AUTOMATING A PRODUCTION CELL

Case: Sisu Axles

Bachelor's thesis

Automation Engineering

Valkeakoski 23. November 2012

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ABSTRACT

Valkeakoski
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ABSTRACT

This thesis was commissioned by Sisu Axles, a manufacturer of heavy duty axles. The object of the project was to determine the current status and operational limits of a differential casing manufacturing cell (TPKS), to produce improvements to the process flow, and to help with the investment decision regarding the machinery.

Background data for the project was gathered during multiple visits to the production cell during the spring and summer of 2012. Information was mainly gathered by interviewing the personnel operating the cell and members of management. The current process and material flow were studied *in situ* and different production phases were carefully timed and analysed. The current production equipment and machinery were examined for a better understanding of the requirements of the project.

Based on the data collected, different machinery configurations and layouts were studied. In a number of meetings and e-mail correspondence with different CNC machine, industrial robot and measuring device suppliers the equipment available was surveyed and their costs examined. Since the accusation process is still open, no bids are published in this study.

The data was also used for estimating new production capabilities and estimate payback times.

Analysing all the data revealed that automation is needed to increase productivity and allow unmanned runs. Additional turning capacity is required and processes redefined and simplified.

With all the data collected, the company can proceed in the automating project by planning their budget and applying funds for it. The data collected gives a good overview to the costs structure included and the thesis shows the issues that needs to be taken into account when making the final decision.

Keywords machine automation, process flow, automated measuring

Pages 50 p. + appendices 13 p.

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TIIVISTELMÄ

VALKEAKOSKI
Automaation koulutusohjelma

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TIIVISTELMÄ

Tämän lopputyön tilasi Sisu Akselit Oy, Hämeenlinnalainen raskaita akselistoja valmistava yritys. Työn tavoitteena oli selvittää tasauspyörästönkotelon valmistussolun (TPKS) tuotantokapasiteetti ja tutkia sekä prosessin, että laitteistokannan parannusmahdollisuuksia. Työn pohjimmaisena tarkoituksena oli koota taustatietoa tukemaan solun investointipäätöksiä.

Taustatutkimus toteutettiin keväällä 2012 ja ymmärrystä syvennettiin työsuhteessa kesän ja syksyn aikana. Materiaali kerättiin pääsääntöisesti haastattelemalla yrityksen henkilöstöä ja laitteistotoimittajia. Nykyiseen toimintamalliin perehdyttiin tarkkailemalla solun toimintaa ja kellottamalla prosessin osavaiheita.

Kerättyyn materiaalin tukeutuen selvitettiin mahdollisia laitteistokokoonpanoja haastattelemalla - kasvotusten, puhelimitse tai sähköpostitse – laitetoimittajia eri osa-alueilta. Haastatteluilla syvennettiin ymmärrystä työstökoneista, robotiikasta ja mittaustekniikasta ja kartoitettiin samalla hintavaihtoehtoja.

Kellotuksissa kerättyä tietoa hyödynnettiin apuna arvioitaessa eri laitteistovaihtoehtojen suoritusarvoja.

Eri laitteistovaihtoehdoista laadittiin takaisinmaksusuunnitelmat.

Tutkimuksen tuloksena havaittiin, että automatisoinnilla on saavutettavissa huomattava tuotantokapasiteetin kasvattaminen. Saavutettuja johtopäätelmiä voidaan hyödyntää solun investointipäätöksien tukena.

Avainsanat automaatio, tuotannonohjaus, mittausjärjestelmät

Sivut 50 s. + liitteet 13 s.

CONTENTS

APPENDICIES

1 INTRODUCTION

After two school projects and four months summer training in the summer of 2011, I approached Sisu Axles and asked if they could offer a subject for my final thesis. I was asked to find possibilities of automating and streamlining the production of their differential gear housing manufacturing cell (TPKS).

The work was started in the spring months of 2012 by first visiting the axle factory and interviewing members of management and production teams. After acquiring a basic understanding of the process flow, I concentrated on timing the production stages and examining the bottle necks in the production process. This was done during numerous visits to the production cell during April and May.

From the beginning of June to mid July I worked as a full time employee for Sisu Axles and deepened my understanding of the process and started to plan different solutions for the new process flow and equipment required. During this time calculations and estimations were made of the production capabilities of the different basic machine configurations.

The basic investment calculations were then made and various suppliers contacted regarding basic information on different measuring devices, robots and machinery. The body of the thesis text was produced during this period.

The summer holidays of Sisu Axles and their suppliers disrupted my work in mid July and the work was finally continued in the fall. During September and October multiple CNC-machinery and measuring equipment suppliers visited Sisu Axles and discussions on the possibilities of different machine configurations were held. The financial and production capability calculations were finalised and summed up by early November.

2 THE COMPANY

2.1 Sisu Axles

Sisu Axles is a producer of heavy duty axles for trucks, military vehicles and harbour equipment. The axle line-up includes both steerable and rigid axles. The company specializes in relatively low volume axles for difficult working conditions and high loads. By streamlining production and designing, modular components they can offer great flexibility and take customers special needs into account. (Ansamaa 2012)

The Sisu Axles assembly plant is located in Hämeenlinna, Southern Finland. The company serves customers both in Finland and globally. About 90% of the company's production goes to exports. Traditionally a major Finnish customer has been Sisu Trucks and recently increasingly Patria. (Ansamaa 2012)

2.2 History

The company's history lies in O/Y Suomen Autoteollisuus A/B, established in 1931 in Helsinki, and also in Vanaja trucks. During World War II the Finnish army needed trucks desperately. To meet this demand a state owned Yhteissisu Oy was, established in 1943 in Vanaja, Hämeenlinna. Later in 1981 the companys name was changed into Sisu Corporation.

Sisu Corporation lived until 1996 when it was split into several companies. The military business was turned to Patria. Sisu Terminal Systems, Sisu Trucks and Sisu Axles were sold to Partek Oyj.

The current Sisu Axles assembly plant in Hämeenlinna, next to the Patria owned old Vanaja works, was opened in 1985. At this point all axle production moved from Helsinki to Hämeenlinna.

During 1998-2008 Sisu Axles went through various changes in its organization and ownership, and finally it ended into private ownership of venture capitalists.

In the end of 2011 Sisu Axles was sold to Marmon-Herrington of Marmon Highway Technologies (MHT). Marmon Highway Technologies is a Berkshire Hathaway company serving the global heavy-duty transportation industry. Marmon-Herrington, which has its headquarters in Louisville Kentucky USA, produces axles for automotive and industrial use. The products of Sisu Axles present the heaviest models of Marmon-Herrington's product line. (Veteraanikuorma-auto seura Ry 2012.)

In 2011 Sisu Axles Oy had ca. 100 employees and sales of EUR 31 million.

Sisu Axles is an ISO-9001 and ISO-14001 certified company, and it holds AAA business rating classification.

3 ‘THE PROBLEM’ AND THE AIM OF THIS STUDY

3.1 Problem

In previous years, the production of differential gear housings was largely outsourced and depended heavily on various subcontractors. The high costs, long delivery times, inflexibility and quality issues raised by strict machining tolerances have caused problems and Sisu Axles has not been entirely satisfied with this operational model.

Lately, to lower the dependency on sub-contractors, the production of the differential gear housing cell (tasauspyörästönkotelosolu, TPKS) has been increased by operating the cell in three shifts to meet the production quota. In 2012 Sisu Axles has been able to suspend further purchases from sub-contractors.

Even with an extra weekend shift, the production capacity of the TPKS is on its limits. The weekend shift is both taxing for the operators and expensive for the company. The demand for axles is expected to grow, and to meet the future challenges decisions must be made on how to organize the production to meet these demands.

There are two basic solutions; either the in-house production must be increased and streamlined, or new subcontractors sought to replace the company’s own production. The company has set a strategic goal to produce in-house all the differential cases needed for axle production and spare part service.

Sub-contracting quotes have been requested and received from an Italian company. These quoted prices offer a good point of comparison and set the target for new production goals on Sisu Axles.

3.2 Aim

The aim of this study was to determine and document the current status and operational limits of the differential case production cell, to find out the bottle necks and to examine possibilities for enhancing productivity and raising the production capacity of the cell.

An important task was to determine which machine configuration and which machine types produce the best productivity and utilization rate - within given monetary limits. It was also of interest how the machinery, storage and work stations should be arranged to ensure an optimal material flow and good, ergonomic working conditions for the operators.

From an automation engineering’s point of view, it was also of interest to study the possibilities of automating the production line, at least partly, to allow unmanned short span production runs.

4 DESCRIPTION OF THE PRODUCTION CELL AND PROCESS FLOW

4.1 Differential gear housing

The TPKS produces differential gear housings for axle assemblies.

A differential gear divides the power, or torque, provided by the engine via a drive shaft to the wheels. While turning the vehicle, due to different turning radii, the wheels travel different distances and therefore run at different speeds. The differential gear allows the wheels to rotate at different speeds. Without a differential gear a great strain would be inflicted to the axle.

Figure 1 shows the components of typical differential assembly. It consists of:
- differential gear housing, two halves (marked as 28 in the drawing). These are the parts produced by the TPKS
- side gears (30)
- pinion gears (31)
- cross shaft aka. spider (32)
- thrust washers (39 and 34)
  (Marmon-Herrington 2009)

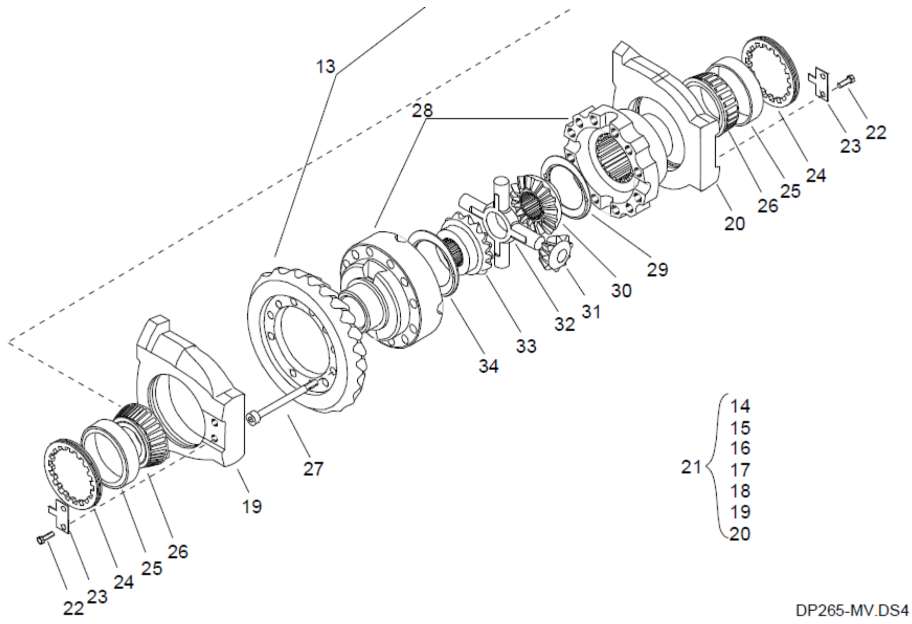

Figure 1 Explosion view of a typical Sisu Axles differential gear. (Marmon-Herrington 2009)

4.2 Production stages

The Sisu Axles TPKS (Differential gear housing cell) produces differential gear housings by machining cast iron, or cast steel, castings. The production process of a typical differential case includes the following machining phases:

– Two lathe machining runs for each half of the case to produce the basic shape required.
– Drilling of the bolt holes (A and B in Figure 2).
– Threading the bolt holes into one of the halves* (A).
– Machining of the splines in a broaching machine* (C).
– Drilling of the cross shaft holes (D). Manual assembly ('mating') of the housing halves is required before the cross shaft drilling.

*) when required.

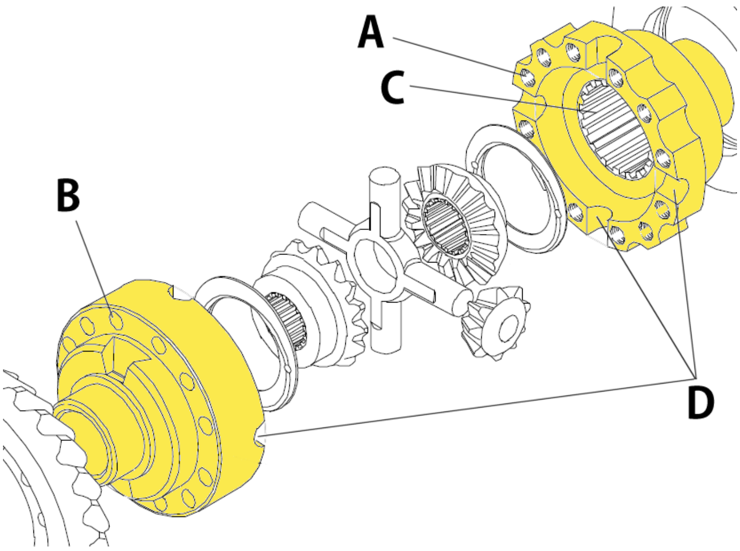

Figure 2 Typical differential gear case and the machining phases. (Marmon-Herrington 2009)

Usually, only one halve of the casing is produced at a time. After the patch is ready, they are put into temporary storage, machines are retooled and a patch of second halves are run. The mating and cross shaft drilling can be performed parallel to the second lathe run.

4.3 Personnel and their responsibilities

The common procedure in differential gear housing machining requires two lathe runs, a drilling and a threading phase, broaching, assembly ('mating') and drilling of cross shaft holes. The process requires two operators to run smoothly. One is in charge of the actual machining and takes care of the lathe, the drilling station and the broaching machine. The other worker assembles the casings for cross shaft drilling, operates the cross shaft drilling station and stamps the halves. He usually also operates the washing machine. The evening and weekend shifts are run by only one man, the lathe/drilling station operator. As there are three rotating shifts of lathe/drill operators and one shift of cross shaft driller, there are four people in total manning this production cell.

4.4 Machinery and work stations

The machinery at the differential gear housing production cell in Sisu Axles (TPKS) is comprised of two CNC-machines, a lathe and a drilling station (marked 1 and 2 in Figure 3), a broaching machine (4), a washer (5) and a cross shaft drilling station (8). In addition to these, there are also manual work stations for the deburring (3) and alignment of the housing halves (6 and 7).

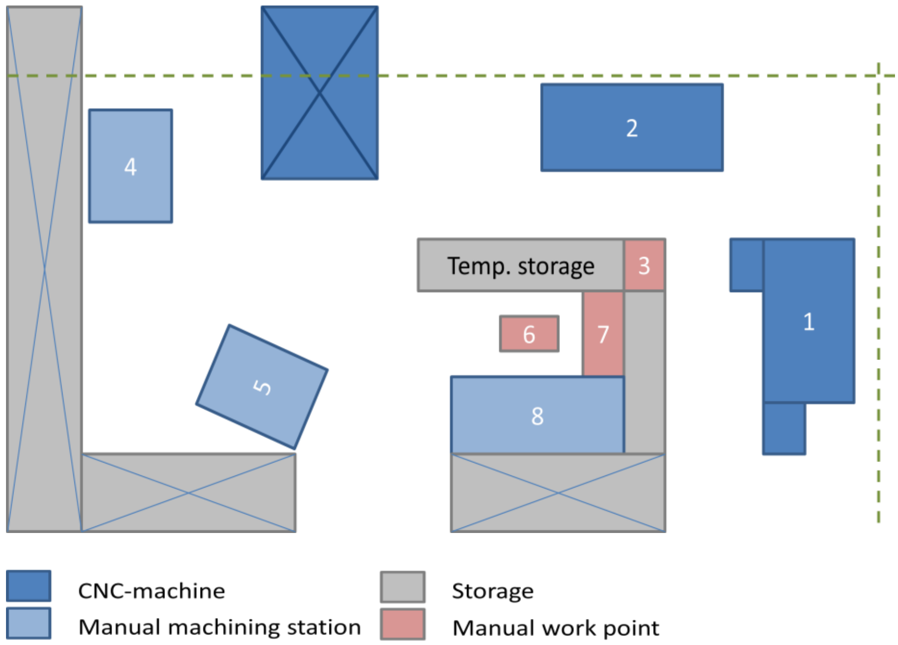

Figure 3 Machinery and works stations of the TPKS.

Leadwell LTC-35C (1, see also Figure 4) is a horizontal CNC lathe equipped with revolving tools. It has an internal tool magazine capable of storing twelve tools. It is not equipped with tools for automatic measuring of the machined parts, or hardware for monitoring the condition of the cutting tools.

