysical boundary of the study.

5 THE PRODUCTION LINE OF THE WUC

To simplify production of the wings, it can be said that the production process consists of three different steps, as illustrated in Figure 5. At first there is the production process of the stringers and the skin, which will be discussed briefly in the following paragraph. After this, the covers will be transported into the so called finishing area, where it will be painted and prepared for transport. Transport to the finishing area is the last part of the process.

In this study only the production process will be taken into account, this means that the finishing and the transportation will be assumed to be in line with the production.

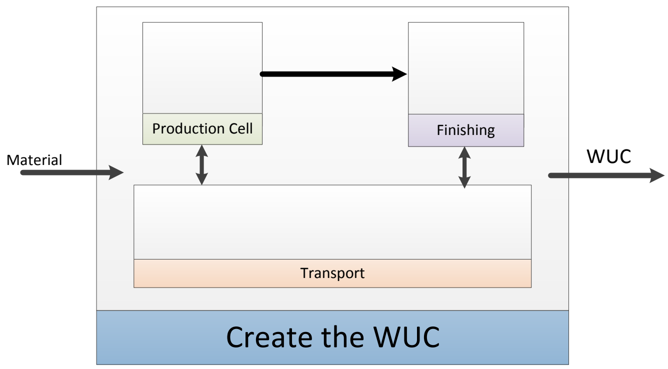


Figure 5: Production process level 2

5.1 THE PRODUCTION LINE IN GENERAL

Before going into detail into the different processes, a general overview of the process is created. Characteristics of the process are that the process is based on a single piece flow concept, since the cover flows through the line, and editing is done on the physical cover. This results in mostly sequential work.

In order to produce the WUC, the production line is layed out with a sequence of different processes. To simplify the production line, the process is divided into four topics; the stringer production (create stringers), the skin production (create skin), the assembly of the two (curing in Autoclave) and taking the created WUC of the mould (demoulding). An illustration of this process is shown in **Error! Reference source not found.**. evertheless some parallel processes exist within the line, like the curing in the autoclave. Also some workstations are used repetitively along the full process. Some resources (i.e. molds) are tied up to the parts along multiple process steps. And the biggest reason to work in TAKT is the fact that workstations are planned with different availability (operational availability, shift models, etc.). In the following paragraph the 14 different processes are discussed briefly.

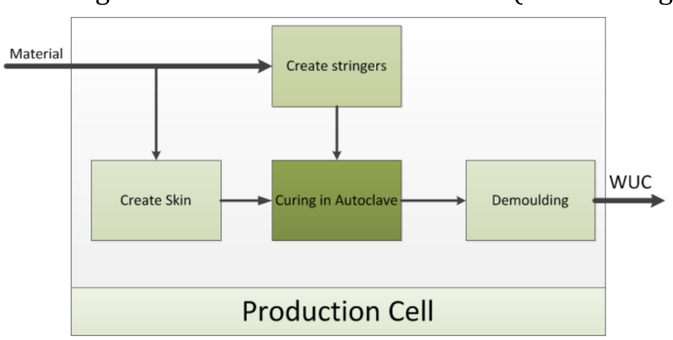


Figure 6: Production process Level 3

5.2 THE PRODUCTION PROCESSES

Since a general study is done on the scheduling of the production line, the actual processes steps are of less importance. In this paragraph a short summation of the processes is done, the workstations are listed and the tools are explained briefly.

A simplified process sequence to form a WUC is listed in Figure 7. In this figure all the process times (including transport between processes) is shown and their shift models, dependent of the process type; manual (H) or automated by a machine (M).
The process starts by creating the skin (X1). The skin of a WUC exists of carbon fiber layers, which will be laid up by an automated 3D tape; the automated tape laying process.
After this process the skin is wrapped in a vacuum bag (X2, X3) before the skin will be cured in the autoclave for the first time (X4). After the curing the skin has to be cooled down (X5) and the vacuum bag has to be removed (X6). Now some measurements are done on the skin (X7), to check the quality of the product. And the skin is prepared (X8) before its co-bounded with the stringers.
During the skin production, the stringers are prepared. Also the stringers are laid up by an automated fiber laying process (X15), the stringers and the material is pressed into the right shape (X14) and the stringers are prepared to join the skin (X13).

Process (X_n)	Roundup (hr's)	Shift model	Process type
Automated Tapelaying (X_1)	139	3S18	M
Vacuum Bagging (Skin) (X_2)	9	2S10	H
Vacuum holding cycle (X_3)	8	3S18	M
Autoclave cycle (1) (X_4)	11	3S18	M
Cooling after 1st. Autoclave (X_5)	6	3S18	M
Debagging (Skin) incl. reference hole drilling (X_6)	9	2S10	H
RJ Thickness measurement (X_7)	3	2S10	H
skin preperation (X_8)	4	2S10	H
str pos on skin & vacuum bagging (X_9)	13	2S10	H
Autoclave (2) (X_{10})	11	3S18	M
Debagging (Skin + Stringer) (X_{11})	9	2S10	H
Demoulding (Stringer and ancilliary Tools + Skin Demoulding) (X_{12})	22	2S10	H
Stringer prep (X_{13})	29	2S10	H
Stringers (Pressforming) (X_{14})	22	2S10	H
Laying stringers + cutting + scrapping (X_{15})	65	3S18	M

Figure 7: list of processes

Now it is time for the positioning of the stringers on the skin and the vacuum bag (X9) in order to go into the autoclave for the second cycle. In the autoclave the skin and the stringers are bounded (X10). Now the process is almost finished, but before going into the finishing area the skin (incl stringers) need to be debagged (X11) and demoulded (X12).

5.3 THE TOOLS

For the production of the WUC the produced parts is for most of the process steps (X1- X12) on a mould. This mould is a working tool on which the entire carbon fiber wing upper cover will be build-up. The coefficient of thermal expansion is the same for skin and mould, so the mould is made from a special material. This makes it an expensive tool and therefore there is paid some extra attention to this tool in order to reduce the amount of moulds. Next to the mould, there are tools in the stringer production process, to form the stringers and keep them in place during the processes; these tools are beyond the scope of this research. Next to the real practical tools, there are cranes and AGV's used in the process. Because of the ongoing development of a dynamic simulation, these transport tools are also chosen to be beyond the scope of the research.

5.4 THE WORKSTATIONS

All the processes are taking place in different workstations; in total there are 8 different stations. In Table 1 the different workstations with their processes are shown. It is important to know what process is happening in which station in order to be able to calculate the amount of workstations that are needed per ramp up rate.

Workstation (W_n)	**Process (X_n)**
3D-Tapelayer (W_1)	X_1
Skin Vacuum Bagging (W_2)	X_2 and X_3
Autoclave (W_3)	X_4 and X_{10}
Coolingbuffer (W_4)	X_5
Debagging (W_5)	X_6, X_7 and X_{11}
Workstation C2 / Stringer Positioning (W_6)	X_8 and X_9
Demoulding (W_7)	X_{12}
Workstation B (W_{10})	X_{13}
Workstation C (W_9)	X_{14}
Workstation A - FLU (W_8)	X_{15}

Table 1: List of workstations

5.5 THE SHIFTS MODELS

The production line is not only defined by the production processes itself, but also by the available resources. One of these resources is the available men hour. It is standard that a shift has duration of 8 hours. But the amount of shifts per week are depending on the shift model. Normally the automated processes are done within a 3S18 model and the manual processes in a 2S10 model. The definition of these models lie within the names. 3S18 means that there are 3 shifts per day and that there are 18 shifts per week. This means that the days available are 6 days and that on Saturday there will also be worked. When the amount of hours per shift is multiplied by the available shifts per week, it can be shown that in the 3S18 model there are 144 available hours per week to work on the processes. So for the 2S10 model, there are 2 shifts per day and 10 shifts per week. This means that when working in this shift model, there will only be work done from Monday to Friday (5 days a week). In this shift model there are 80 available hours per week.