Figure 4 Leadwell LTC-35C.

Machine 2 is a Dah Lih MCV1020 vertical machining station (Figure 5) used for drilling all necessary bolt holes into the housing halves and also for machining the threads as required. It is also used for various other smaller machining tasks as needed.

Figure 5 Dah Lih MCV1020.

Machine 4 is a Fellows 6A Type Gear Shaper -broaching machine used for machining inner splines (Figure 6). All products manufactured at TPKS do not require the splines and in their case this production step is omitted. Fellows 6A dates back to the 1950s and it is of old design requiring manual setup and operation. During tooling for new production runs it requires a changing of gears to adjust the produced spline count and a manual adjustment of stroke length and radius limits. This is a time consuming, multi-step procedure that requires skill and concentration from the operator.

Figure 6 Fellows 6A Type Gear Shaper.

Broaching leaves metal chips and cutting fluid on the surface of the machined parts and they need to be washed in the washer (5) before they are ready to be transferred to the assembly phase. The cross shaft drill, a Lidköping PNF 23 (Figure 7), is also of old design and nearing the end of its production days.

Figure 7 Lidköping PNF 23 cross shaft drill.

As this study started the production cell had one overhead lift to serve the lifting and transportation needs of the two operators. This was deemed insufficient and another lift was installed in early June to aid the operators and to improve the process flow.

4.5 Process flow

The process flow is represented here as material flow between the work-stations. A traditional process flow chart is shown in Appendix 5.

The process starts with conveying the cast iron blanks from storage shelves to the production cell (shown as ‘**a**’ in Figure 8). The transport crate is left as a temporary work top. The most common procedure is to machine a run of the first halves of the assembly, re-tool and run a batch of the second halves. In some cases, primarily with ring type housings such as 143-310-3611 that use the same casting for both halves, the halves are made one after the other by alternating the machining program loops.

Depending on the weight of the part, a hoist may be used for lifting the work piece. The piece is fastened to the Leadwell lathe (1) and the machining is started. In this first lathe phase the inner surfaces of the piece are machined. Also, the surfaces needed for the fasting to the second phase are levelled (Figure 9). The piece is turned around and refastened for the second machining phase. In this second phase the outer diameter of the ‘neck’ area is machined (Figure 10). See Appendix 1 and 2 for technical drawings of a typical differential gear assembly and casting. The actual measurements have been deleted from the drawing by request from the commissioner.

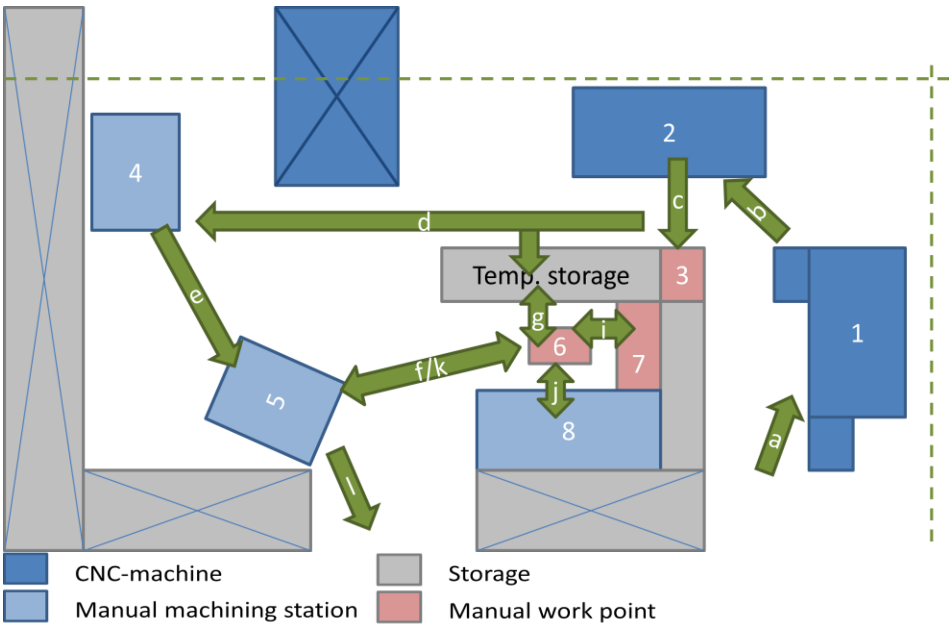

Figure 8 Process flow at TPKS.

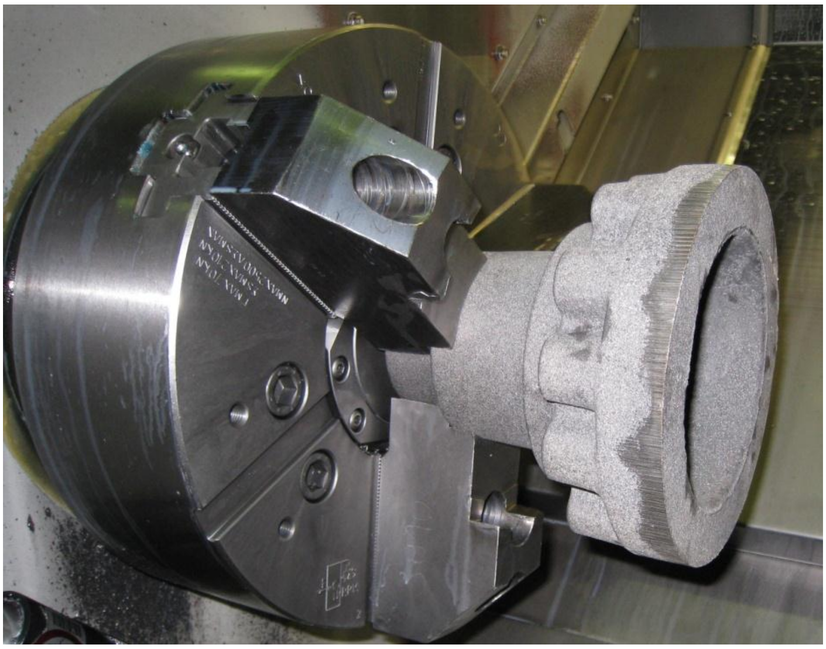

Figure 9 A new casting mounted for the first Leadwell turning phase.

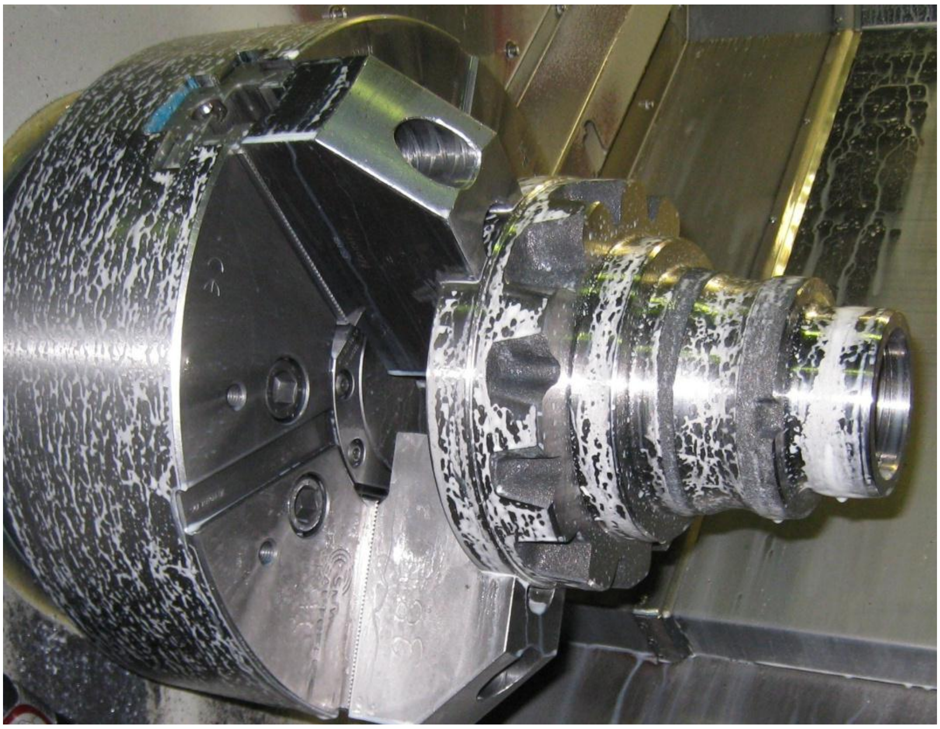

Figure 10 Machined part after the second Leadwell turning phase.

After the turning phases the piece is carried (b) to the Dah Lih machining station (2), where bolt holes are drilled and threads machined as required. A typical mounting can be seen in Figure 11. Usually, this phase is also used to run smaller machining tasks, such as rounding edges. Only one of the two halves may require the threading.

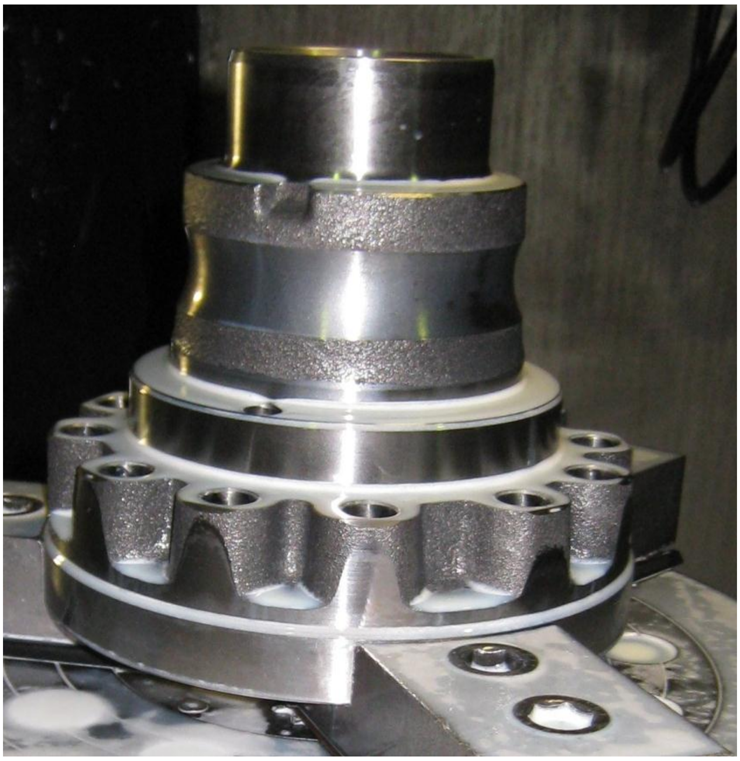

Figure 11 Bolt holes have been drilled in Dah Lih.

Ready drilled piece is lifted (c) to the deburring station (3), where the piece is inspected and all sharps edges are manually ground off. As the lifting position from the drilling station is difficult, moving of the heavier pieces may require the use of the hoist.

Depending on the type of the item worked on, it is then either lifted (d) to the broaching station (4, see also Figure 12) or straight to a temporary storage table to wait for assembly. The broaching machine is rather far away from the drilling station and the pieces are carried by hand. This can be taxing for the operators. The broaching phase leaves metal chips and cutting liquid on the parts and they need to be taken (e) to the washer (5 and Figure 13) before continuing to the assembly station.

Figure 12 Broaching.

Figure 13 Washer.

After both of the housing halves have been machined, they are assembled, or mated, in the assembly station (6). This phase requires the halves to be bolted together and the combined assembly to be lifted between different tool stands. First, the assembly is moved to a stand where the halves are pressed in line and the bolts secured tight (station 6). The alignment is checked (i, 7) in a revolving stand using a micrometer, and if required adjusted (Figure 14). The checked assembly is marked as approved and lifted (j) straight to the cross shaft drilling station (8) or back to temporary storage (i, 6 or a temporary storage table). The assemblies are heavy (up to 30kg) and the continuous lifting and moving of them causes strain to the operators. An overhead lift is available, but in many cases ignored by the operators due to its cumbersome operation routines.

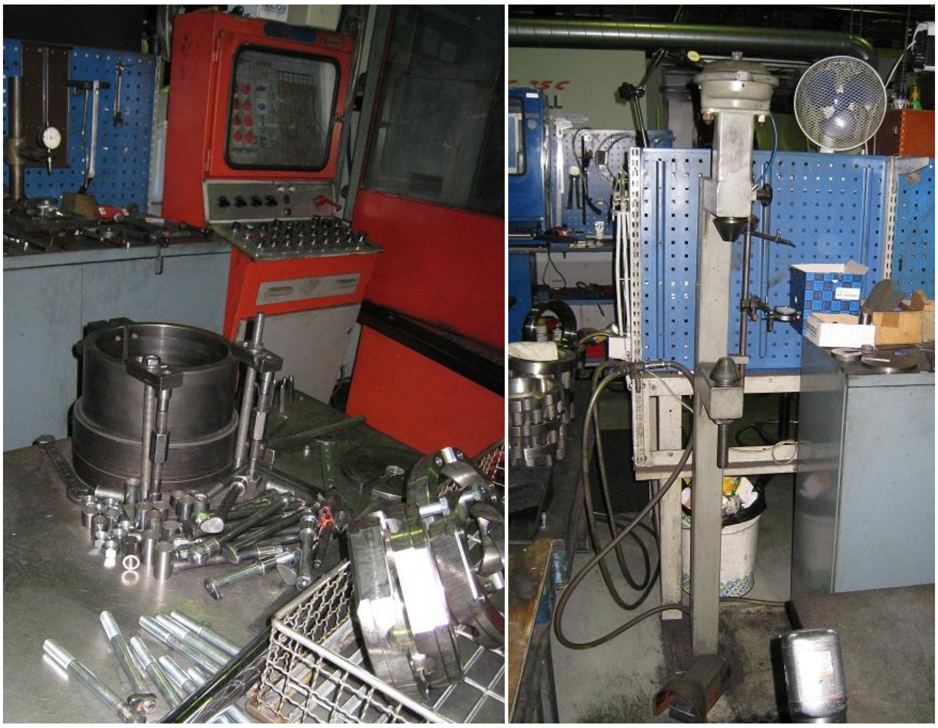

Figure 14 Alignment fixture (left) and micrometer for checking the alignment (right).

After the cross shaft drilling is completed, the part is measured in the drilling station and lifted back (j) to the assembly table (6), where it is stamped with alignment marks and a running pair number. The pair number is required for matching the halves in the final assembly phase (Figure 15).

In some cases, primarily with ring type housings such as 143-310-3611, another machining phase may be required in the drilling station (2). Then, the parts are disassembled by removing the bolts and transported (k) to the washing machine (5). After washing the housing is ready to be conveyed (l) to storage or straight into the final axle assembly area (Figure16).

Figure 15 Cross shaft holes are drilled as an assembly. Note the lining stamp and numbering. The cross shaft fit is being tested.

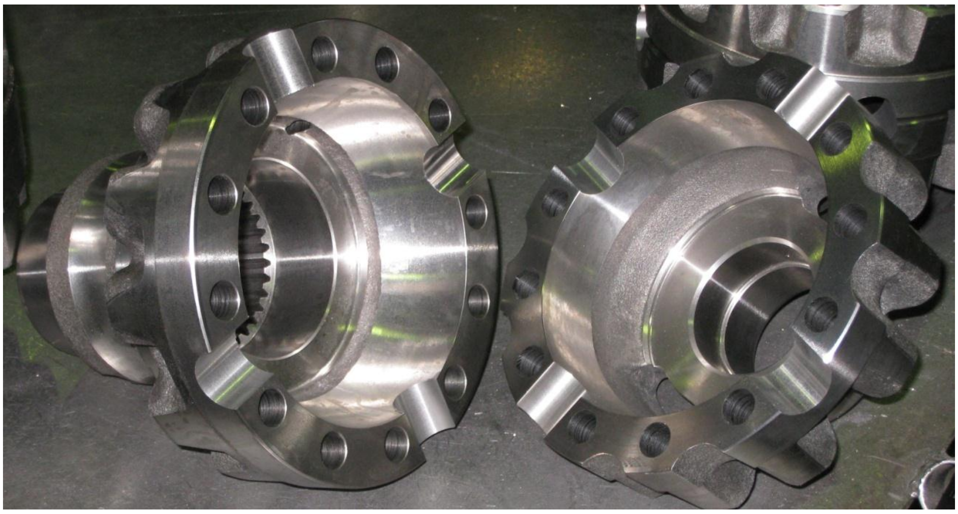

Figure 16 Cross shaft holes are drilled and the housing is ready for assembly.