At this moment Airbus is only aloud to work in these two models, however, the impact of changing the 2S10 model to a 2S12 model could be interesting. That's why this model will also be mentioned in this report. It is self-evident that the available hours will be raised to 96 hours per week instead of 80 compared to the 2S10 model. Also it must be mentioned that in this model there are 2 shifts per day and 12 shifts in total per week, which implicate 6 days of working and therefore the extra working day on Saturday.

5.6 HIGHLIGHTS OF THE PRODUCTION LINE

The autoclave

The process that needs the most attention in this study is the autoclave. At the moment there is one autoclave, and also for future rates there will be one autoclave available due to the costs. In the autoclave there is room for two products. This could be Left and Right skin, and also skins with stringers and skins without stringers. In order to work at the full efficiency of this autoclave, it is striven for that the autoclave will always be working with two parts. This emphasizes the need for synchronization of the processes.

Workstation W2, W5 and W6

A special focus should be on the workstations where more than one process will take place. This in order to be able to give a prognosis on the amount of workstations and area needed at ramp up rates.

6 THEORY: TAKT, CT, WIP, AND TH

Before the working principles of making the schedules is explained, it is important to have a basic theoretical knowledge to understand the decision. In this chapter the TAKT times will be introduced and explained. Also the relation of the cycle times (CT), the work in progress (WIP) and the throughput time will be discussed.

6.1 TAKT

Following a Lean approach, the production time is defined by taking the customer order (demand) and the total available time at the plant into account. To make sure the system outputs meet the customer due dates, the so called TAKT times and production quota can be calculated (1);

$$\mathrm{Takt} = \frac{t_{\mathrm{available}}}{D} \qquad (1)$$

Where,

Where,	Takt	=	Time between different outputs (time/WUC)
	$t_{\mathrm{available}}$	=	Time available (time/period)
	D	=	Demand per period (# WUC/period)

Takt time, derived from the German word **Taktzeit**, translated best as *meter*, sets the pace for industrial manufacturing lines so that production cycle times can be matched to customer demand rate. Matching the cycle time with the TAKT time, on a production-cycle level, avoids building up inventories. This because every TAKT a product is finished which is the determination of the TAKT time. This allows for counting on a steady output and therefore facilities planning and due data quoting, as described in chapter 13 of *Factory Physics* by Hopp and Spearman. Working in TAKT also sets the production quota per workstation, which simplifies facility planning.

In the strictest form, working in TAKTs from a Lean approach, this means that;

- Production stops if the quota is reached in order to prevent inventory to build up, which wouldn't be lean.
- **Make-up time** is scheduled at the end of a period to make up any shortages that occurred during regular production time. This is actually easier said than done, because in a production line for parts like WUC, a default in the line would cause a snowball effect, because almost all the production processes are dependent of the previous process. This means if there is any shortage in the line; the whole production line suffers from this.
- This also means, that if any production process exceeds the TAKT time, there is a need for more machines to work parallel and start production of the next part within the production process of the earlier part, while producing in TAKTs.

If all of this is met, there is a steady output to count on and therefore the planning and the due date quoting is facilitated and made possible. The TAKTs can be determined on different levels; weeks, days, shifts or hours.

6.2 CT, TH AND WIP

Another aspect of a Lean approach is to define the production time by taking the customer order (demand) and the total raw processing time (per machines). These two combined in a formula, and defined by Little's law (named for John D. C. Little), are shown in (2);

$$\mathbf{WIP} = \mathbf{TH} \cdot \mathbf{CT}; \tag{2}$$

Where,	WIP	=	Work in process at time t (# WUC's in system at time t)
	TH	=	Throughput time or demand (# WUC's per hr)
	CT	=	Cycle time (hr per WUC)

By combining the formulas (1) and (2), formula (3) is found;

$$\mathbf{TAKT} = \frac{\mathbf{CT}}{\mathbf{WIP}} = \frac{\mathbf{1}}{\mathbf{TH}} = \frac{\mathbf{t_{avail}}}{\mathbf{D}} \tag{3}$$

Where,	TAKT	=	Definition of the TAKT; Amount of time between delivery (# shifts/TAKT)
	WIP	=	Work in process (# parts/TAKT)
	CT	=	Cycle time (# shifts/part)
	TH	=	Speed of the process (# TAKT/shift)
	t_{avail}	=	Time available (# shifts/week)
	D	=	Demand per period (# WUC/week)

As formula (3) indicates, the WIP can be calculated when the TAKT time is known and the CT is calculated. When the CT increases and the TAKT remains the same; the amount of WIP also increases.

6.3 CONWIP: CONSTANT WIP

It is highly recommended to have a constant amount of WIP in the production line. CONWIP systems are easier to implement and adjust as explained by Hopp and Spearman in Factory Physics. ConWIP can easily be managed since a simple KANBAN system can be used; when one product is finished a new product can enter the line. Also having a conWIP makes it easier get a grip on the line, since there are a predictable amount of parts flowing through the line. Most straightforward way to establish a WIP cap is to just do it! That is, for a given production line, establish a limit on the WIP in the line and simply do not allow releases into the line whenever the WIP is above the limit. In other words; a protocol under which a new job is introduced to the line each time a job departs.

When combining this theory with the formulas found in the previous chapters, it becomes clear that when a constant WIP is desired, the CT should be a rounded amount of TAKTs. This means that there will be a strive for the CT to be an integer amount of TAKT. This means that all the different products will have a similar CT that will be calculated. The impact is that there will be buffer time at the end of all the cycles of all the individual products in order to have a set CT.

7 Parameters of a balanced line

To create the final production schedules for the balanced line at the different rates, a few more steps need to be taken. The needed input and the desired output need to be determined in order to create the wanted schedule. At the end of this chapter all the preparation will be done and a balanced line will be made. In the next chapter the model to balance the line will be explained.

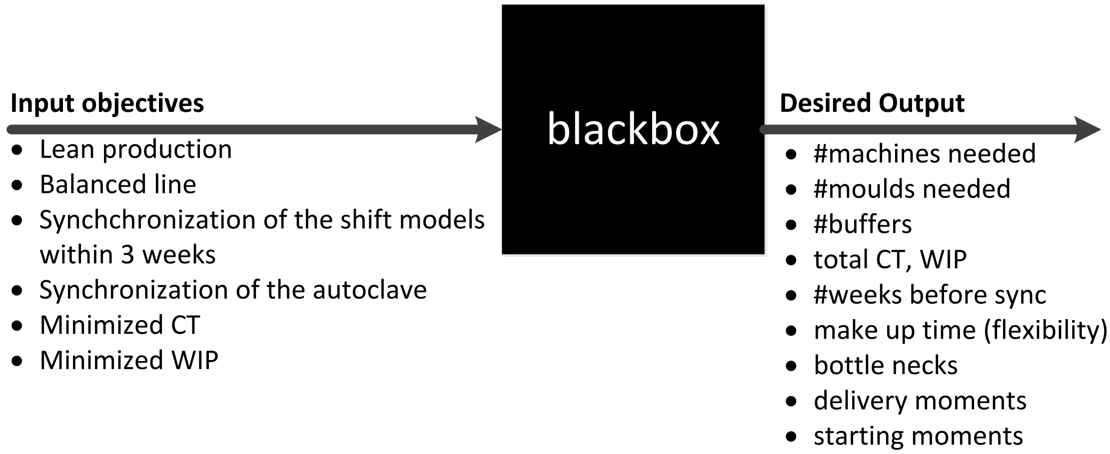


Figure 8: input and output of schedule

In Figure 8 an overview of the needed input and desired output is given. The blackbox represents creating the schedule. In order to be able to draw the line balance a few different aspects need to be determined and used as an input for the schedule. Also the desired output must be determined in order to create the desired schedule.

7.1 The input parameters

As shown in Figure 8 there is a list of different input needed in order to create the schedules. All the different parameters will be discussed one by one in the following paragraphs.