4.6 Production figures of the TPKS

The 2008-2012 production figures of TPKS were examined for this study. Since the 2012 figures cover only the first months of the year, they can only be used as guidelines on estimating the total production volume of this year. 2008 was an all time record year for Sisu Axles, as well as for TPKS, and the production peaked at 5451 assemblies. The recession set for years 2009 and 2010 and the production dropped down to 2723 and 1967 assemblies respectively. The global economics revived again in 2011 and the production rose accordingly to 4044 assemblies. This timeframe of 2008-2011 offers good variation for the data of this study, as it shows the both extremes in the production figures and sets the limits where the production capacity should be aimed at. See Appendix 1 for full production figures of the TPKS during years 2008-2011.
(Sisu Axles 2012)

As the distribution of production figures between different models produced, and also the models themselves, have changed, examining of earlier years would produce wrongly balanced data on the requirements for production. So, for this study the production figures of 2011 were chosen as a benchmark. The TPKS production figures per model for 2011 are given in Appendix 2.

Since the acquisition of Sisu Axles by Marmon-Herrington expanded Sisu Axles North American markets, the axle demand can be expected to rise in the future. Therefore, the production capacity must be increased to make this possible.

In 2011 TPKS produced 14 different types of differential assemblies. Of these fourteen models seven assemblies are considered as the ‘main’ products and they represented nearly 88% of the total production. Due to the modular design of Sisu Axles production, some of these seven differential housing assemblies share the same components (machined halves and/or castings). More than one component may be machined from the same casting with a slight alteration. The number of different castings needed for the 88% of production total is only seven – remember that all housings consist of two halves that usually are not the same. When we include the lesser volume assemblies that use the same castings, the cores cast with just these seven moulds cover nearly 91% of the total production. See Appendix 4 for a complete break down of the casting and part numbers by housing model.

It needs to be note on the part numbering system used with Sisu Axles that each raw casting has its own part number. The same casting can be machined in different ways producing different parts, each with their own part number. When the machined halves are mated together they are referred to by the assembly part number. As a rule of thumb, when the second three-digit code in part number is ‘310’ the part in question is an assembly, when it is ‘311’ it is a halve or a casting.

Example 1: assembly 143-310-1621 consists of parts 143-311-3280 and 143-311-3380 which are machined from castings 143-311-3260 and 143-311-3360.

Example 2: assembly 143-310-1611 consists of parts 143-311-2400 and 143-311-2410. Both of these are machined from casting 143-311-2460.

Table 1 Differential assembly production in 2011. The main products are highlighted. *Note, part 143-311-3800 is used in multiple assemblies.

Assembly:	*Part no Side 'A'*	*Part no Side 'B'*	Assemblies produced by: TPKS	Sub contractors	Total
143-310-1611	*143-311-2400*	*143-311-2410*	70		70
143-310-1621	*143-311-3380*	*143-311-3280*	107		107
143-310-2711	*143-311-0310*	*143-311-0210*	19		19
143-310-3611	***143-311-3480***	***143-311-3490***	**642**		**642**
143-310-3811	***143-311-3810***	***143-311-3800****	**661**	**50**	**711***
543-310-1641	***543-311-3080***	***543-311-3180***	**295**		**295**
543-310-3721	***543-311-3900***	***143-311-4000***	**382**		**382**
543-310-4561	*543-311-4180*	*543-311-4290*	119		119
543-310-4611	*543-311-4690*	*543-311-4680*	83		83
543-310-4711	*543-311-4790*	*534-311-4780*	151		151
543-310-4811	***543-311-4880***	***143-311-3800****	**527**	**71**	**598***
543-310-4821	***543-311-4990***	***143-311-3800****	**205**		**205***
543-310-4831	***543-311-4980***	***143-311-3800****	**568**	**92**	**660***
543-310-5111	*543-311-5090*	*543-311-5080*	2		2
			3831	**213**	**4044**

As we can see in Table 1, the total production of all the assemblies in 2011 was 4044. As all assemblies consist of two halves, the machining requirement thus was for 8088 halves. Of these assemblies, 3831 were produced in the Hämeenlinna production facilities and 213 were outsourced and came from various subcontractors. See Table 2 below for a complete breakdown of production figures by TPKS and subcontractors per model number.

Table 2 Production of differential assembly casing halves in 2011.

Part no:	Parts produced by: TPKS	Subcontractors
143-311-0210	19	0
143-311-0310	19	0
143-311-2400	70	0
143-311-2410	70	0
143-311-3280	107	0
143-311-3380	107	0
143-311-3480	**642**	**0**
143-311-3490	**642**	**0**
143-311-3800	**1961**	**213**
143-311-3810	**661**	**50**
143-311-4000	**382**	**0**
534-311-4780	151	0
543-311-3080	**295**	**0**
543-311-3180	**295**	**0**
543-311-3900	**382**	**0**
543-311-4180	119	0
543-311-4290	119	0
543-311-4680	83	0
543-311-4690	83	0
543-311-4790	151	0
543-311-4880	**527**	**71**
543-311-4980	**568**	**92**
543-311-4990	**205**	**0**
543-311-5080	2	0
543-311-5090	2	0
Total:	**7662**	**426**

The 3831 assemblies TPKS produced out of a total 4044 manufactured adds to about 95% self-sufficiency. During recent years Sisu Axles has aimed at lowering its dependency on subcontractors. For example in 2008 the self-sufficiency rate was only around 36% in differential gear housing production. During the first months of 2012 Sisu Axles has machined all the differential cases in house by running an extra 24 hour weekend shift in addition to the two standard shifts and by machining the most used 143-311-3800 in another production cell whenever possible.

As TPKS is running annually for approximately 46 weeks (52 weeks – 4 weeks of holiday – 2 weeks of national days off) in two 8 hour shifts and one (2*12 hour) shift during weekends, the total production time, as calculated below, is roughly 4496 hours.

	Weeks	Days/Week	Hours/Day	Total hours
Normal shift	52	5	8	2080
Weekend shift	52	2	12	1248

	Days	Hours/Day	Total hours
Holidays	25	8	200
Pekkaset'	13	8	104
		Total:	304

Normal working hours:

2 operators * 2080 hours – 2*304 holiday hours = 3552 hours

Weekend shifts:
1 operator * 1248 hours –304 holiday hours = 944 hours

Total: 4496 hours

If we estimate the loss of production due to illnesses etc. to be 5% we arrive at 4271 operating hours annually.

So, the 7662 pieces fabricated in Hämeenlinna take theoretically on average 34 minutes each. To be able to stop the costly weekend shift, the average production time for one piece would need to be brought down to 28 minutes. Also, to compensate for the 426 pieces machined by the subcontractors, the average needs to be dropped down to 26 minutes.

TPKS uses three operators to cycle the three lathe/drill shifts. One starts with a morning shift, changes to the evening shift the next week and then continues with a 24h weekend shift (2 * 12 hours). After the weekend shift the operator has a one week free. So, in practice the 24-hour weekend shift costs Sisu as much as a normal week shift. The fourth person, the cross shaft machine operator, is omitted from these calculations as he works parallel with the day shift. His contribution to the overall costs was taken in consideration, and is included into the payback estimations.

5 BOTTLE NECKS

The production capacity of the TPKS was examined by timing various production stages and operations performed. These studies were conducted during the spring of 2012. To eliminate false information, the times given are averages calculated from multiple machining runs. The samples out of ordinary deviation were omitted. A record was kept of the following machining stages:
- first lathe run
- second lathe run
- drilling
- broaching
- cross shaft drilling

Also, the manual work measured included:
- mounting and handling of the work pieces
- measuring
- adjusting of machining parameters
- deburring
- mating

The clocked production times are summarized in Table 3 below. The given times represent the actual milling times. Setup, adjustment and machine tending times are not included. It was noted, that the turning times are always the longest compared to the drilling phase. Bear in mind, that turning (phases one and two) and drilling are parallel task, performed at the same time. So, the turning phase dictates the cycle time of the production cell.

Table 3 Drilling and turning time of the work pieces in the Leadwell LTC-35C, phases one and two and the drilling times of Dah Lih MCV-1020A.

Assembly	Half	1. stage (min:sec)	2. stage (min:sec)	Total lathe time (min:sec)	Drilling time (min:sec)	Total (min:sec)	The longest phase (Cycle time) (min:sec)
543-310-1642	543-311-3080	7:15	4:15	11:30	**8:40**	20:10	**8:40**
	543-311-3180	5:00	3:55	8:55	**6:25**	15:20	**6:25**
143-310-3611	143-311-3480	4:10	2:25	6:35	**5:35**	12:10	**5:35**
	143-311-3490	**4:20**	2:15	6:35	2:25	9:00	**4:20**
143-310-3811 / 143-310-4821	143-311-3800	6:50	**9:20**	16:10	6:45	22:55	**9:20**
	143-311-3810	**12:00**	9:25	21:25	9:40	31:05	**12:00**
543-310-3721	543-311-3900	**9:30**	6:30	16:00	5:05	21:05	**9:30**
	143-311-4000	5:05	8:35	13:40	**10:10**	23:50	**10:10**
543-310-4811 / 543-310-4831	543-311-4880	**11:30**	8:40	20:10	5:10	25:20	**11:30**
	143-311-3800	6:50	**9:20**	16:10	6:45	22:55	**9:20**

This leads to a poor utilization rate of the drilling station. Utilization rates are given in the Table 4 below. Also, it is worth noting that the turning phases are not of equal in length. Generally the first phase is the longest.

This has an effect on the machine configurations discussed later on this study.

Table 4 Utilization rates of the CNC machines by percentage of the longest production stage.

Part no:	Utilization rate/MAX	
	Turning (phases 1 and 2)	Drilling
543-311-3080	100 %	75 %
543-311-3180	100 %	72 %
143-311-3480	100 %	85 %
143-311-3490	100 %	37 %
143-311-3800	100 %	42 %
143-311-3810	100 %	45 %
543-311-3900	100 %	32 %
143-311-4000	100 %	74 %
543-311-4880	100 %	26 %
143-311-3800	100 %	42 %

As the production already is ran with overtime shifts the extra capacity must be found by improving the procedures and tools, not by adding the man hours.

If we compare the clocked cycle times to the average production times calculated in the section 4.6 we notice a conflict. The current cycle times in average are much less than the set 26 minute goal. This is in great deal caused by delays in manual part handling, measuring and tool maintenance. Also, the setup times, machine warming periods, etc. take a good deal from the production time. In addition, the lunch and coffee brakes cause interruptions in production. By studying the machine operating logs, it was noticed that the average utilization rate of the lathe is only about 55% during the working hours.

The broaching machine is of an old design. It is manually operated and configured, which leads to long setup times. The actual machining, or rather the time taken by it, on the other hand, does not cause major bottle necks. The tedious operating routines of the machine do seem to aggravate some operators, but it does not significantly slow down the production.

The Lidköping cross axle shaft drill is performing fast enough and does not in that sense hinder production. Thou, it is old and has recently suffered many technical problems and required long maintenance breaks. It is considered to be a threat to process that should be addressed.

The manual operations performed in the production cell are either of short duration (measuring, material handling and servicing of the tools) or run parallel to the milling (deburring and mating). These however add up and must be taken into account when determining the work load of the operators and the production capacity of the cell. We can estimate that about one and half hours of every shift is spent on warming the machines (in the morning), cleaning (evening shifts), and on lunch- and coffee breaks. Also, the setup periods while tooling for to new production runs are major time consumer. There are basically two types of tooling phases, a larger where all the major clamps are replaced and settings changed on all machines, and a smaller one, where only the CNC programmes are changed. There are in average one of both kinds of tool changes per week. The longer can take up to four hours if performed by a single operator and the shorter from 30 minutes up to two hours.

The data collected form timing of the process confirmed the previous experience, that the biggest bottle necks in the production of differential gears are the two first machining stages were the pieces are turned on a single CNC lathe. This is partly caused by delays and inefficacies in manual handling of the material.

6 POSSIBILITIES AND THE LIMITATIONS

6.1 Improved mating process

The currently used method of lining the halves in a stand and checking the alignment using a micrometre in another stand is labour intensive and time consuming. Mating and cross shaft drilling is a sole responsibility of one day shift operator.

This alignment and mating procedure of the halves can be improved. Actually, test runs of new method have already been successfully completed. This new procedure uses the lathe to drill three holes in the halves for alignment dowel pins (See typical pin arrangement in Figure 21).
(Murtola 2012)

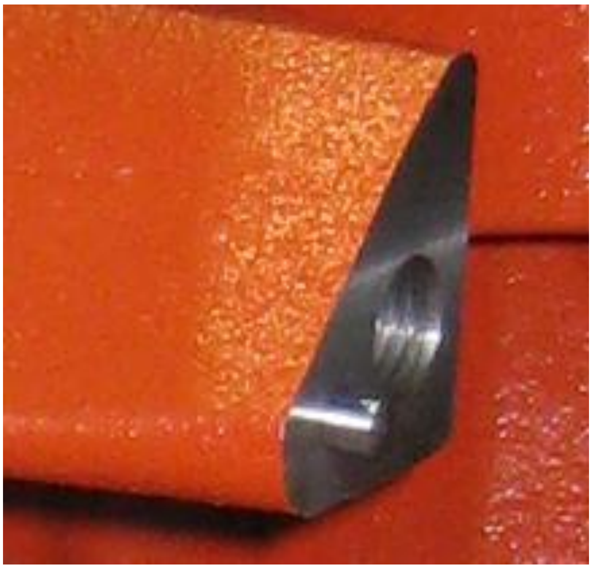

Figure 17 A guide pin as used in Sisu Axles differential cases.

Basically, during the mating only the pins would need to be installed and halves bolted together before the cross shaft drilling, removing the need for alignment and micrometre measuring. The drilling off the pin holes adds approximately one minute per casing halve to the lathe time. The following calculations take this into account.

6.2 Industrial robot

The usage of an industrial robot would minimize the production interruptions caused in the current system by the manual handling of the parts. Robots are at their best when performing monotonous, repetitive tasks. Their part handling times are predictable and performance constant over long periods, they do not need to take brakes and can operate, at least for relatively long periods, without human operators.
(Kalpakjian 2010, 1071-1076)

So, our basic concept starts with automating the part handling of the CNC-machines by adding an industrial robot to the production cell. The robot tends both the Leadwell lathe and Dah Lih drilling station. If we estimate the handling time of the work piece to be three minutes, we can give the following cycle times:

Table 5 Cycle times using an industrial robot.

Assembly	Halve	Cycle time
543-310-1641	543-311-3080	0:14:30
	543-311-3180	0:11:55
143-310-3611	143-311-3480	0:09:35
	143-311-3490	0:09:35
143-310-3811 / 143-310-4821	143-311-3800	0:19:10
	143-311-3810	0:24:25
543-310-3721	543-311-3900	0:19:00
	143-311-4000	0:16:40
543-310-4811 / 543-310-4831	543-311-4880	0:23:10
	143-311-3800	0:19:10

The average cycle time is now a little under 17 minutes. Extra three minutes would allow time for automated measuring and adjusting of the milling parameters after the turning.

If we assume that two hours of every shift in unproductive (start up, lunch breaks, etc.) the total working hours annually drops down to 3086 hours, of which 700 is performed during weekends. This would allow about 23 minute cycle times. However, this would require the workload of all the three shifts. Using just the normal morning and evening shifts would demand 18 minute cycle times. So, in theory, by optimizing the material handling the current production could be squeezed into two shifts. In practice this does not seem feasible, as there would be little room for delays or errors in the process flow.

Also, the current Leadwell 12-place tool magazine would put serious constraints on the length of unmanned runs. Since there is no room for backup tools, the unmanned production run would be limited even in optimal conditions to less than two hours.

Furthermore, the limited turning capacity would hinder all improvements in the mating process. As noted, the mating process and cross drilling now takes the full work load of a one shift. Since this is a parallel process, it is omitted from the cycle times given above. Improving the mating process would include adding dowel pins to help the alignment of the halves. The drilling of these holes would need to be done in the turning phases and would therefore add about two minutes to cycle times.

In summary, using an industrial robot would bring increase in productivity by minimizing the breaks in the process. This increase in productivity would not be high enough to allow deletion of the weekend shift and the implementation of the new process in mating which requires extra time on the lathe. In any case, even if the shifts could be discontinued, the total production capacity would be in absolute maximum. There would be no room for increase in production volumes or even for malfunctions in the manufacturing process.

6.3 Machine configuration options

6.3.1 Machine configuration using two lathes and Dah Lih

As it is previously shown, the main bottle neck in the TPKS production is the lathe turning capacity. The most obvious solution is to add a second CNC lathe to speed up the production. This would remove the biggest bottle-neck in the procedure by theoretically doubling the turning capacity.