7.1.1 Lean production

To work with a lean production line, the first challenge is to deliver in time to the customer. The production rate is therefore one of the most important parameters that are defining the schedule. For future ramp up a prognosis of the future rates is done. This prognosis results in a ramp up of 4 different rates; Rate 1= 5 AC/month, Rate 2 = 7 AC/month, Rate 3 = 10 AC/month and Rate 4 = 13 AC/month. When the term ‘rate’ is mentioned, it must be clear that it is about the amount of AC per month. Because one AC has two wings and therefore needs 2 WUC parts, the rate can be translated into parts/week by;

$$\mathrm{Rate_{week}} = 2 \cdot \mathrm{Rate_{month}} \cdot \frac{t_{\mathrm{avail,months}}}{t_{\mathrm{avail,weeks}}}$$

Example: a rate of 5 AC/month can be translated into a production amount of 2,2 parts/week.

7.1.2 BALANCED LINE AND SYNC OF THE SHIFT MODELS

Because one of the objectives is to have a standard balanced line, the rates not only dependent of the customers' orders and the prognosis of the rates, but are also on the possibility to synchronize the different shift models within the desired 3 weeks maximum.

In order to calculate the TAKTs for which the shift models are able to synchronize, the common multiplier of the total available hours and/or shifts of the two different models have to be found. As shown in the formulas the TAKTtimes are calculated by dividing the available hours by the demand. Of course the demand remains the same per shift model, but the amount of available hours differs per shift model. The 3S18 shift model has 3*8*6=144hours available per week, whereas the 2S10 model has only 2*8*5=80hours available to finish work in. A found common multiplier reflects the amount of TAKTs after which it is possible to synchronize. The calculation of the multipliers is shown in Figure 9.

common multiplier	1 week		2 week		3 week	
	1		2		3	
	144 3S18	80 2S10	288 3S18	160 2S10	432 3S18	240 2S10
1	-		-		-	
2	x		-		-	
3	-		-		-	
4	x		x		-	
5	-		-		-	
6	-		-		x	
7	-		-		-	
8	-		x		x	
9	-		-		-	
10	-		-		-	
11	-		-		-	
12	-		-		x	
13	-		-		-	
14	-		-		-	
15	-		-		-	
16	-		-		x	
17	-		-		-	
18	-		-		-	

Figure 9: Calculation of the TAKT times

It is important to understand what this multiplier stands for. The multiplier is the amount of TAKTs per week. So for example, if a common multiplier is found in column 4 (week 3) of 8, this means that both the 2S10 and the 3S18 models will be starting a new product after the start of 8 times a new product. This common multiplier is found in 3 weeks, so this can be recalculated to a weekly rate of 2 2/3 parts. This means TAKT times of 54 hours for the 3S18model and a TAKT time of 30 hours for the 2S10 model. On a monthly basis, this means 6,06 AC/month.

As is shown in the figure, there are a few restrictions used to find these common multipliers.

1. First of all it is decided that the maximum amount of weeks before synchronization of the line is 3 weeks at a maximum. In the first row of the table this is shown by taking the different amount of weeks 1, 2 and 3 into account.
2. Also the minimum amount of parts per week is set at 2 parts/week. Therefore for minimum amount of parts after 2 weeks is 4 and for week 3 the amount would be 8.
3. The upper limit is set at a rate of around 6 parts/week because the maximum ramp up rate to be calculated is X4 = 13 AC/ month (= 5,8 parts/week).
4. Common multipliers that result in the same TAKT times are excluded

As a result of the restrictions the integers that are taken into account are indicated by the light grey and light pink cells. Of these inters, the common multipliers that are found, are depicted by an 'x' in the cells in Figure 9. When all the doubles are deleted, the result is 4 different common multipliers. This result is shown in Table 2.

Rates to balance					
Rate X_n	**# Products/Week**	**# AC/month**	TAKTS (hours)		
			3S18	2S10	Sync in (weeks)
x_1	2	**4 5/9**	72	40	1
x_2	2 2/3	**6**	54	30	3
x_3	4	**9**	36	20	1
x_4	5 1/3	**12 1/8**	27	15	3

Table 2: common multipliers of shift model 3S18 and 2S10

The rates that are listed in the table are the only rates at which the production line is able to produce in order to synchronize the two different shift models. This means that the influence of the restriction of balancing the line, it is only possible to deliver and produce at the shown rates.

The amount of hours per TAKT indicate, that to produce and deliver in TAKT, this is the amount of hours between all the starting processes. Also to synchronize the autoclave, there must be a multiple amount of TAKTs between the two processes.

When for example rate 2 is studied, it is shown that producing in TAKT at this rate, the production line balances after 3 weeks. This means that after 3 weeks, the previous 3 weeks of production scheduling will be repeated. So for example, every 3 Mondays the work that has to be done on a day will be the same.

7.1.3 LEAN PRODUCTION: START OF THE LINE

The found rates in the previous paragraph are the input for the schedule to produce LEAN and to synchronize the autoclave. To produce LEAN and deliver LEAN it is important to start the production of a new part 1 TAKT after the previous product was started. Also, the delivery of a part must be 1 TAKT after the previous delivery. And this principle applies for all the products in the line. For creating the schedule this means that the start of the second part in the first process (X1 = tape layer) has to start while the first part is still in production.

7.1.4 LEAN PRODUCTION & CONWIP: DELIVERY OF THE PRODUCT

As discussed earlier, the input for the schedule should also take care of the constraint that there must be a conWIP and a LEAN delivery. These constraints result in the input for the model that the CT of the whole process should be an integer amount of TAKT. This will be done by creation of a time buffer and the end of the process. This amount of time that will be in the time buffer is na indicator for the flexibility in the case of delays in the production line. The time in this time buffer can also be spread over the other processes, but this will lead to physical buffers, which consume a lot of space.

7.1.5 SYNCHRONIZATION OF THE AUTOCLAVE

Now the rates are calculated and the TAKT times are defined, it is important to take a look at the principles behind the synchronization of the autoclave. There are two scenarios in which the autoclave can be synchronized; having two different covers that are in the same cycle (so for example both in the 1st cycle) at the same time in the autoclave, or having one cover in cycle 1 and one cover in cycle 2 at the same time in the autoclave. In this report the second scenario is studied. It is found that the constraint to synchronize the autoclave is that the time between process X4 and X10 (time in between the 2 cycles) must be an integer amount of TAKT. Depending on the desired rate, the amount of TAKTs can be defined. In order to be able to have an integer amount of TAKT's between the 1st and the 2nd autoclave, a buffer must be created before the second cycle. It is also studied that when the production line starts producing a new left cover after a right cover just started and the other way around, that an odd amount of TAKT between the first and the second autoclave results in a LEFT +RIGHT cover in the autoclave. On the other had results an even amount of TAKT between the autoclave cycles in two same parts in the autoclave at the same time: LEFT+LEFT or RIGHT+RIGHT.

7.1.6 JUST IN TIME STRINGER PRODUCTION

In order to prevent buffers after the stringer production, it has to be assured that the whole stringer production (X13 – X15) is finished when the skin is ready for bonding. This is another input for the schedule drawing.

7.2 THE OUTPUT PARAMETERS

Next to input parameters, the schedules are made with a goal; desired output has to be defined. The different parameters that define the desired schedule will be discussed in the following paragraphs.

7.2.1 #MACHINES

In order to be able to give a prognosis about the amount of investment needed for future ramp up plans the amount of machines needed, need to be calculated. The first rough calculation is done by dividing the total raw production time of a machine by the TAKT time, as shown in formula (4).

$$\#\text{machines} = \frac{\text{raw production time}}{\text{TAKT time}}. \tag{4}$$

This means that when the raw processing time of a process exceeds the TAKT time, more machines are needed in order to produce in TAKT.

7.2.2 #BUFFERS

Next to the amount of machines, it is important to get an understanding of the scale of the buffers.. Looking at the difference in ending time of one process and the starting time of the next process gives an overview of the amount of buffers that are needed. Also the amount of time needed to synchronize the autoclave needs to be calculated and the make up time in the end. This will be done by taking the total CT into account and round it up to an integer amount of TAKT.

7.2.3 #MOULDS

The amount of moulds that are needed in future ramp up scenarios can be calculated by taking the amount of WIP. This is equal to the amount of moulds needed because the process uses the moulds from the start of the process until ending the last process (X12), so the complete CT.

Next to calculating the amount of moulds, the amount can also be read from the constructed schedule.

7.2.4 TOTAL CT

The CT will be calculated by taking the difference of the starting times of the processes and the ending times of the final process (X12) into account. The buffers need to be included to calculate the total cycle time. The CT without the buffers, so the CT that could be reached relaxing the constraint to synchronize the autoclave and deliver lean, will also be calculated. This can be used as a reference to define the influence of synchronization of the autoclave and delivering lean on the total cycle time.

7.2.5 WIP

The WIP is related to the CT, so when the CT is known, the WIP can also be defined by taking formula (3) into account. The longer the CT, the more WIP there is.

7.2.6 BUFFER TIMES

The buffers for the autoclave can be determined by calculating the difference in processing time between X4 and X10. The calculated time needs to be reflected to an amount of TAKT and rounded up to an integer amount of TAKT. So for example, when the time between the start of process X4 and the end of process X9 is 86 hours (taking the different shifts into account), this results in about 1,6 TAKT, which has to be rounded up to 2 TAKT to synchronize the autoclave. The difference between the total process time and the integer amount of TAKT (=0,4 TAKT) defines the amount of buffer time that is needed.

7.2.7 STARTING AND ENDING TIMES

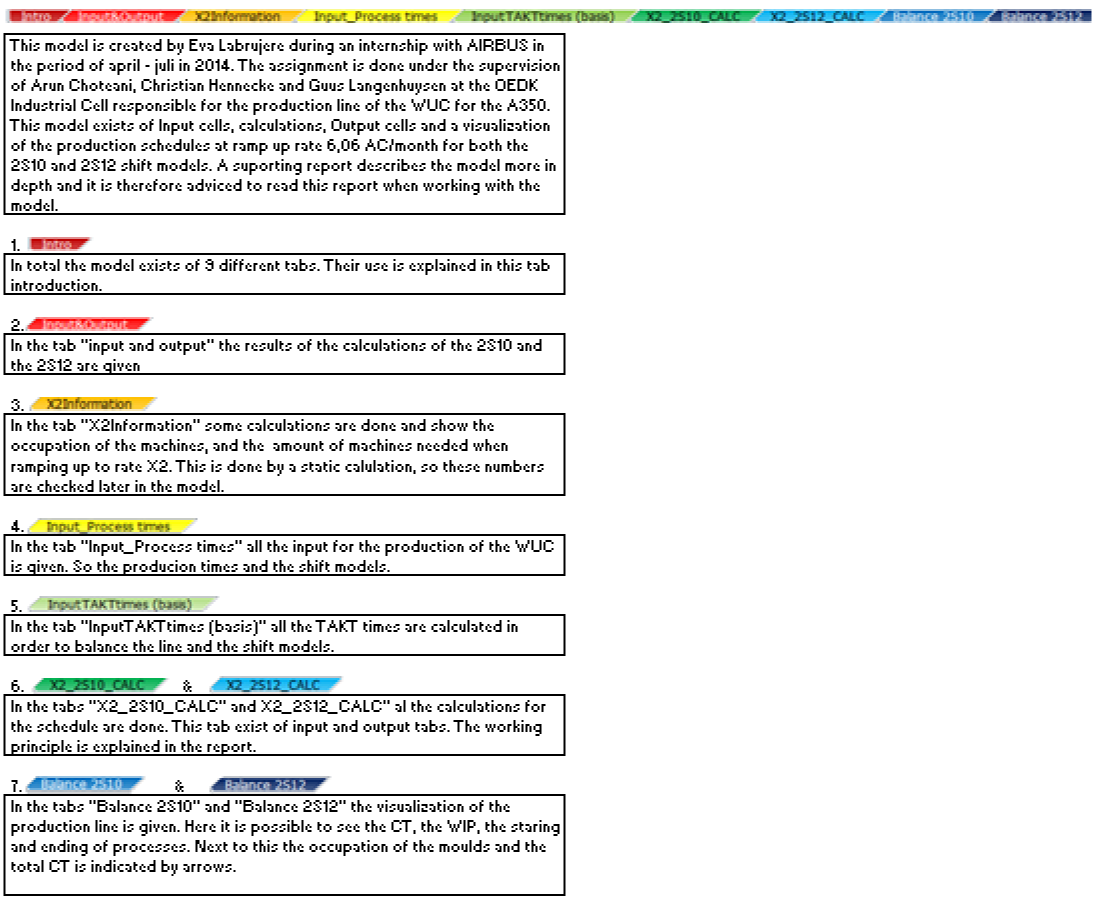
When all the processes are shown sequential in the constructed schedules, all the ending and starting times of the processes relative to weeks, days and hours are known. Also the final ending of the whole process (the delivery moment) can be read from the schedule.

Now all the desired input and output is listed, the construction of the model can be explained.

8 THE MODEL

The model that is created is called "CALCULATOR to balance lines". This excel file exists of an input sheet, calculations, output tables where conclusions can be drawn, a comparison of the 2S10 versus the 2S12 and the visualization of the production line schedule. It is important to understand that all the calculations are based on one ramp up scenario at rate X2 = 6,06 AC/month. This rate is choses because this is an average rate that differs enough to give some new insights compared to the existing rate and lay out of the line. Also, at this rate the synchronization is after 3 weeks, which shows the impact of longer synchronization after a 'long time'.

An overview of all the different tabs of the Excell file is shown in Figure 10, and in the first tab "intro" in the excel file.



Intro | Input&Output | X2Information | Input_Process times | InputTAKTtimes (basis) | X2_2S10_CALC | X2_2S12_CALC | Balance 2S10 | Balance 2S12

This model is created by Eva Labrujere during an internship with AIRBUS in the period of april - juli in 2014. The assignment is done under the supervision of Arun Choteani, Christian Hennecke and Guus Langenhuysen at the OEDK Industrial Cell responsible for the production line of the WUC for the A350. This model exists of Input cells, calculations, Output cells and a visualization of the production schedules at ramp up rate 6,06 AC/month for both the 2S10 and 2S12 shift models. A suporting report describes the model more in depth and it is therefore adviced to read this report when working with the model.

1. Intro

In total the model exists of 9 different tabs. Their use is explained in this tab introduction.

2. Input&Output

In the tab "input and output" the results of the calculations of the 2S10 and the 2S12 are given

3. X2Information

In the tab "X2Information" some calculations are done and show the occupation of the machines, and the amount of machines needed when ramping up to rate X2. This is done by a static calulation, so these numbers are checked later in the model.

4. Input_Process times

In the tab "Input_Process times" all the input for the production of the WUC is given. So the producion times and the shift models.

5. InputTAKTtimes (basis)

In the tab "InputTAKTtimes (basis)" all the TAKT times are calculated in order to balance the line and the shift models.

6. X2_2S10_CALC & X2_2S12_CALC

In the tabs "X2_2S10_CALC" and X2_2S12_CALC" al the calculations for the schedule are done. This tab exist of input and output tabs. The working principle is explained in the report.

7. Balance 2S10 & Balance 2S12

In the tabs "Balance 2S10" and "Balance 2S12" the visualization of the production line is given. Here it is possible to see the CT, the WIP, the staring and ending of processes. Next to this the occupation of the moulds and the total CT is indicated by arrows.

Figure 10: explaination of the model

8.1 THE INPUT

All the previous discussed input parameters are taken into account in the model, but where and how will be discussed in this chapter.