The two-lathe configuration would offer two basic process models. Either each lathe could be used to run its own phase of the same part, or they could both be turning their own halves of the assembly at the same time.

Producing both halves in unison would seem an attractive option at the first glance. It would remove the need for temporary storage of the first halves, and mating and cross shaft drilling could run parallel to turning without delays.

The new machining times can easily be estimated from the data collected and presented earlier in the Table 3. These new times include 3 minutes for robot handling and measuring. The drilling time consists of both halves of the assembly.

Table 6 Cycle times using two lathes and a drill.

Assembly	Lathe 1	Lathe 2	Drill
543-310-1641	0:14:30	0:11:55	**0:17:05**
143-310-3611	0:09:35	0:09:35	**0:10:00**
143-310-3811 / 143-310-4821	0:19:10	**0:24:25**	0:18:25
543-310-3721	**0:19:00**	0:16:40	0:17:15
543-310-4811 / 543-310-4831	0:23:10	**0:19:10**	0:13:55

This gives average cycle time of eighteen minutes per *assembly*, average of nine minutes per halve.

However, since the milling times of assembly halves can vary greatly, this would result in unbalanced utilization rates. Also, once again we must consider Leadwell’s limitations. The 12-space tool magazine has no room for spare tools. The length of the unmanned run would be short and not exceeding two hours even in most favourable conditions.

Producing of the both halves of the casing at the same time sets demands on the measuring device needed. Either there must be two independent stations or one capable of measuring different halves without tooling or manual adjustments in between.

Also, by tending all the three machines and the measuring station(s) required, the robot could turn out to be the slowest link. Another problem is the reach of the robot. Tending three machines and a separate measuring station(s) requires a robot with a long arm. This generally means heavier and more expansive robot as well. One option would be to use track for the robot, but this brings considerable extra cost to the budget.

The floor space required by the three CNC-machines, robot, measuring station(s) and transport systems is considerable. Conveyors and pallet systems are further studied in the chapter 6.5.

Since now, two lathes are producing halves for the drilling station (Dah Lih), the drilling station sets the cycle time in two cases out of five. By dividing the phases to their own lathes we can expect to achieve the following utilization rates (Table 7) between the lathes and drill:

Table 7 Utilization rate of the three machining centres.

Assembly	Lathe 1	Lathe 2	Drill
543-310-1641	85 %	70 %	**100 %**
143-310-3611	96 %	96 %	**100 %**
143-310-3811 / 143-310-4821	78 %	**100 %**	75 %
543-310-3721	**100 %**	88 %	91 %
543-310-4811 / 543-310-4831	**100 %**	83 %	60 %

As we can see, the longest machining time varies now from a part to part between different stages. As the cycle time depends on the longest phase the utilization still remains rather poor. This is still far from optimal. There is much to be gained by optimizing the machining and handling order of the halves by model, but this falls beyond of this study.

6.3.2 Machine configuration using two lathes with revolving tools

The Lidköping cross shaft drill is nearing the end of its service life and replacing it with a new machine must be taken into consideration. The new drill would offer better performance, reliability and easier usability – even possibilities for automation.

As the Leadwell is equipped with revolving tools (drills), the Dah Lih's tasks could be combined to the lathe runs and by doing so free Dah Lih to be used as the new cross shaft drilling station. Leadwells 12-space tool magazine has no room for all the tools needed for both of the turning phases and drilling. This only leaves the possibility of running a batch of halves at time, both lathes turning their own phases.

As the drilling speeds would remain basically the same between the different machines. We can give following estimations of the new cycle times:

Table 8 Phase times in two-lathe configuration.

Assembly	Halve	Phase 1 (h:mm:ss)	Phase 2 (h:mm:ss)	Total
543-310-1641	543-311-3080	0:07:15	**0:12:55**	0:20:10
	543-311-3180	0:05:00	**0:10:20**	0:15:20
143-310-3611	143-311-3480	0:04:10	**0:08:00**	0:12:10
	143-311-3490	**0:06:45**	0:02:15	0:09:00
143-310-3811 / 143-310-4821	143-311-3800	**0:13:35**	0:09:20	0:22:55
	143-311-3810	**0:20:17**	0:10:48	0:31:05
543-310-3721	543-311-3900	0:09:30	**0:11:35**	0:21:05
	143-311-4000	0:08:28	**0:15:22**	0:23:50
543-310-4811 / 543-310-4831	543-311-4880	0:11:30	**0:13:50**	0:25:20
	143-311-3800	**0:13:35**	0:09:20	0:22:55

As the cycle time is dictated by the longest phase in the process, this leads to quite uneven phase times. This model would produce fewer finished units per hour than the three-machine model described in previous chapter.

Table 9 Cycle time comparison between current and two-lathe configuration.

Assembly	Halve	Current (h:mm:ss)	2 lathes (h:mm:ss)	%
543-310-1641	543-311-3080	0:07:15	**0:12:55**	56,13 %
	543-311-3180	0:05:00	**0:10:20**	48,39 %
143-310-3611	143-311-3480	0:04:10	**0:08:00**	52,08 %
	143-311-3490	0:04:20	**0:06:45**	64,20 %
143-310-3811 / 143-310-4821	143-311-3800	0:09:20	**0:13:35**	68,71 %
	143-311-3810	0:12:00	**0:20:17**	59,16 %
543-310-3721	543-311-3900	0:09:30	**0:11:35**	82,01 %
	143-311-4000	0:08:35	**0:15:25**	55,68 %
543-310-4811 / 543-310-4831	543-311-4880	0:11:30	**0:13:50**	83,13 %
	143-311-3800	0:09:20	**0:13:35**	68,71 %

The down sides, in addition to the fore mentioned long cycle times and the temporary storage of the first halves, of this configuration are the lack of spare tools in the revolver, lack of automated process control and uneven utilization of the machines. Also, the new second lathe requires considerable floor space.

The tool magazine size limits the number of spare tools available. Without spare tools unmanned production runs are limited to only short batches and there are no backup against tool breakage. Also, whether there is room in the magazine or not, the internal tool magazine limits the possibilities to use automated measuring tools in the machine, as the metal chips and cutting fluid could cause problems and incorrect readings.

6.3.3 Dual spindle lathe configuration

One option is to replace the Leadwell entirely with machining centre equipped with two spindles. These types of machines are much faster compared to the traditional horizontal lathes and could compensate for two such CNC lathes. A two spindle machine is capable of running both phases of casing halves simultaneously and provides automated change of a work piece between the stages. In this operating model the CNC station changes the piece worked on from the first phase mount to the second phase mount all by itself. The robot handles only the insertion of new blanks and removal of the finished parts.

In addition to greater speed, new dual spindle centre would offer better machining tolerances. The main advantages, however, would come from possibility to better even out the phase times between the spindles. The orientation information of the piece worked on can me maintained between the phases. This feature allows the distribution of the drilling task between the two spindles to completely level the phase times.

Dual spindle machines are better equipped for automated measuring and process control functions. The external, larger tool magazine could accommodate touch sensor measuring devices needed to automatically control the process. With feedback control the measuring tools can adjust the turning parameters and keep the process under control during medium length unmanned production runs without the need of the operators to interfere.

Also, the larger tool magazine would allow room for spare tools, at least for the main spindle, and thus enable longer unmanned batches and automatic recovery in case of a tool breakage.

The floor space required for only one machine instead of two or three separate machines is obviously also smaller. This would enable the usage of smaller, and thus cheaper, robot tending the machine.

The main drawback in dual spindle machine is its very high cost. Also, since the Leadwell would not be needed anymore, it might have to be written off as a loss in accounting.
(Lindberg 2012)

6.3.4 Dual spindle lathe with gantry

There are so called gantry lathes on the market. The lathes are equipped with integrated conveyer- and feeding systems. No separate robot is needed. The lathe itself can handle material flow from the conveyer to the spindle, machine it and return the finished product back to the conveyer system.

Such systems do have their own automated measuring stations available. These stations can be a touch probe integrated into the lathe or a separate measuring station located along the conveyer.

However, such systems tend to come with a very high price tag. General opinion amongst the suppliers seems to be, that gallery is an option for a high volume products and long production batches. The gantry can be an attractive option if its purchase cost can be kept relatively low. A EUR 50 000 robot is in most cases capable of providing the same service. Therefore, due to its high cost, gantry lathes fall outside of this study.

6.3.5 Summary of the cycle time comparison between machine options

Robotization of the current machine configuration would bring a boost to the production volumes. This increase would not be high enough to bring major savings in labour costs.

Purchase of a new horizontal lathe will bring substantial increase in manufacturing capacity. The utilization of a three-machine configuration (two lathes and drilling station) would be the most efficient. By replacing the Lidköping drill with Dah Lih and assigning its drilling tasks to the lathes, cycle time will be considerably longer than in a true three-machine configuration.

The most expensive dual spindle configurations are expected to be faster than two lathes, but not as fast as the three machines.

If we compare cycle times of the different machine configurations to the calculated cycle times of the current system automated with a robot we archive following efficiency rates:

Table 10 Cycle time comparison between current and two-lathe configuration.

Configuration	Efficiency
2 Lathes & drill/Phases	167 %
2 Lathes & drill/Halves	181 %
2 Lathes	114 %
2 Spindles	138 %

The cycle times of the housings for different machine configurations are illustrated in Figure 18 below:

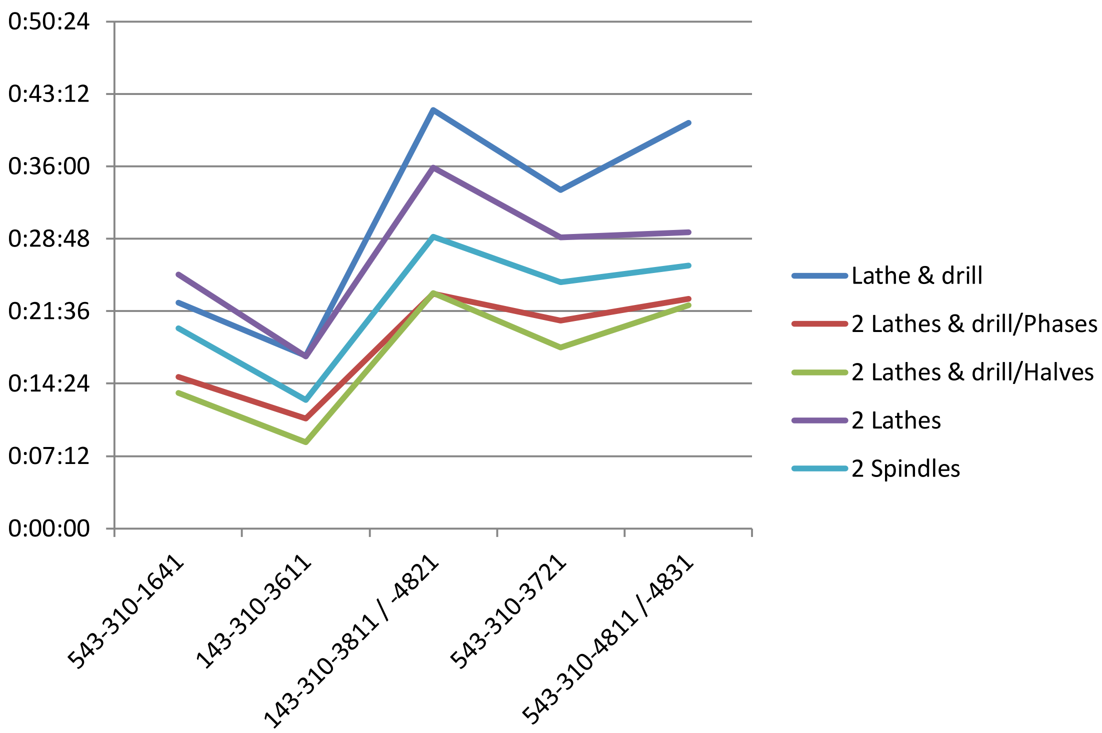

Figure 18 The cycle times of the housings in different machine configurations.

6.4 Measuring procedure

The CNC machines sculptures the work piece by moving the cutting tool along a pre-programmed path. Tool wear, vibration and temperature changes can cause variations in the dimensions of the machined work piece. Traditionally operator measures the item worked on, between or during the machining circle, and adjust the programmed cutting parameters of the CNC machine accordingly to compensate for the variations.

Automated process control uses feedback information from measuring devices to monitor the deviation from set dimension and takes corrective actions to ensure constant quality. For an unmanned production to be feasible, the system has to be equipped with automated measuring system. Depending on method and equipment used, the actual measuring can be done by the CNC machine itself (via probes), or provided by the industrial robot tending the machine. In this case, the measuring instrument can be attached to the robot or robot may place the measured work piece on a purpose build measuring station. If the measuring is not done by the CNC-machine, a compatible data transfer system must be in use between the CNC station and the robot, or the measuring station, and appropriate M-codes programmed into the CNC-program.

There are measuring tools available for CNC machines. They are usually inserted into the tool magazine like the regular cutting tools. Their operation principle can be based on touch or optical sensors.

There are two basic types of tool magazines: internal carousels and external magazines. Measuring instruments placed in an internal tool magazine are exposed to a harsh environment. Metal chips and cutting fluid on surface of the machined part, or on the measuring device itself, can produce erroneous readings. At minimum, a thorough flushing and/or air blasting is required to clean the components before taking a measurement. In a production environment, it is better to use these kinds of sensitive tools in much better protected external tool magazines. Unfortunately, external tool magazine usually also means a larger and more expensive CNC-machine.

One solution to overcome this limitation with Leadwell –type machines would be to use robot controlled measuring devices. Robot’s end effector can be equipped with a three point micrometer for measuring inner diameters of machined parts. Using robot operated gauge would allow part to be still fastened into lathe during measuring and milling parameters could be changed ‘on the fly’. If external measuring station is used, robot must remove the machined piece from the CNC-centre and move it to the measuring station. In this case, if the measurements are out of tolerance, the piece cannot be refastened to the lathe and fixed, but must be scrapped. The control information would correct the milling parameters for the next part machined. In theory, if no tool breakage occur, this method should be sufficient on keeping the process under control. When measurements get too close to the tolerance limits, but still clearly within them, the feedback control automatically corrects the milling station parameters. (Salmi 2012)

The ideal way would be to measure the work piece in the lathe with a measuring instrument attached to the CNC machine. This would eliminate the need for data transfer between the CNC machine, robot and CNC measuring station, and thus allow a less complicated data handling system.

With tool magazine probes, the data transfer is usually handled by using optical, radio or inductive transmitters. Separate measuring stations are generally hard wired to the control unit and CNC-machines controlled.

In optical transmission the signal in transmitted by an infrared beam. The transmitter and receiver must have a line-of-sight between them to function. A more versatile method is to use radio transmission. The transmission operates at 2.4 GHz range and system is capable of channel hopping. The maximum range is 15 meters. Multiple transmitter/receiver pairs are allowed in the same premises, as they are coded with unique identifiers.

An inductive transmission works by sending the signal over a small gap (of air) between transmission modules. Inductive systems are not available as retrofitted services.

The basic measuring system includes the probe with transmitter and a receiver that acts as a CNC-controller communicating with the machining centre and adjusting its parameters.
(Renishaw 2011c, Renishaw 2011d)

6.4.1 Measurements taken in the TPKS

There are three basic measurements required for each housing model: outer diameter of the neck (A in Figure 17), inner diameter (B) and flange thickness (C). The measuring can be arranged, depending on equipment chosen, either internally in the CNC machine or externally in a purpose build measuring station.