8.1.1 INPUT SHEETS

In the tabs "Input_Process times" and "InputTAKTtimes (basis)" some of these general input can be found. In the tab "Input_Process times" all the input for the production of the WUC is given. So the producion times and their shift models. In the tab "InputTAKTtimes (basis)" all the TAKT times are calculated in order to balance the line and the shift models.

8.1.2 REFERENCE NUMBERS

Next to the input sheets, a method to add automatically compare the passing hours in the 2S10 model and refer this moment in time to the 3S18 model is developed. This is done by the so called reference numbers.

The schedules are drawn by calculating the starting and ending times of all the different processes while taking the shift model into account. Reference numbers are used to be able to compare the end of one process in 3S18 to the same moment in time at the 2S10. So the reference numbers make it possible to compare starting and ending times in the different shifts models. An example is given in Figure 11.

	Montag																							
2S10									F								S							
	0	0	0	0	0	0	0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3S18	N								F								S							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

	Dienstag																							
2S10									F								S							
	16	16	16	16	16	16	16	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
3S18	N								F								S							
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

	Mittwoch																							
2S10									F								S							
	32	32	32	32	32	32	32	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
3S18	N								F								S							
	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72

Figure 11: reference numbers to calc starting and ending times

In Figure 11 the reference numbers can be seen.

<u>Example:</u> To give an example, look at the 1st hour of the 3th shift on Dienstag. In the 2S10 model, in total 25 available hours have passed, whereas in the 3S18 model 41 hours have passed. If the next process up will be a machined process (automated), the 3S18 model will used. If this process takes 9 hours from starting until the end, there will have passed 9 available hours in the 3S18 model, so now the point in time can be referred to the number 50, but in the 2S10 model a lot less available hours are used. This can be seen by looking up the reference number vertically in the 2S10 row above the number 50 given in the 3S18 model. As can be seen, this reference number is 32. This means that if the next up process will be a manual process, the amount of time for this process should be added to 32hours, to look up the new point in time. An overview of the outcome of these calculations will be shown in the following paragraph.

8.1.3 PROCESS TIMES

	Product 1 = MSN30LH				
	L1 - Start process - CA	L1 - Start process -2S1	L1 - Start process -3S1	L1 - End process -2S1	L1 - End process -3S1
		0	0	0	0
Automated Tapelaying (X1)	330	0	0	31	47
Vacuum Bagging (Skin) (X2)		31	47	40	64
Vacuum holding cycle (X3)		40	64	48	72
Autoclave cycle (1) (X4)		48	72	51	83
Cooling after 1st. Autoclave (X5)		51	83	57	89
Debagging (Skin) incl. reference hole drilling (X6)		57	89	66	106
RJ Thickness measurement (X7)		66	106	69	109
skin preperation (X8)		69	109	73	113
str pos on skin & vacuum bagging (X9)		73	113	86	158
sync = flex for autoclave	22	86	158	100	180
Autoclave (2) (X10)		100	180	111	191
Debagging (Skin + Stringer) (X11)		111	191	120	208
emoulding (Stringer and ancilliary Tools + Skin Demoulding) (X1		120	208	142	238
Delivery time buffer	48	142	238	160	286
Stringer prep (X13)		71	111	100	180
Stringers (Pressforming) (X14)		49	81	71	111
Laying stringers + cutting + scrapping (X15)		32	48,5	49	81

Figure 12: output, process times

Now the reference numbers are set, the different processes and there times can be calculated. In Figure 12 the different processes are shown in the first column. In the 3 – 6th columns, all the reference times are calculated. In column 3 and 4 the starting times are shown, in column 5 and 6 the ending times per process are shown.

The lookup of these reference numbers, introduced in the previous paragraph, is done by making use of the Horizontal Lookup function in Excel (HLOOKUP). This function enables the lookup of a number in a table in the referring column of the given number. These numbers are shown in the columns 3 until 6.

It can be seen that the ending of one process, is the start of the process next up. This is because one of the objectives is to limit the amount of buffers and to have a minimum cycle time. Only for the autoclave cycle this does not count. This is due to the fact that one of the objective is to synchronize the autoclave (green lines). To enable this, a buffer is introduced. The size in time of this buffer is shown in the blue box, and the buffer is always taking place before the second cycle.

Another buffer is added in order to deliver in TAKT. This means that when the product is finished, it has to wait a certain amount of hours, before the delivery will take place.

Also it is good to understand that the last three columns depict the stringer production which is parallel to the skin production but ends just in time before going in the autoclave with the skin. This explains the different reference times.

8.1.4 ASSUMPTIONS

The model that is found is based on a few assumptions.

1. The boundaries of the production line are set around the acclimatized area, so only the production of the WUC is considered
2. The stringer production is simplified
3. The transport is simplified and transport time is added to the production times of the processes (amount of cranes or AGV available is not limited)
4. The models of 2S10, 3S18 and 2S12 are based on the schemas as shown in the Excel file (Calculator to balance lines)
5. The synchronization of the line (the line balance) is set to be within 3 weeks
6. The process times are set as listed in the tab "Input_Process times"
7. The autoclave must be synced → there is a buffer before the autoclave
8. The CT is an integer amount of TAKT → The production line works with conWIP → there is make up time at the end of the process (time buffer before delivery)
9. The TAKTs are rounded at complete hours or complete shifts
10. Automated processes work in a 3S18 shift model AND manual processes can only work in a 2S10 or 2S12 shift model.
11. All the processes need to be finished before the next process can start
12. The start and the delivery of the process is in TAKT

8.2 THE VISUALIZATION

Knowing all the starting and ending times for the balanced production line, the schedule can be drawn. This done in the tabs “Balance 2S10” and “Balance 2S12” for the different shifts. An example of this schedule is shown in Figure 13.

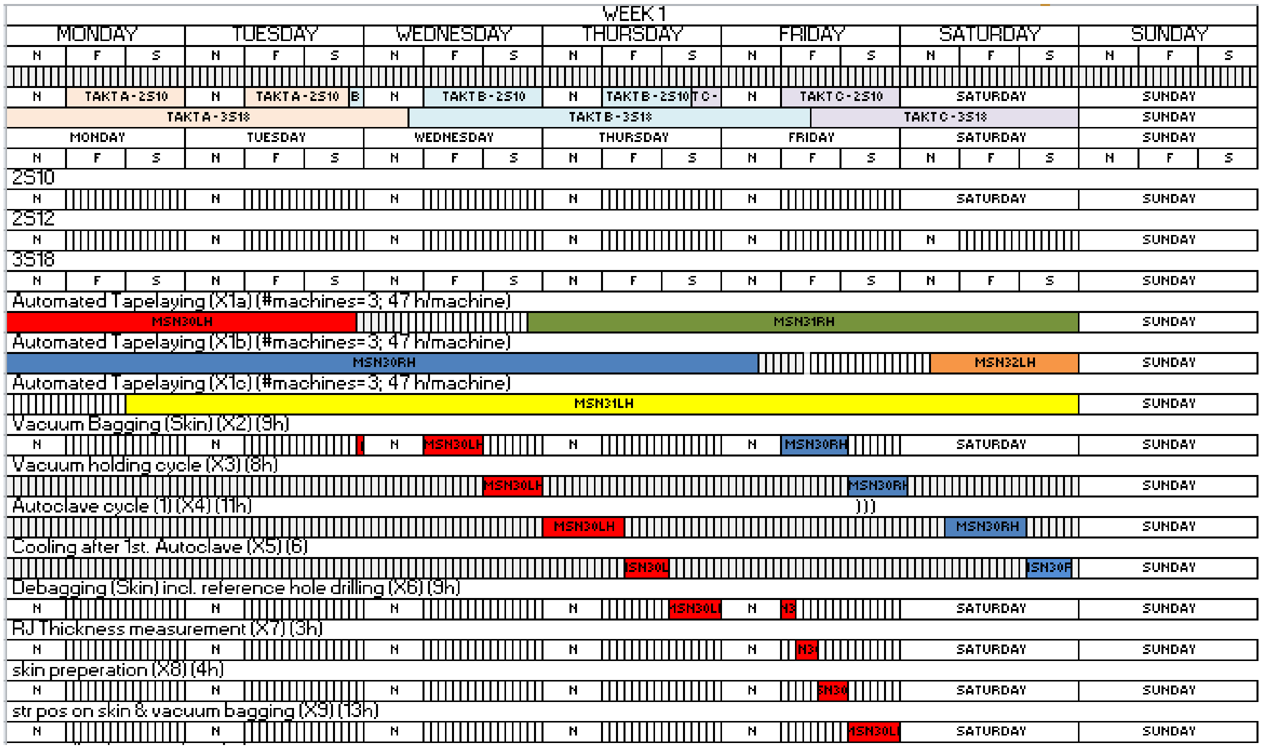


Figure 13: an example of a schedule for rate X2

In the first row the number of the week is given, the day of the week and the shifts. In the rows further down, the different TAKTs per shift model is showed. More down, in the lines with the colored blocks are the different process steps, where the colors indicate different products. The products are moving from the first row down to the bottom through the processes regarding the shift model.

8.3 THE OUTPUT TABLES

Next to finding these ending and starting times, some calculations are done in order to draw conclusions and get an insight in the production line.

The output table that gives most information is shown in Figure 14. This table shows the output of the outcomes of the calculations on production at rate X2 (=6,06 AC/month) with the availability of the 2S10 and the 3S18 shift model.

Notice: This is not an optimal solution, make some changes to the layout

OUTPUT

	MSN30LH	MSN30RH	MSN31LH	MSN31RH	MSN32LH	MSN32RH	MSN33LH	MSN33RH	MSN34LH
TAKT (AC/month)	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06	6,06
# products/week	2 2/3	2 2/3	2 2/3	2 2/3	2 2/3	2 2/3	2 2/3	2 2/3	2 2/3
$TAKT_{2S10}$ (hours)	30,0	30,0	30,0	30,0	30,0	30,0	30,0	30,0	30,0
$TAKT_{3S18}$ (hours)	54,0	54,0	54,0	54,0	54,0	54,0	54,0	54,0	54,0
CT_{min} (TAKT)	5,7	5,6	5,2	5,7	5,7	5,2	6,1	5,4	5,7
CT_{Sync} (TAKT)	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
WIP (parts)	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
t_{au} desired (TAKT)	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0
RR, LL or LR, RL	LL & RR	LL & RR	LL & RR	LL & RR	LL & RR	LL & RR	LL & RR	LL & RR	LL & RR
Sync autoclave 3S18 (hours)	22	45	51	22	46	46	27	46	22
Make up time 3S18 (hours)	48	29	48	48	24	53	24	41	48
Make up time 2S10 (hours)	68	67	84	68	68	83	68	77	68
Sync time (weeks)	3	3	3	3	3	3	3	3	3
Sync time (# products)	8	8	8	8	8	8	8	8	8
Flex time between tapelayor (hours)		23	23	23	23	23	23	-	-
Cycle time 2S10 (hours)	160	160	158	158	158	160	158	158	160
Cycle time 3S18 (hours)	286	286	286	286	286	286	286	286	286

Figure 14: Output table

The first row shows the 9 different products that are taken into account for this model. It is chosen to show 9 products because synchronization is taking place after 8 TAKT and thus just before starting producing a product for the 9th time. This means that the 1st and the 9th product are synchronized and should have the exact same parameters. The other rows show more information, which can be studied by the interested.

Hightlights to point out

It is interesting to discuss row "CT_{Sync}". It is shown that the cycle time of all the products in order to sync (both the delivery time as the autoclave) is 7 TAKT. When comparing this with the fasted CT that can be reached, it is shown that around 1,5 TAKT on average is lost due to synchronization needs. Also, the row named tau is interesting to study. Here it is shown that the time between the first autoclave and the second autoclave is synchronized with the buffers up to 2 TAKT.

In the coming paragraphs all the other output as discussed before is shown.

8.3.1 #MACHINES

The total amount of machines needed to ramp up to the desired rates are shown in tables like the illustration in

Figure 15.

# of machines per process	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
	3	1	1	1	1	1	1	1	1	1	1	1	1	1	2

Figure 15: #machines

Also the amount of machines can be seen by studying the drawn schedule as illustrated in Figure 13.

8.3.2 #BUFFERS

The size in time of the buffers is firstly shown in the blue cells as shown in Figure 12.

Next to these calculated and planned buffers, some unforeseen time buffers exist. In these cases the next process cannot start jet, while the previous process has ended. This can be caused by the fact that there are two different shift models. These buffers can be found by comparing the differences in the number of starting and ending times as shown by Figure 12. This is not a convenient way of tracking these buffers, so this comparison should be done by the model.

Also in the visual schedule an overview of the amount of machines can be distracted.

8.3.3 #MOULDS

The first impression for the amount of moulds could be drawn by taking the WIP into account. The amount of processes for which the moulds are used includes almost all processes, therefore this can be taken as a first educated guess.

Also the occupation of the mould can be shown in the schedulde. In Figure 16, the release of the mould is depicted by the start of the arrow and the assignment of the mould to the new process by the end of the arrow. The usage times and amount of mould could differ due to the fact that the mould will be available before the delivery buffer and has therefore a shorter cycle time than the products.

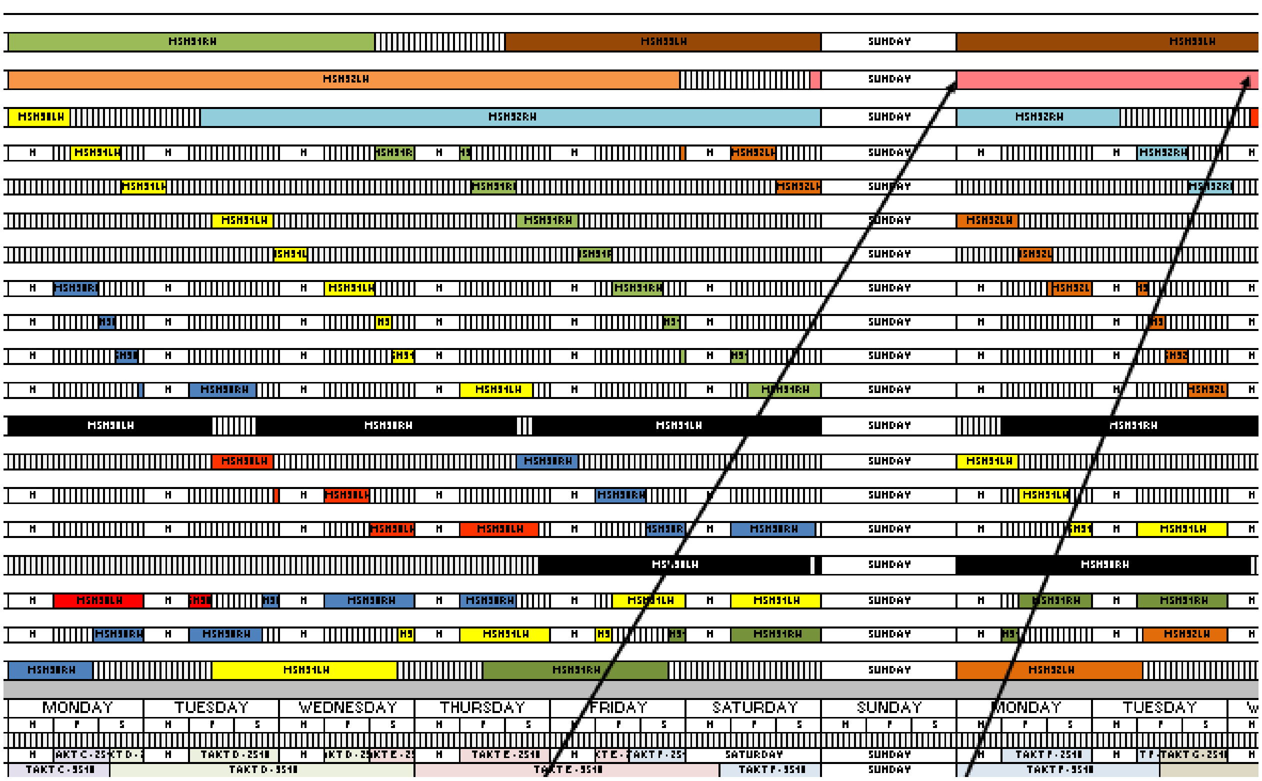


Figure 16: black arrows indicate the amount of moulds

8.3.4 Total CT

The total cycle time could be best shown by the output table as shown in Figure 14. In the lines CT_{min} and CT_{sync} the cycle times per product can be read. CT_{min} indicates the shortest cycle time possible, releasing the constraint to balance and deliver lean. The rows with the CT_{sync} are all the same and are an indicator for the rate. In this case 7 TAKT.