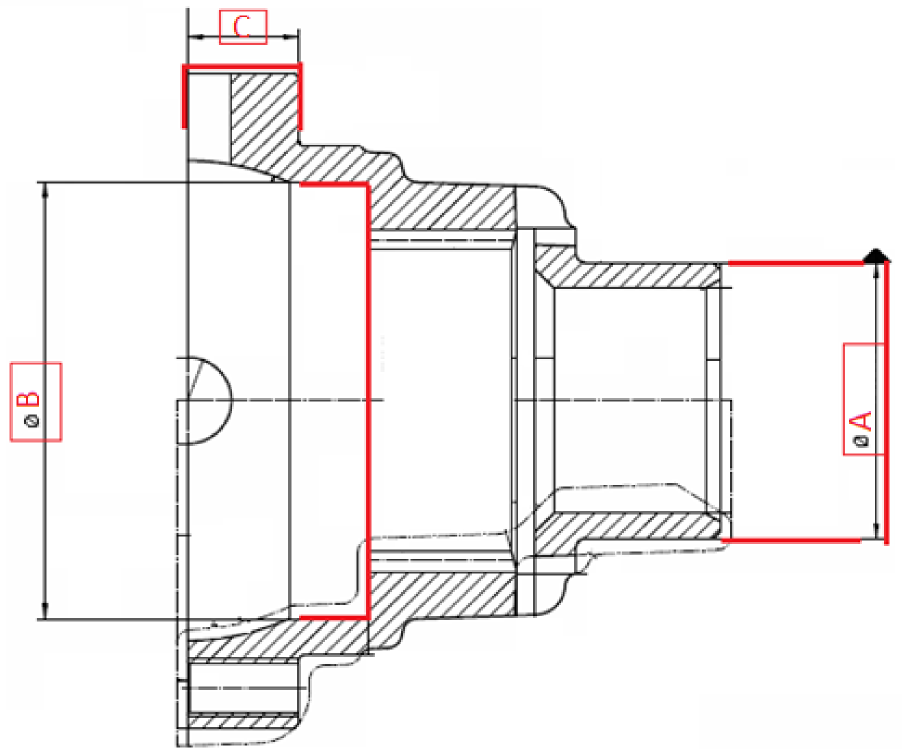

Figure 19 The key measurements of a typical casing halve.

6.4.2 Internal measuring

Some new machines offer touch sensor measuring devices that are integrated to the lathe. They can handle inspection and correction of the milling parameters automatically. In these machines the probe can be partially protected from the hostile environment created by cutting fluid and chips by a physical barrier (wall or cover) or by a high pressure air blast.

Magazine loaded probing tools are offered by measuring device manufacturers such as Renishaw or Marposs. The basic operation principle is based either on touch sensors or optical (laser) sensors. A probe can be loaded into tool carousel or magazine like a cutting tool. The CNC program is modified to take automated measurements during the turning process and results are fed back to the system as correctional information. (Renishaw 2011c, Sjöö 2012)
A touch sensor is preferred on harsh conditions over an optical sensor. The reading of an optical sensor might be affected by drop of fluid in a measuring point.

The traditional Lathes, such as Leadwell, are not equipped for automatic measuring. Leadwell has room for twelve tools in its magazine. This space restrain in Sisu Axles case does not allow the use of these types of probes. Also, the use of cutting fluids can affect the performance and reliability of sensors over a period of time. These sensors are more suited on ‘dry’ cutting that keeps the sensors cleaner.

However, larger machining stations that use external tool magazines are not hindered in the same extent by these limitations. Measuring probes with these types of machines, especially when cutting ‘dry’ are a feasible option.

6.4.3 External measuring

If the lathes do not offer measuring functions, or room for reliable probes, measuring must be handled externally. Externally conducted measuring requires a gantry type CNC machine or an industrial robot to handle the transfer of the work piece to the measuring station.

There are suitable purpose build 3D measuring stations commercially available. For example Marposs offers station that has been used for years with Volvo’s car manufacturing plant. The machine uses touch sensor probes for measuring the work pieces and offers feedback loop control back to the machining centres. The main disadvantage with this solution is its high cost. Systems, such as Marposs M2024 3D-measuring station can cost close to EUR 300 000. Such an investment is not feasible in Sisu Axles without combining multiple machining cells together to utilize the measuring stations services. (Sjöö 2012,).

So, a more economical solution must be found. One option for measuring outer diameter can be for example an optical (laser) scan micrometre offered by Mitutoyo (Mitutoyo 2006). See Figures 20 and 21 for basic operation principle.

The robot places the work piece between the measuring probes and laser beam records the diameter. The information is processed and fed back to the CNC-program to adjust the parameters. Finnish company Pathrace Oy has provided this kind of solutions in 2009 at least to two different customers in Finland. (Kuutela 2012)

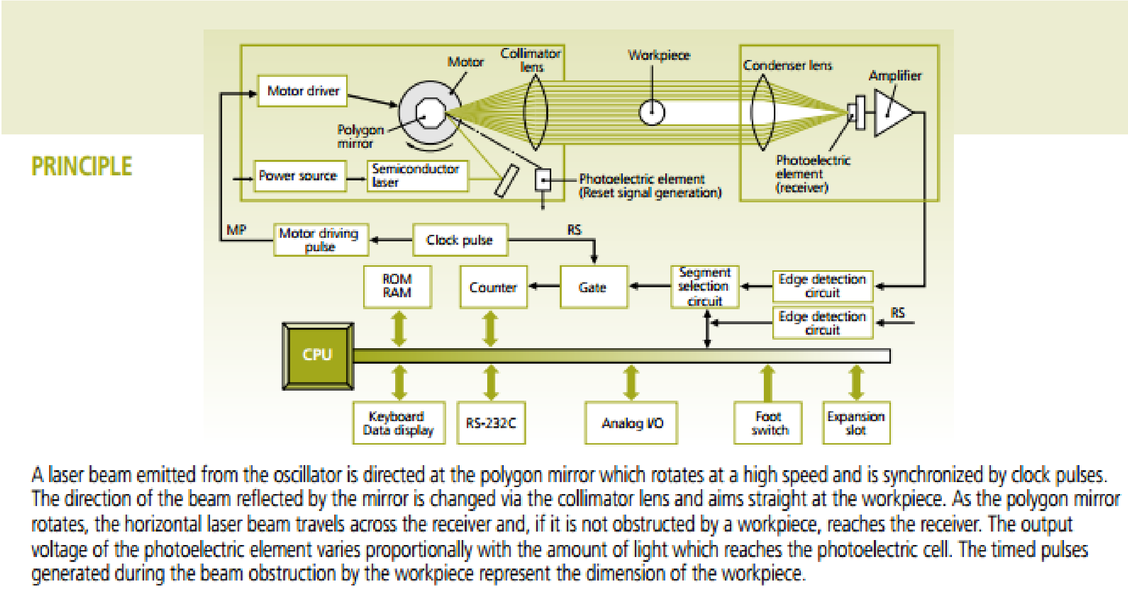

Figure 20 Working principle of the Mitutoyo laser scan micrometer. (Pathrace Oy. 2009)

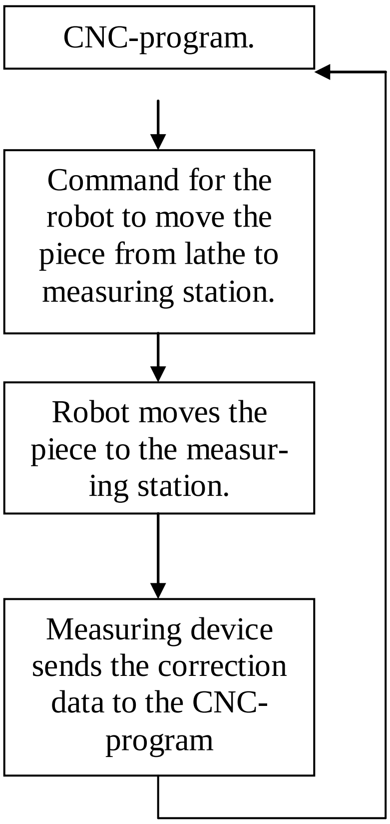

Figure 21 Working principle of the Mitutoyo laser scan micrometer command loop. (Pathrace Oy. 2009)

The inner diameter can be measured with a three point digital micrometer attached to the robots arm. The program sends command to the robot after the piece is finished in the lathe, robot moves the tool in position, locks brakes and takes the measurements. While robot arm is held in place, the servo motors may cause slight vibrations that can affect the readout. To avoid this, the robot must be parked and servo motors stopped for duration of the measuring. This does not affect the cycle time. Robot can process the measurement and send corrections to the CNC-program as required. (Lindewall 2012, Saarinen 2012, Salmi 2012)

Using a laser scanner and a robot controlled measuring device require considerable amount of integration and programming between multiple devices: CNC machine – robot – micrometre and the laser scanner. The system can thus be prone to malfunctions, and lengthy and costly installations. Also, the responsibilities between different suppliers can be vague and in case of malfunction may lead to finger pointing.

A more robust solution is a custom build retoolable measuring bench proposed by Marposs. The station is based on touch sensors. Robot places the piece measured on a revolving stand. Touch sensors move in and check the inner and outer diameter. The bench rotates the piece and the flange thickness is checked in multiple positions. The calibration of the bench for different models is handled by using master pieces. The measurements are processed and correctional information send to the lathe(s). This machine can also log process data and save it over Ethernet to a database for further analyze.

6.5 Adaptive control and tool health monitoring

Adaptive control uses feedback information from lathes sensors to optimize the cutting parameters. By measuring, for example, turning torque, cutting force required, temperature change, tool wear rate and surface finish, the system can adapt to changing conditions and produce optimal cutting speed and quality. This also helps to minimize the production costs. (Kalpakjian 2010)

The cutting tools suffer normal wear from usage and they need to be replaced between certain intervals. In addition to normal wear, the cutting tools may be damaged for example by low quality casting. Castings may have sand or unevenly melted particles in them. These particles can instantly damage the cutting tool and render it unusable.

Tool health monitoring systems keep track of the tools cutting capabilities by, for example, measuring machine vibrations, temperature or the cutting torque needed. By analysing this data, the system can decide when the tool is worn out of acceptable tolerances and in need of change.

Some tool health monitoring systems also are able to detect and react very quickly to tool breakage. When breakage is detected, the cutting tool is moved away from the work piece to prevent further damage to it. A timely detection of a broken, or worn-out tool, can stop the production and thus reduce number of defective products.

These kinds of tool health monitoring systems are of little use by themselves in unmanned production. The usefulness of a tool monitoring system is really felt when combined with automatic tool magazines for the machining stations. The magazines need to be large enough to hold enough spare tools to be able to cope with tool breakage during the unmanned runs. An acceptable compromise must be found between the probability of tool breakage and magazine size.

The lack of functional tool health monitoring system can be circumvented by running shorter unmanned runs and accepting the possibility of premature halt of the system when the measurements run out of acceptable tolerances. The risk of tool wear can be minimized by replacing all the cutting blades as a batch before unmanned runs. This is “a poor man’s” solution, but could perhaps be acceptable if indeed the runs are short and casting quality is high enough.

If the tool magazine is large enough, the CNC program could be modified to automatically change the cutting tool to a new one after certain usage time. This would multiply the turning time and enable longer unmanned runs. Yet another solution is to use cutting tools with multiple cutting edges. These used with the fore mentioned tool change intervals, would allow an even longer production runs.
(Renishaw 2010, Renishaw 2011a. Renishaw 2011b)

6.6 Material flow

The unmanned operation of the cell requires constant feed of cast iron blacks to the process. Two basic solutions for a robot fed system are a) pre-loaded pallets or b) a conveyer system. The choice depends greatly on the size of a planned production run. The specialized pallet is a more economical solution, but it’s downsize is the limited number of blanks it can hold. Limited floor space around the CNC-machines, and robot serving them, determines the number of pallets available for the system. See Figure 22 below for a basic pallet.

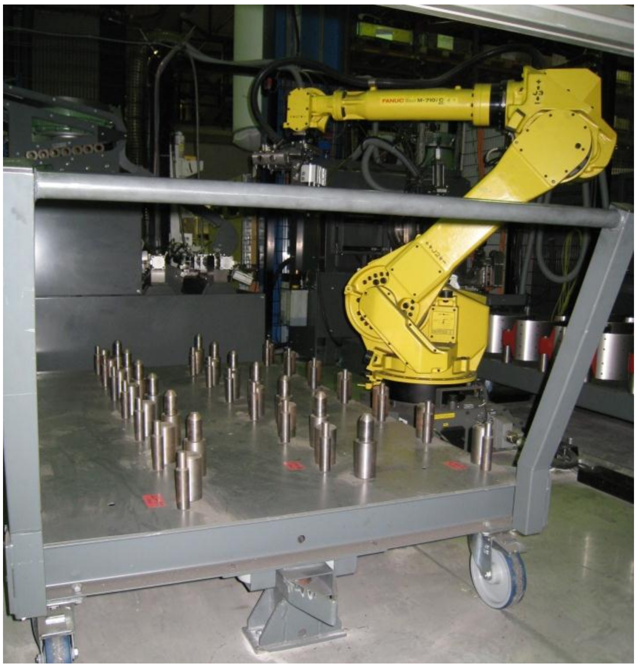

Figure 22 Robot material pallet at Sisu Axles brake shoe manufacturing cell.

A conveyer system (Figure 23) can reduce the space needed for the transport system near the robot and CNC-machine(s). Its capacity is only limited by the length of the conveyor and the system feeding it. If the blanks are manually loaded to the conveyor, the run can be only as longs as there are room for blanks it the conveyor system. A long conveyor line can be problematic to install and may hinder free movement in the production hall.

Figure 23 Conveyor system at robotized Sisu Axles Planetary carrier and – housing manufacturing cell.

So, the major question in deciding the feeder system is the production run size and machining time per one item. The average current cycle time using two lathes is from 11 to 13 minutes. This total includes feeding times, turning and measuring. A two hour run thus means roughly 10 pieces and a four hour run 18 to 21 pieces. The diameter of the blanks varies between 183 and 227 millimetres. Depending on the robot gripper arm used, a standard 800 by 1200 mm size pallet could hold up to 13 blanks. This would suffice to 2 to 3 hour runs, depending on the part machined. See Figure 24 for a basic pallet layout scheme.

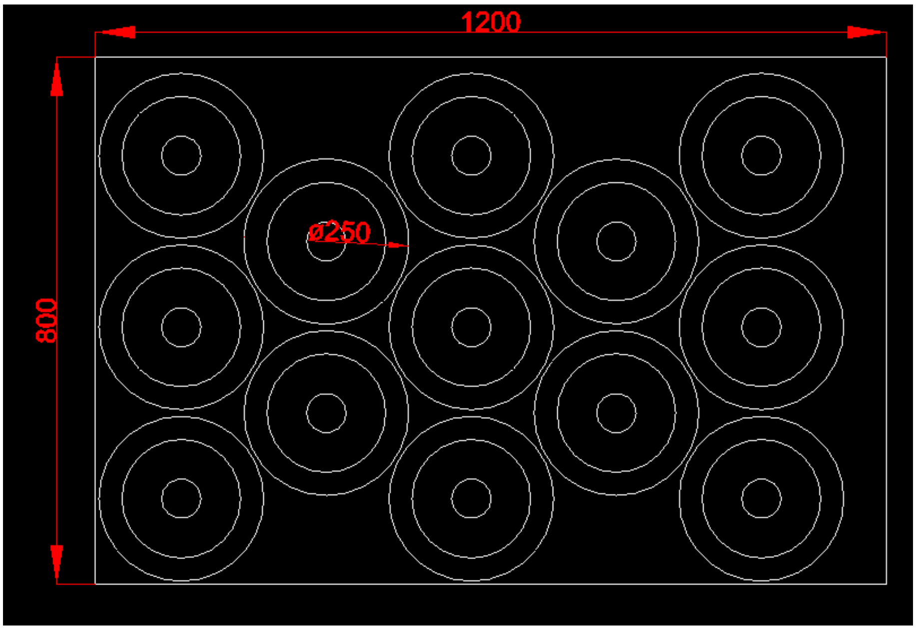

Figure 24 Basic pallet layout.

7 FINANCIAL CALCULATIONS

The American parent company of Sisu Axles has set a three-year payback limit on all major new investments. In order to get funding for new machinery, it must be shown that savings gained by the improvements are substantial.

Brief financial calculations were made to estimate the payback times of different proposed configurations. The calculations first defined the hourly production costs of the cell. This Figure is comprised of:
- personnel costs
- rent
- electricity
- spare parts
- tools (cutting bits, etc.)
- maintenance costs
- machinery book value and depreciation

These calculations were then made based on the current production cell configuration and expanded to the planned machine configurations. The data collected on the machining times and the estimated new cycle times were used to calculate TPKS production costs per item for all the configurations.

The savings gained by utilizing an industrial robot and improved processes come mainly from labour costs. Eliminating two shifts: weekend and the mating, will bring roughly EUR 80 000 savings annually.

The basic calculations were based on the production figures of both 2008 and 2011, and further studies were conducted using a multiplier to allow easy experimentation with rising and decreasing production volumes.

For further comparison, the annual costs of for outsourcing the production were calculated based on a quotation made by an Italian manufacturer. The calculations showed that in-house production, with reasonable fluctuation, was always preferable to outsourcing.

The book value depreciation was calculated for a ten-year period and then transferred to the payback times. Also, different cycle times of previously shown machine configurations were included to study their effects on the pay back times.

Since the machinery acquisition process is still open, no exact quotations are published here. The prices given in Table 10 below are only directional. In the first two configurations the new lathe purchased is the same, but due to its more complicated layout the three-machine option uses a larger robot and a more complicated measuring station. This is reflected in a slightly higher price.

The gantry type machine is only included here to show the price difference between this and a robot tended dual spindle machine. Since conveyer, robot and measuring station are integrated into the gantry machine, only a price for the whole unit can be given.

The cost of a 'robot' includes basic material handling pallets, safety features such as fences, and the configurations required.

Table 11 Cycle time comparison between current and two-lathe configuration.

	Two lathes & drill	Two lathes	Dual spindle	Gantry CNC
CNC	EUR 180 000	180 000	610 000	820 000
Material Handling (Robot)	117 000	107 000	90 000	
Measuring station	75 000	50 000	50 000	
	EUR 362 000	**337 000**	**750 000**	**820 000**

The calculations showed (Figure 25) that the two-lathe configurations are well in reach of the set three-year payback time goal. However, all the considered twin spindle machines seem to be out of Sisu Axles reach with current production volumes. The payback time of these is almost six years.

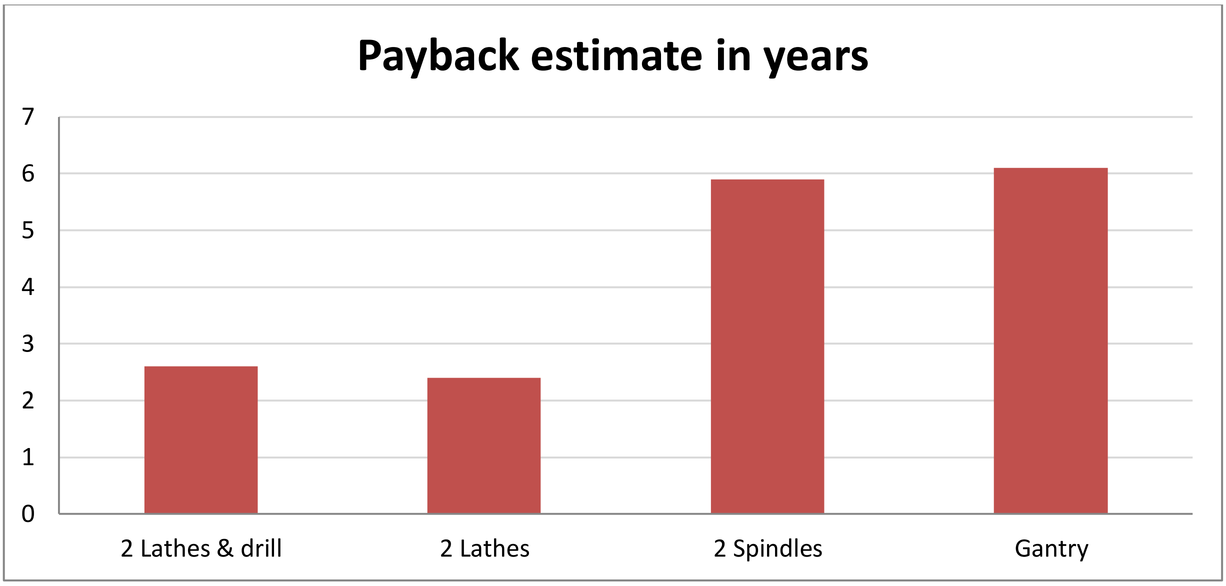

Figure 25 Payback estimate with different configurations.

8 RECOMMENDATIONS

This study offers two basic solutions for the new production cell. Both of them add a second horizontal lathe and utilize both the current Leadwell lathe and the Dah Lih drilling station. A crucial element with both of these solutions is the implementation of an industrial robot for material handling and automated process control. The main difference between them is the role of the Dah Lih drilling station.

Both solutions are within of the set three-year payback time.

With both solutions, a new improved mating process is implemented to speed up the production and to reduce labour costs. Also, utilising a second, larger, broaching machine for the wider diameter models produced in TPKS will considerably reduce setup times during the tooling phase. This would not cause major expenses on the company, as one such machine already exists on the premises, but is unused.

Both solutions proposed in this study consider the utilisation of an unmanned production line short span operation. The goal was set to enable two to four hours of unmanned runs. To make this feasible automated measuring and process control must be implemented.

A robotization of the current one-lathe configuration is not feasible due to its very limited production capacity. The tool life, and thus the length of an unmanned run, would also be short.

An optimal configuration would consist of a dual spindle lathe served by an industrial robot or a gantry lathe. The lathe would be equipped with integrated measuring tools to adjust the milling parameters as required to compensate for fluctuations in dimensions and a tool revolver large enough to store spares for at least the most common tools. This would by far be the most economical solution regarding the floor space required and considering the lower degree of configuration and integration of the machines and systems needed. However, this configuration is too expensive and falls outside of the set three-year payback time. See Appendixes 7 to 9 for further information.

8.1 Three-machine option

In the first proposal, a new horizontal lathe is added to the current configuration to increase the turning capacity of the cell. Both of these lathes and the Dah Lih drilling station are tended by an industrial robot.

A purpose built retoolable measuring station is added to control the process and to keep the produced parts within acceptable tolerances. Such a station is available for example from Marposs. The measuring station is tended by a robot and it has feedback control to the lathes to correct the milling parameters and database access to log process information for further analysing. (Sjöö 2012)

The tool health monitoring is omitted and unmanned batch sizes are limited to 10 to 15 pieces. This produces about four hour long runs. All the cutting tools are replaced by the operator before every batch to minimize the possibility of tool wear outs. The tool magazine may hold spares for some of the most used tools, but not all. In case of a tool breakage the process is stopped until the tools are manually replaced.

Bids for the robot and its accessories have been requested from both ABB and Fastems (Fanuc). Suitable models are for example the ABB IRB 6640-185 or Fanuc R-2000iB/165F. The robots use stationary mounts and no need is seen for robot track system in the proposed solution.
(Saarinen 2012, Lindevall 2012)

The performance of this option is good and allows room for considerable increase in production if so required. The system could either be used to run a batch of halves with both lathes turning their own phases or a batch of casings with lathes turning their own halves.

The major drawbacks are the complicity of the system, timing and optimizing of the material handling between the stations, and the rather large floor space required.

This solution would not completely remove the problems associated with the old Lidköping cross shaft drill. The labour required on mating the halves would be reduced and process simplified, but it would still be included as a work station. Replacing the cross shaft drilling station with a newer CNC machine would have to be planned in the near future. This will raise the total cost involved.

It is foreseen, that with automated material handling, automated process control and improved mating processes the human labour required to operate the cell can be reduced. This would allow deletion of two operating shifts.

The basic operation cycle of the cell is described in Figure 26. The cast blanks are manually placed on purpose build material pallets. The robot lifts pieces from the pallets to both lathes. After the first phase is completed, robot moves the work piece to the measuring station. The measurements are processed and corrections transmitted to the lathe. Then the pieces are lifted back to the lathe for the second phases.

After the second phases are completed, measurements are checked again, the measurements processed and corrections transmitted to the corresponding lathes.

The first halve is then moved to the drilling station and new castings loaded to the lathe. The second halve can be either left in the measuring station or the lathe to wait for the completion of the drilling of the first halve. The drilling and turning tasks are parallel. The cycle times are set by the drilling of the first halves.

The automated cycle is completed by moving the ready machined item from the drilling station to a pallet.

Operator transfers the machined halves to deburring station for grinding of sharp edges and overall manual inspection. Depending on the halve worked on, it then either continues to broaching, washing and temporary storage, or to mating, cross shaft drilling and washing. The process flow is presented in the Figure 27.

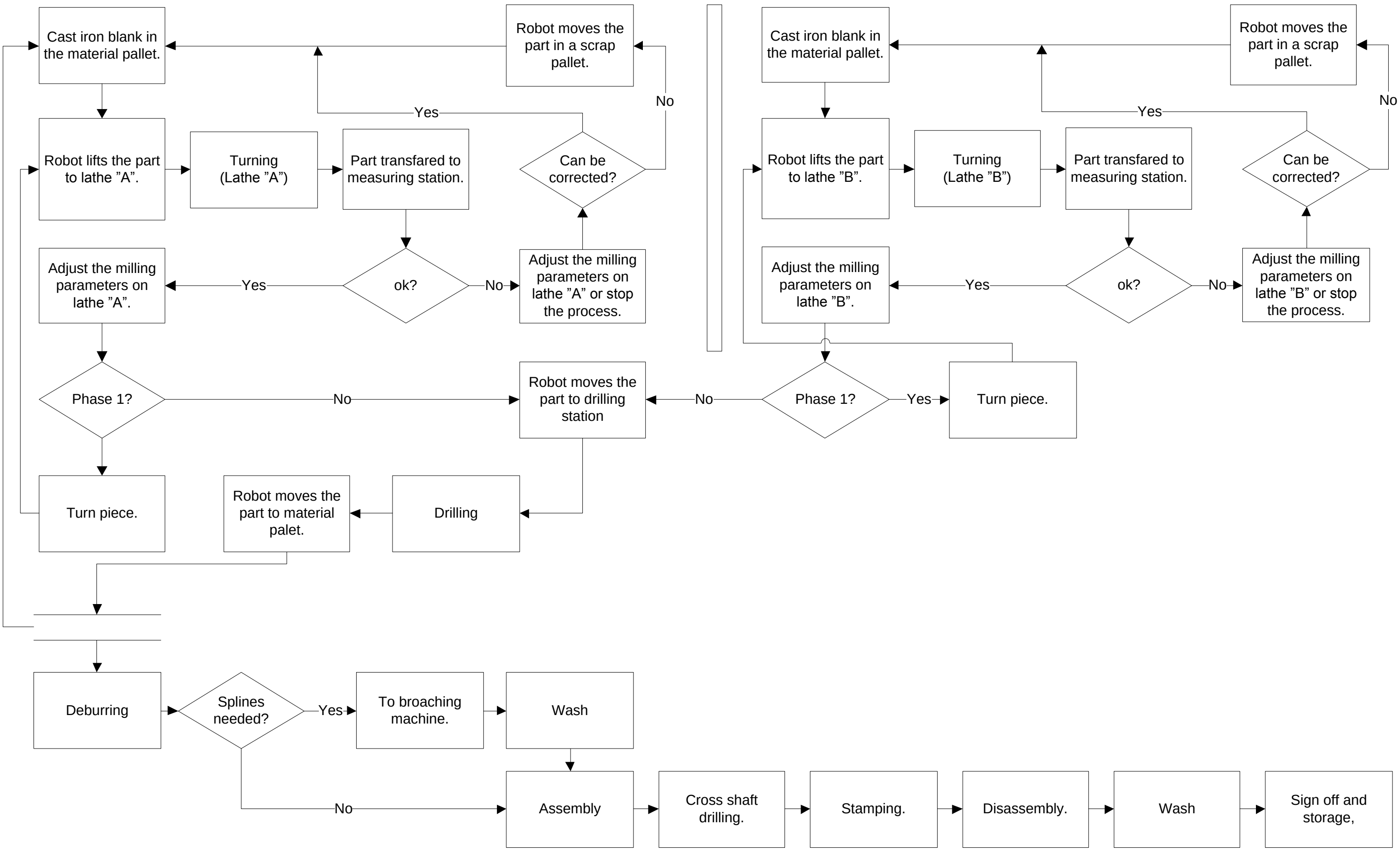

Figure 26 The process flow of the three-machine configuration.

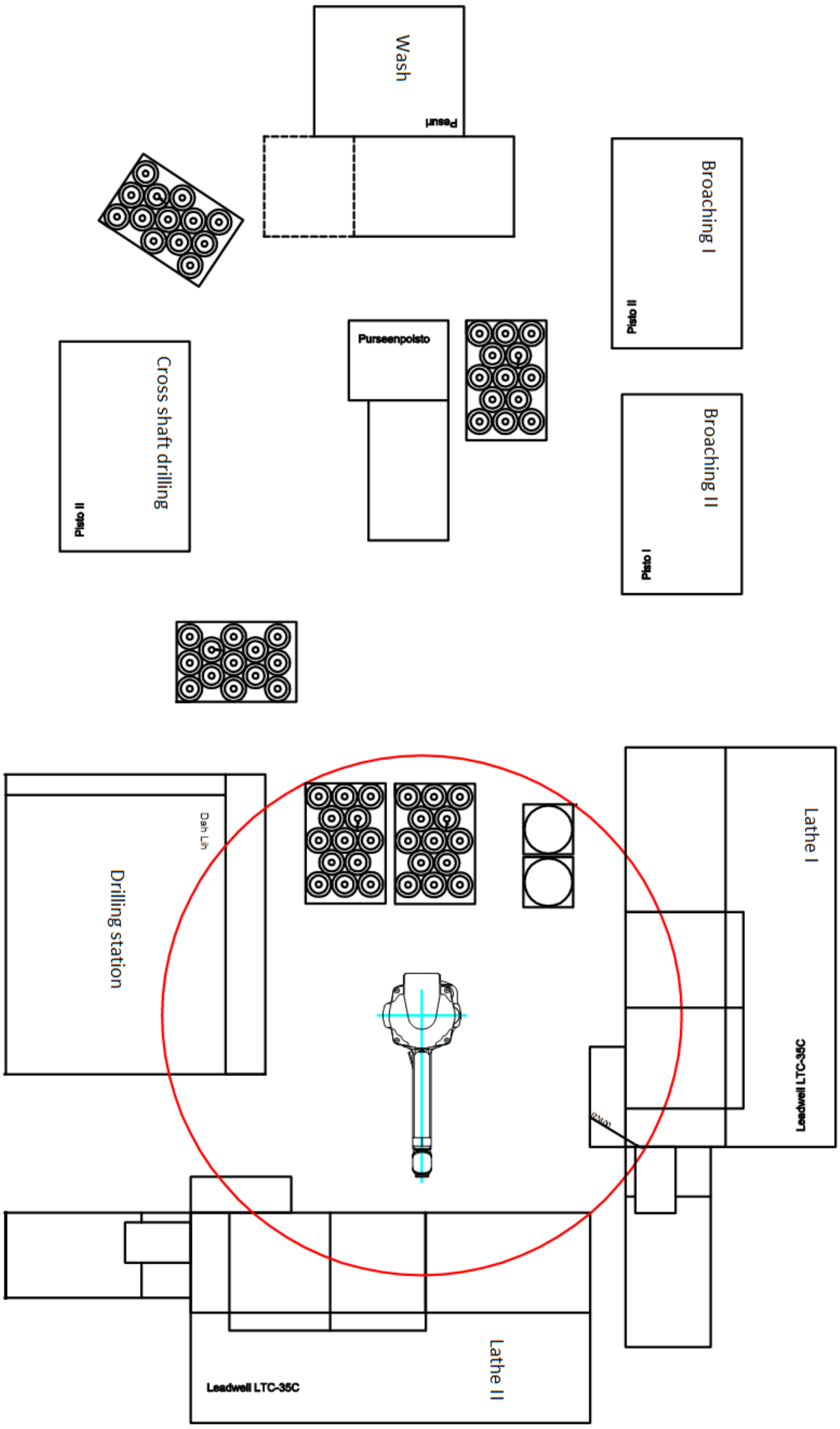

Figure 27 The three-machine configuration layout.

8.2 The two-lathe option

The second configuration is in many ways similar to the three-machine option described above. It too keeps the Leadwell LTC-35 lathe and Dah Lih MCV-1020A drilling station, and adds another CNC based lathe to the configuration. However, the drilling and threading are performed by the lathes utilizing their rotating tools and Dah Lih is used as new cross shaft drilling station replacing the aging Lidköping drill.

The two CNC lathes are served by an industrial robot. As assembly is required before cross shaft drilling, that station is served by the human operator, not the robot. The material flow is handled with special build pallets to store the raw material and finalized products. The pallet system is considered to be adequate for short span unmanned runs. Conveyor system is omitted due to its higher cost and the problems caused to free movement.

The measuring process is handled by an external measuring station similar to one used on the three-machine configuration. As only one halve is produced on batches at time, the measuring station can be of simpler design, handling only one type of a part at the time. This reduces the overall cost of the measuring bench slightly.

The cycle times achieved are not as good as with the true three-machine configuration, but well within the requirements set by production volume demands. The cost of this option is nearly identical to the previous option. The savings mostly come from a slightly smaller robot and the simpler measuring station. Also, this option removes the old and potentially problematic Lidköping cross shaft drill.