Also the CTs can be shown in the schedule, of which an example in shown in Figure 17. Although this picture is taken in a very small zoom, the back lines are visible. The differences in slopes of the black arrows indicate the speed of the product through the production line. The vertical colored line indicates the ending of the corresponding product.

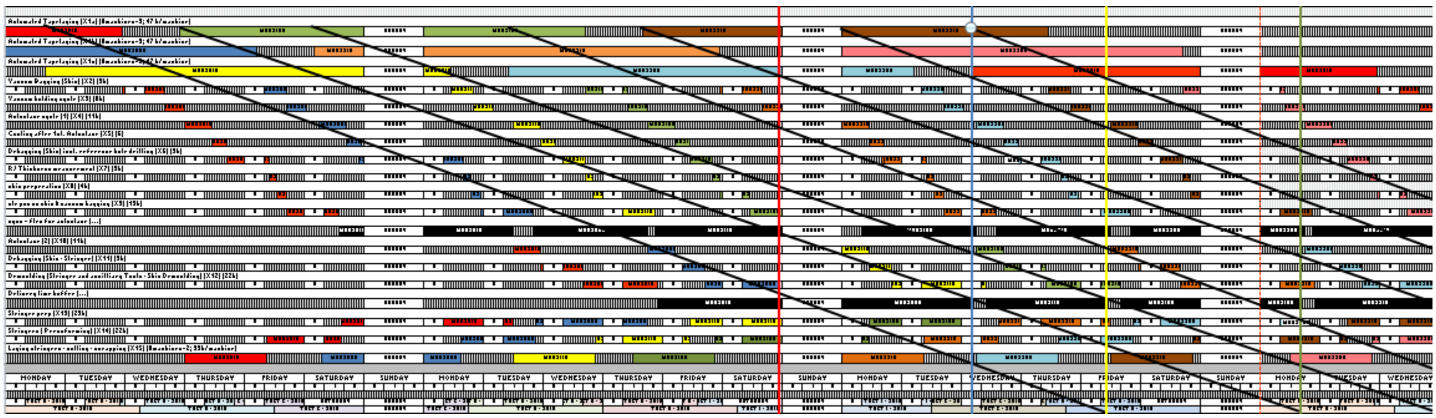


Figure 17: cycle times per product

8.3.5 WIP

The work in progress can be found in the output table and is calculated by formula (3).

8.3.6 Buffer times

The buffer times are summarized in the output table, depicted by “Make up time 3S18 (hours)” and “Make up time 2S10 (hours)”. Also the size of the buffers can be found in the blue cells mentioned earlier and shown in Figure 12.

In the schedule the buffers are indicated by the black blocks.

8.3.7 Sequence: Start and ending times

The starting and ending times can be seen best in the visualization. The ending of the processes after the buffer are shown by the vertical lines mentioned in Figure 17.

8.3.8 The check boxes

To compare the two different scenarios when synchronizing the 2S12 or the 2S10 with the 3S18 models, a look at the check boxes could bring answers.

The checkboxes are designed to get a good overview of the correctness of the productionline. Whe all the boxes are TRUE it means that the calculations that are done in order to get the reference numbers, are in line with the desired outcomes. If there are FALSE statements it means that some layout in the line need to be changed. There are a few different possibilities for this, and not one general consult could be given. But the advantage of building in checkboxes is that a few of these checks are done automatically.

When looking at Figure 18, it can be seen that there is one FALSE statement. This statement checks whether or not all the processes start after the end of the previous product in the same process step. If not, the production line should be designed with more machines. Also, the checkbox checks if at a

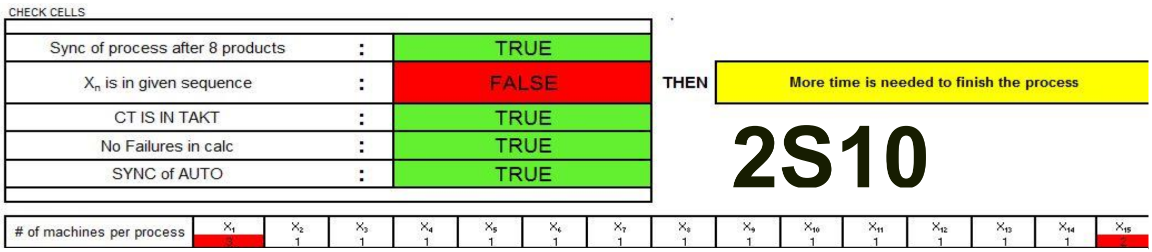


Figure 18: check boxes for 2S10

product level the start of the new process in the sequence is scheduled after finishing the previous process. An error would mean that in practice the process should start when the product can not be there.

When looking into the schedule as illustrated by Figure 19, the origin of the specific failure mentioned, can be explained.

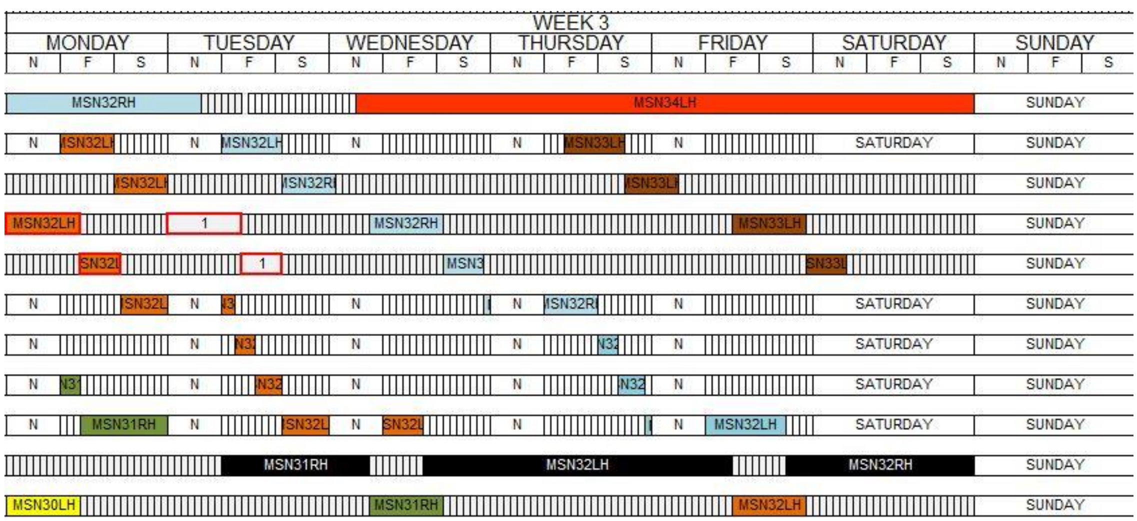


Figure 19: failure in scheduling

In the figure it can be seen that the 5th process fails. It is supposed to take place in the orange block framed by the red borders. But when looking at the previous process, it can be seen that by the time this process should start, the two previous processes have not been finished. This means that in this lay out the schedule is not correct. It is supposed to take place like this, in order to synchronize the autoclave in TAKT. A solution for this problem could be found in a few different aspects.