In the example layout, as shown in Figure 26, the cast blanks are manually placed on purpose build material pallet. The robot lifts piece from the pallet to the first lathe. After the first phase is completed, robot moves the work piece to the measuring station. The measurements are processed and corrections transmitted to the lathe. Then the piece is lifted to the second lathe for phase two. While phase two is running, robot loads a new cast blank to the first lathe. After the second phase is completed, measurements are checked again. The measurement is processed and corrections transmitted to the second lathe. The automated cycle is completed by moving the ready machined item to a pallet. This phase is marked with red in the Figure 26 below.

Operator transfers the machined halves to deburring station for grinding of sharp edges and overall manual inspection. Depending on the half worked on, it then either continues to broaching, washing and temporary storage (blue arrows), or to mating, cross shaft drilling and washing (black arrows). The process flow is presented in the Figure 28.

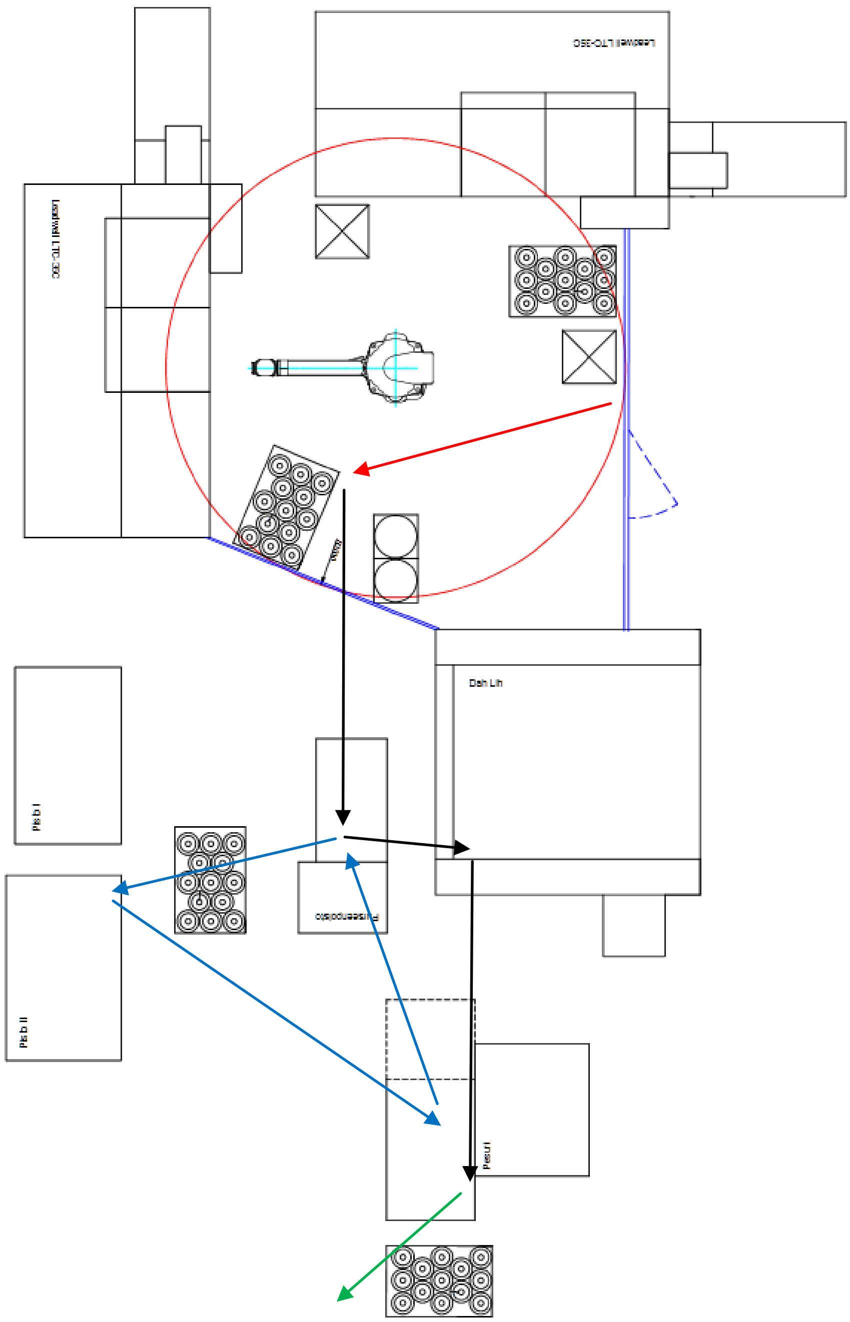

Figure 28 Example of a two-lathe layout.

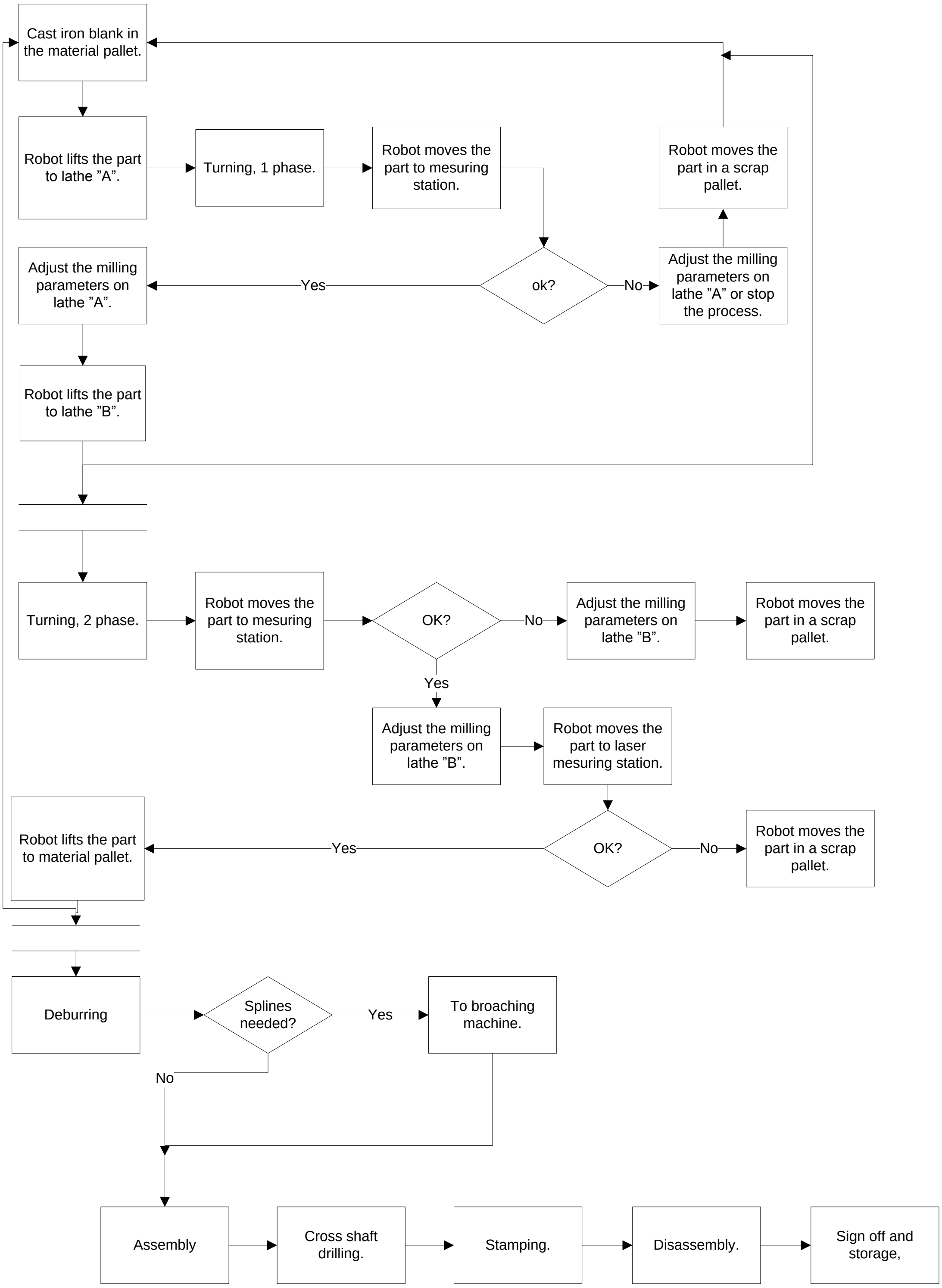

Figure 29 The two-lathe model process flow.

9 CONCLUSION

The production capacity of TPKS has come to its limits. The main bottle neck in the production is the lathe turning capacity. As the production is currently run in three shifts, there is no possibility to add any extra man hours.

Outsourcing the key elements of Sisu Axles production is a difficult task and can potentially be a great risk. There are possibilities of outsourcing some bulk models, but manufacturers for lesser volume items are hard to come by.

Productivity can be increased by improving the processes and by purchasing new machinery. There are basically two main options: acquiring a second lathe to assist the current lathe or to replace it with a completely new two spindle machining centre.

Adding an industrial robot to tend the lathe(s) would enable short span unmanned production runs. The key element in successful unmanned production is automated process control. A measuring system with a feedback loop to the CNC machines is required. Suitable systems for thus purpose are available for example with Marposs. Tool health monitoring with a reserve tool magazine would enable longer uninterrupted automated runs.

The old Lidköping cross shaft drill is nearing the end of its production life. With new extra lathe capacity drilling and threading task of Dah Lih could be assigned to the lathes and Dah Lih converted to a cross shaft drilling station.

The mating process of the differential assembly halves can be improved by using dowel pins. This would remove the need of the labour intensive alignment-clocking procedure and save man hours.

A second broaching machine could be added to the production cell. This would reduce setup times and simplify the process.

The combination of using an industrial robot and a new simplified mating process would reduce the manual labour required in the production cell. With these improvements the current three operator/one assembler personnel could be reduced to one man in the morning and evening shifts. The weekend shift could altogether be cancelled. This would reduce personnel cost of the production cell by 50 percent.

The budget for new machinery and the equipment needed varies depending on the machinery type chosen from EUR 400 000 to 900 000. As the sales volume can be expected to rise only mildly, the payback savings can mainly be made from reduced labour costs. Depending on the equipment chosen the payback time of 3 - 6 years is foreseen.

The purchase of an industrial robot and another lathe to increase the capacity is in reach of the set three-year payback time. However, all dual spindle lathes fall out of the given payback period.

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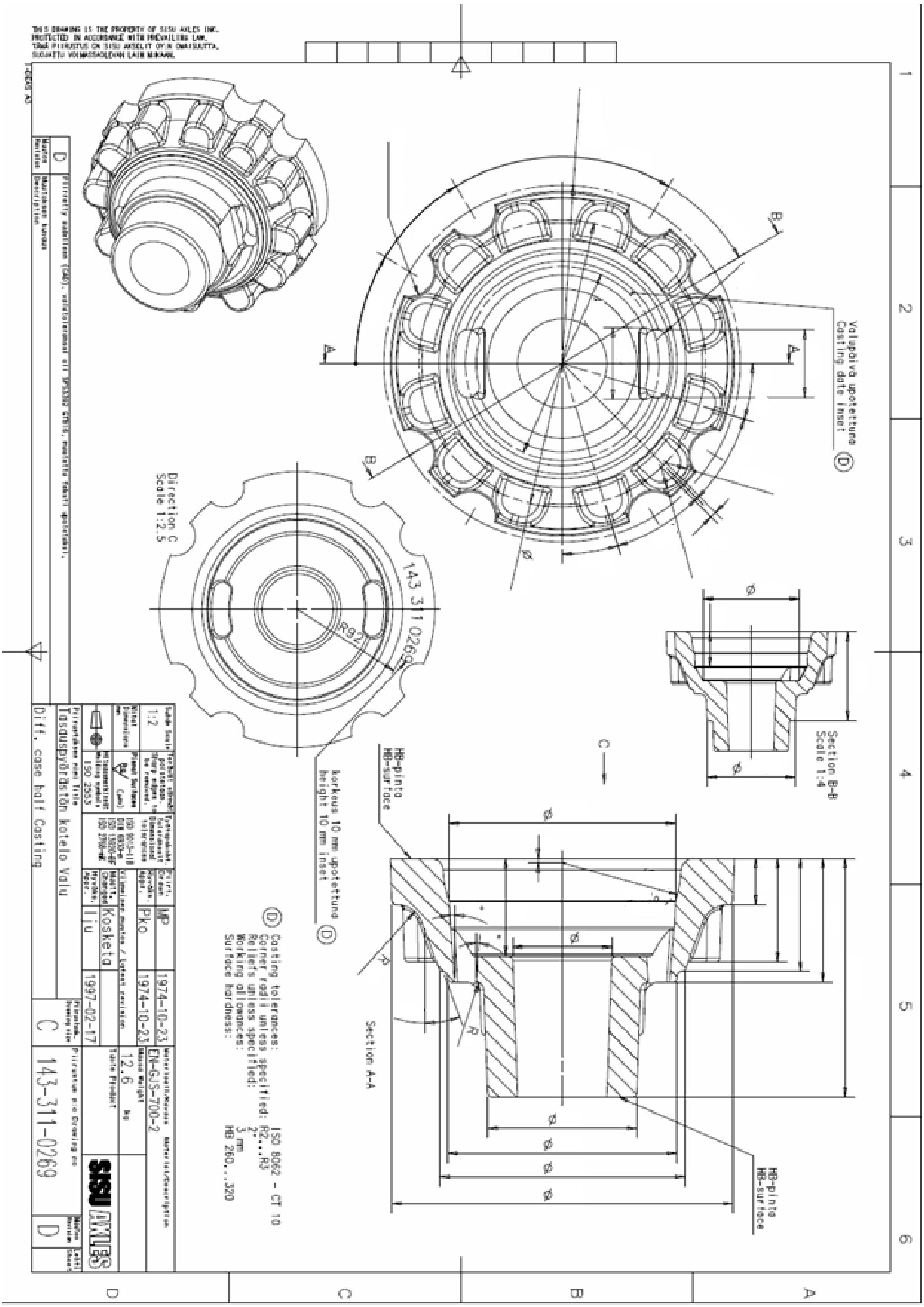
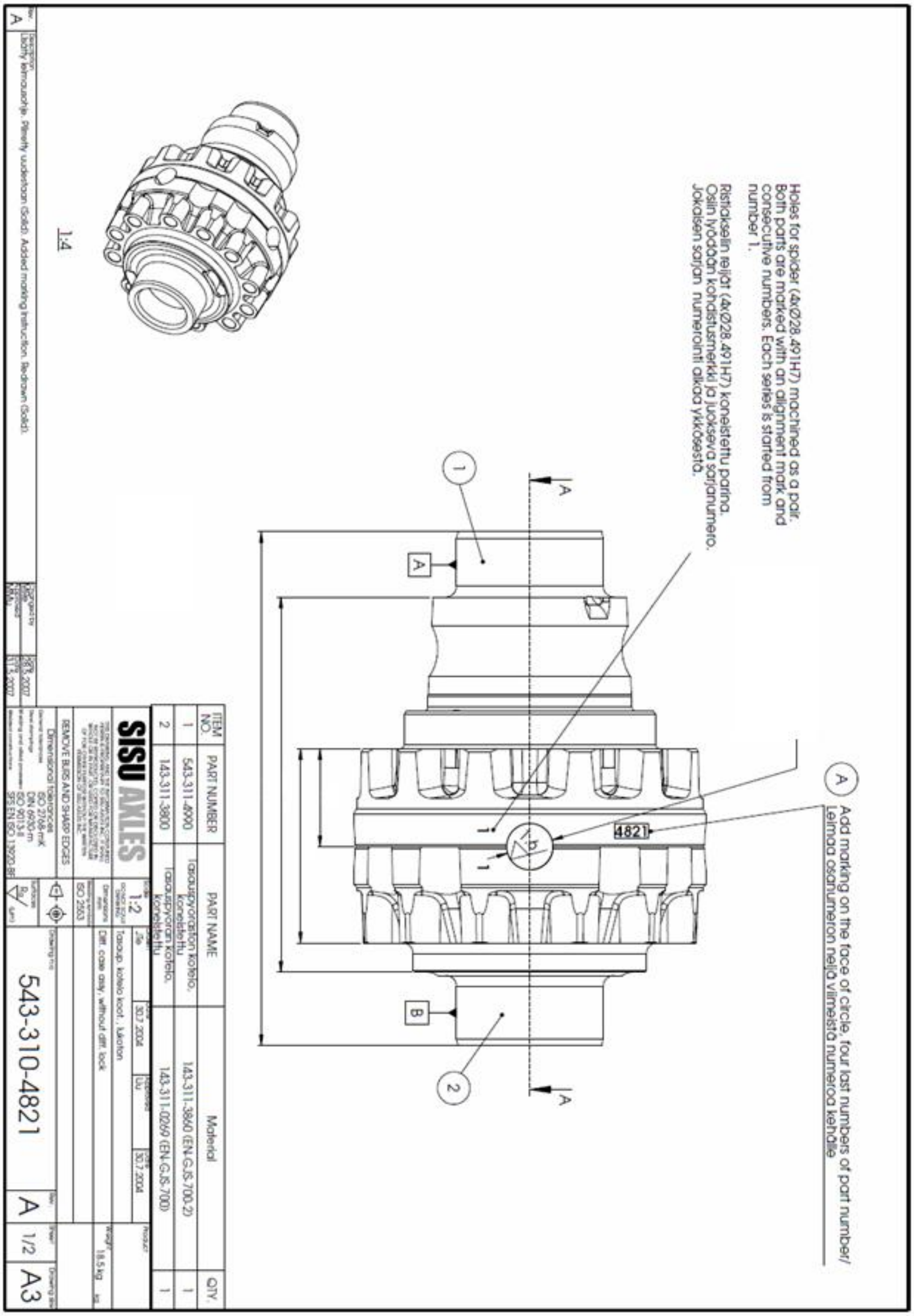
Appendix 1