NON-inTAKT start of the process

When the Tapelayor machine could start earlier (maximum 23 hours in the 2S10 case), it could fore come the clash. But when this is done, this specific product is not produced in TAKT.

Shorten one of the previous processes
A solution could lie within improvement of the prior processes, in order to have the previous ones finished in time to sync the autoclave.

Increase the CT
It could also be a solution to increase the total CT with one, so to 8 TAKT. This means that the buffers will be longer and that the WIP will increase with one. If the WIP will increase the amount of moulds needed at minimum will also increase. So this is not a feasible solution.

Work in the 2S12 model
What could also be a solution is working in the 2S12 model instead of in the 2S10 model .the following paragraph is devoted to this advantages and disadvantages of this case scenario.

8.4 COMPARISON OF THE 2S10 SCENARIO WITH THE 2S12 SCENARIO

When comparing the two different schedules that will follow from the restrictions due to constraints, a few conclusions can be drawn.

8.4.1 TAKT TIMES

First of all when synchronizing the 2S12 and the 3S18, 6 rates are found, in comparison to 4 rates for the 2S10. The two extra rates that are found when sync 2S12 and 3S18 are; rate 6 5/6 and 13 2/3. These two rates synchronize within 1 week. This means that the standarization cycle is shortened. This gives an advantage to produce with the 2S12 shift model in the ramp up phase.

8.4.2 OUTPUT BOXES REVIEWED

The CT
As shown in the output boxes of the 2S12 scenario model, the CT for the synchronized autoclave is not changing when working with the 2S12 shift model. But when looking at the minimum found CT, it can be seen that the difference between the maximum CT_{min} of all the products found is a lot lower that the maximum found CT_{min} for the 2S10 scenario. This means that when it is possible to decrease one of the processes the total CT will decrease. The WIP will also decrease with 1, which means that 1 mould less is needed for the production line at this rate.

Buffertime for the autoclave
If it could be possible to downsite the time between the two autoclave cycles to 1 TAKT, the total CT will be decreased as a result. The numbers in the output table show that the buffers of the autoclave are almost one TAKT; 46 hours as a minumum. This means that when it could be achieved to decrease the processes in between the autoclave cycles by 8 hours in total, the tau can be decreased to 1 TAKT.

8.4.3 CHECK BOXES

Overall it could be said that working with the 2S12 shift model, enables the production line to produce at rate 6,06 while synchronizing the autoclave and using a minimum of 7 moulds. This can also be found in Figure 20, where all the statements are true.

CHECK CELLS

Sync of process after 8 products	:	TRUE
X_n is in given sequence	:	TRUE
CT IS IN TAKT	:	TRUE
No Failures in calc	:	TRUE
SYNC of AUTO	:	TRUE

2S12

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
# of machines per process	3	1	1	1	1	1	1	1	1	1	1	1	1	1	2

Figure 20: check boxes for 2S12

8.4.4 OUTPUT TABLE

When looking at the differences when producing with the 2S10 model and the 2S12 model Figure 21 could be studied best. This figure shows the differences between the two models when all the input constraints are met.

Input X2 6	2S10
rate (AC/month)	6
# products/week	2 2/3
TAKT2S10 (hours)	30
TAKT3S18 (hours)	54

Input X2 6	2S12
rate (AC/month)	6
# Products/Week	2 2/3
TAKT2S12 (hours)	36
TAKT3S18 (hours)	54

Output X2 6	2S10
CT Sync (TAKT)	8
Cycle time 2S10 (hours)	190
Cycle time 3S18 (hours)	340
Make up time 3S18 (hours)	
Min	24
Max	53
WIP (parts)	8
Sync time (weeks)	3
Sync time (# products)	8
Sync autoclave 3S18 (hours)	
Min	76
Max	105
Time waisted to sync 3S18 (hours)	153

Output X2 6	2S12
CT Sync (TAKT)	7
Cycle time 2S12 (hours)	190
Cycle time 3S18 (hours)	286
Make up time 3S18 (hours)	
Min	46
Max	51
WIP (parts)	7
Sync time (weeks)	3
Sync time (# products)	8
Sync autoclave 3S18 (hours)	
Min	46
Max	51
Time waisted to sync 3S18 (hours)	99

Figure 21: comparison of 2S10 with 2S12

As shown in the figure, the biggest difference is found in the CT. Working with the 2S10 scenario forces the production line to have bigger time buffers in order to be able to synchronize the autoclaves. This also leads to the increase of 1 mould compared to the 2S12 scenario.

9 CONCLUSIONS

9.1 GENERAL FINDINGS

The general findings when creating a schedule are listed in Figure 22: learning lessons.

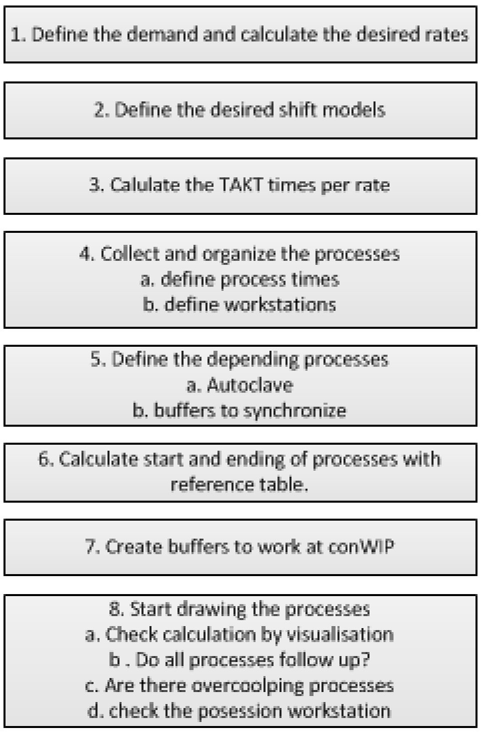


Figure 22: learning lessons

When the other ramp up rates are calculated, this check list, next to the model can be used to start balancing the line.

9.2 THE 2S10 VERSUS THE 2S12 SHIFT MODEL

Studying the two different scenarios, lead to some main conclusions. The advantages of working with the 2S12 is that the amount of available production rates in order to balance are more for the 2S12 model. There are two extra rates available who synchronize within one week, which is also a big advantage. Next to this, the CT can be increased easily; with 8 hours of improvement in the processes only. This will have its influence on the amount of WIP and therefore the amount of moulds. On the other handside is the biggest disadvantage of the 2S12 model, that the workers have to work on Saturday.

Nevertheless the advice that follows from this research is that from a production perspective it would be best to work with a 2S12 shift model.

9.3 RAMP UP SCENARIOS

Fur the future ramp up scenarios it can be said that the rates that can be reached are 4 5/9, 6, 9 and 12 1/8. And in the 2S12 scenario also the rates 6 5/6 and 13 2/3 can be reached. In order to give the exact prognosis on the amount of machines a new schedule has to be drawn.

10 RECOMMENDATION

To end this research a few next steps are recommended. As to the scope of the research it would be recommended to do a prognosis that includes the use of all the tools that are excluded in this research. These are the AGVs, the Cranes and the stringer tooling. Also regarding the scope, the whole production process of the stringers and the production processes in the finishing area should be studied more into detail.

Next to this, it is advised that in order to calculate the ramp up rates, the model should be automated. This will allow making changes at the input parameters while deriving knowledge for the future lay out of the production process.

Last it is advised to make a business model in order to be study the impact of the set input constraints. This research is based on the constraint that the autoclave should be synchronized, which results in a lot of extra time in the cycle time, and therefore in the increased future investment in moulds. In order to give an educated opinion about this decision parameter, the costs for the extra time and extra moulds versus the non-synchronized autoclaves should be taken into account.