DRAWING OF A TYPICAL DIFFERENTIAL HOUSING HALVE



Appendix 2

DRAWING OF A TYPICAL DIFFERENTIAL HOUSING



Appendix 3

PRODUCTION FIGURES OF TPKS 2008-2011

Period 1.1.08-31.12.08			
Assembly	Produced in house	Sub con-tracted	Total
143-310-1611	10		10
143-310-1621	186		186
143-310-2711	17		17
143-310-3211	6		6
143-310-3611	631		631
143-310-3811		834	834
543-310-1641	262		262
543-310-3721	252		252
543-310-4561	156		156
543-310-4711	112		112
543-310-4811		916	916
543-310-4821	88	406	494
543-310-4831	225	1350	1575
	1945	**3506**	**5451**

Period 1.1.09-31.12.09			
Assembly	Produced in house	Sub con-tracted	Total
143-310-1611	13		13
143-310-1621	191		191
143-310-3211	30		30
143-310-3611	226		226
143-310-3811	78	100	178
543-310-1641	197		197
543-310-3721	384		384
543-310-4561	78		78
543-310-4611	132		132
543-310-4711	113		113
543-310-4811	75	189	264
543-310-4821	80	140	220
543-310-4831	86	611	697
	1683	**1040**	**2723**

Period 1.1.10-31.12.10			
Assembly	Produced in house	Sub con-tracted	Total
143-310-1621	75		75
143-310-2711	26		26
143-310-3611	347		347
143-310-3811	360	22	382

543-310-1641	115		115
543-310-3721	133		133
543-310-4561	118		118
543-310-4581	1		1
543-310-4611	25		25
543-310-4711	63		63
543-310-4811	364	11	375
543-310-4821	60	15	75
543-310-4831	136	96	232
	1823	**144**	**1967**

Period 1.1.11-31.12.11

Assembly	Produced in house	Sub con-tracted	Total
143-310-1611	70		70
143-310-1621	107		107
143-310-2711	19		19
143-310-3611	642		642
143-310-3811	661	50	711
543-310-1641	295		295
543-310-3721	382		382
543-310-4561	119		119
543-310-4611	83		83
543-310-4711	151		151
543-310-4811	527	71	598
543-310-4821	205		205
543-310-4831	568	92	660
543-310-5111	2		2
	3831	**213**	**4044**

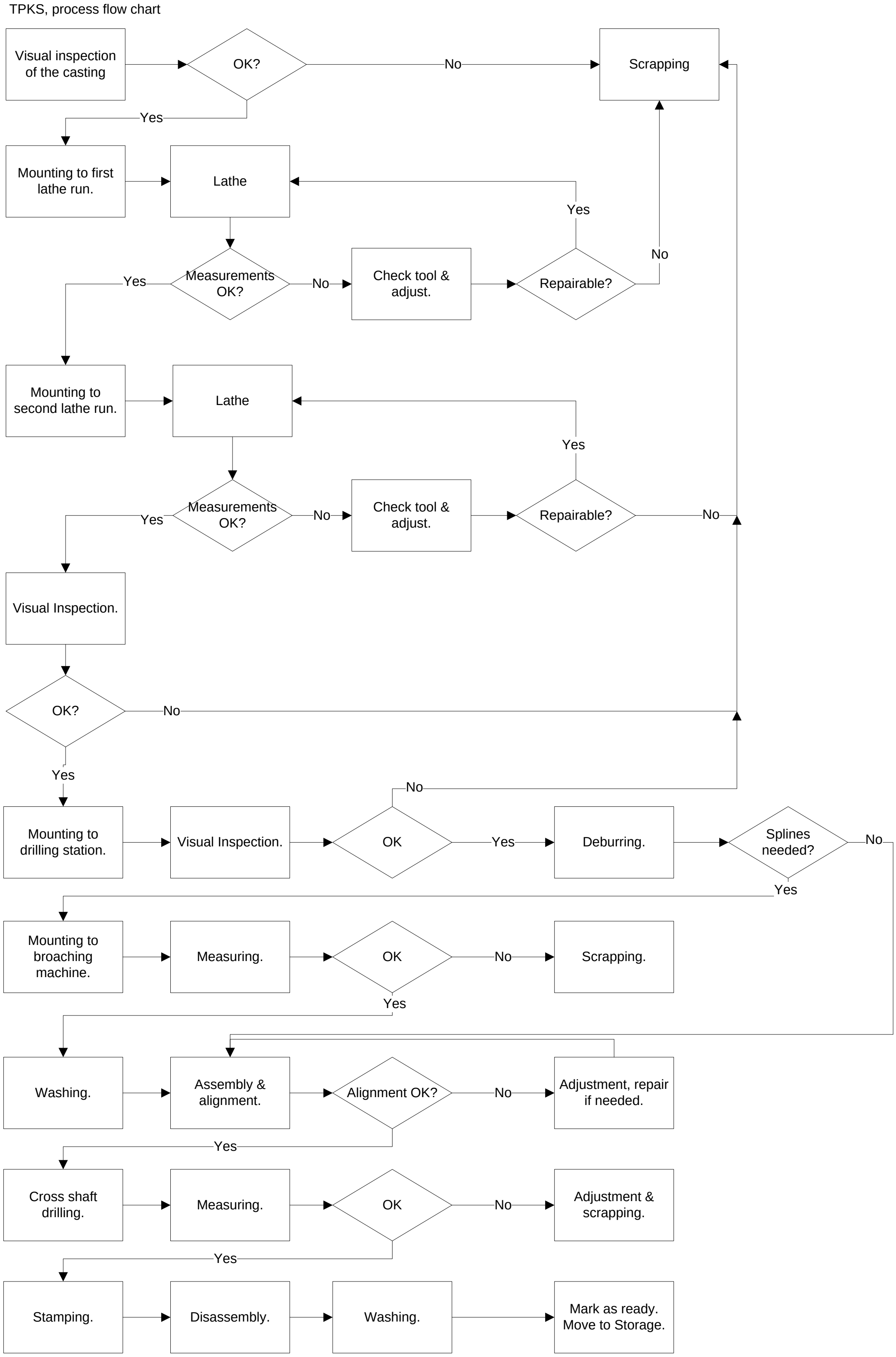
Appendix 4

PART NUMBERING SYSTEM

Assembly	Halve	Casting
143-310-1611	143-311-2400	143-311-2460
	143-311-2410	143-311-2460
143-310-1621	143-311-3280	143-311-3260
	143-311-3380	143-311-3360
143-310-2711	143-311-0210	143-311-0269
	143-311-0310	143-311-0369
143-310-3211	143-311-2700	143-311-2760
	143-311-2800	143-311-2860
143-310-3611	143-311-3480	143-311-3460
	143-311-3490	143-311-3460
143-310-3811	143-311-3800	143-311-0269
	143-311-3810	143-311-3860
543-310-1641	543-311-3080	143-311-3260
	543-311-3080	143-311-3360
543-310-3721	543-311-3900	543-311-3560
	143-311-4000	543-311-3360
543-310-4561	543-311-4180	543-311-4160
	543-311-4290	543-311-4260
543-310-4611	543-311-4690	543-311-4660
	543-311-4680	543-311-4660
543-310-4711	543-311-4780	143-311-0269
	543-311-4790	143-311-0369
543-310-4811	543-311-4880	543-311-4860
	143-311-3800	143-311-0269
543-310-4821	143-310-3800	143-311-0269
	143-311-3810	143-311-3860
543-310-4831	543-311-4880	543-311-4860
	143-311-3800	143-311-0269

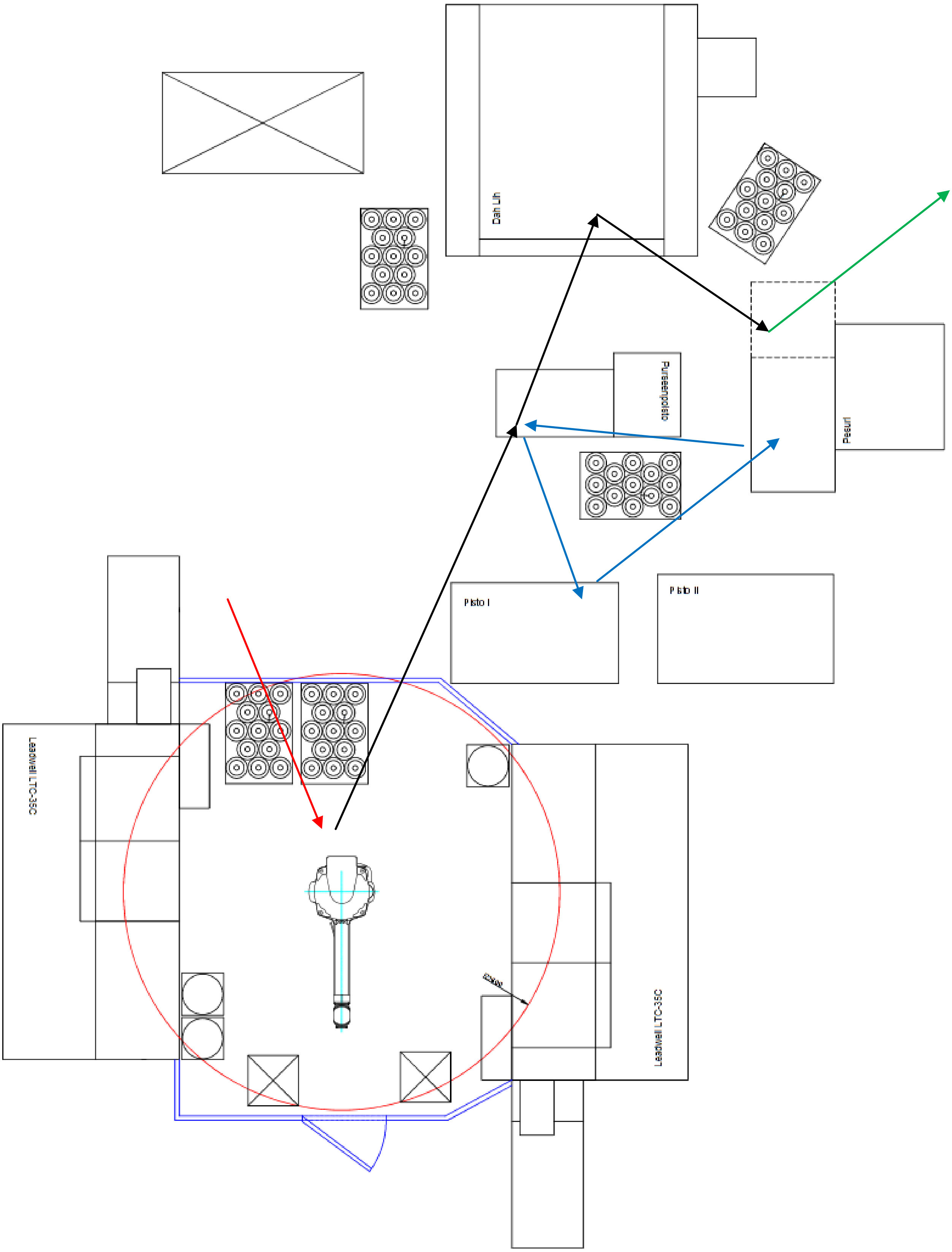
Appendix 5

CURRENT TPKS PROCESS FLOW



Appendix 6

ALTERNATIVE LAYOUTS



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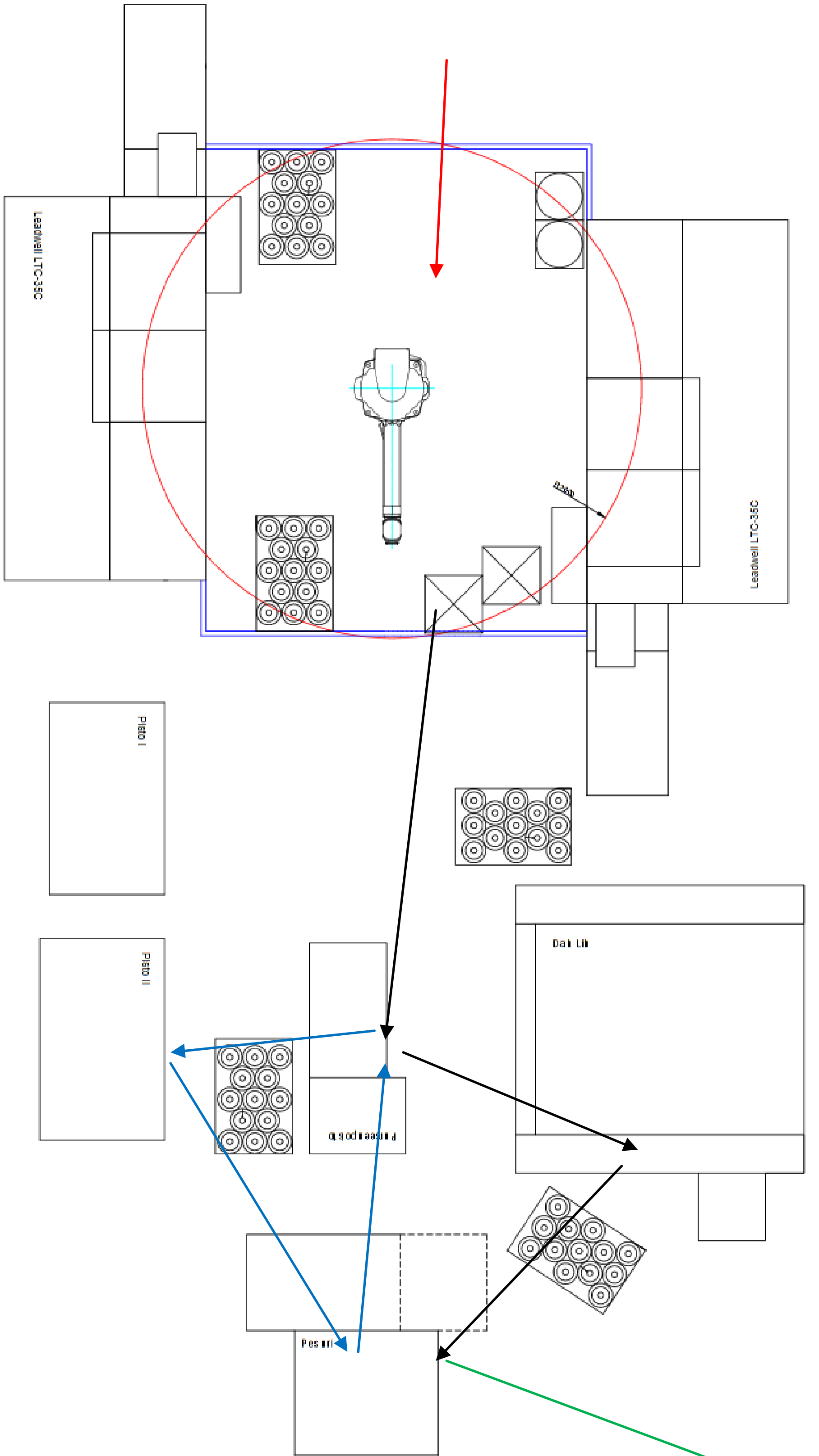

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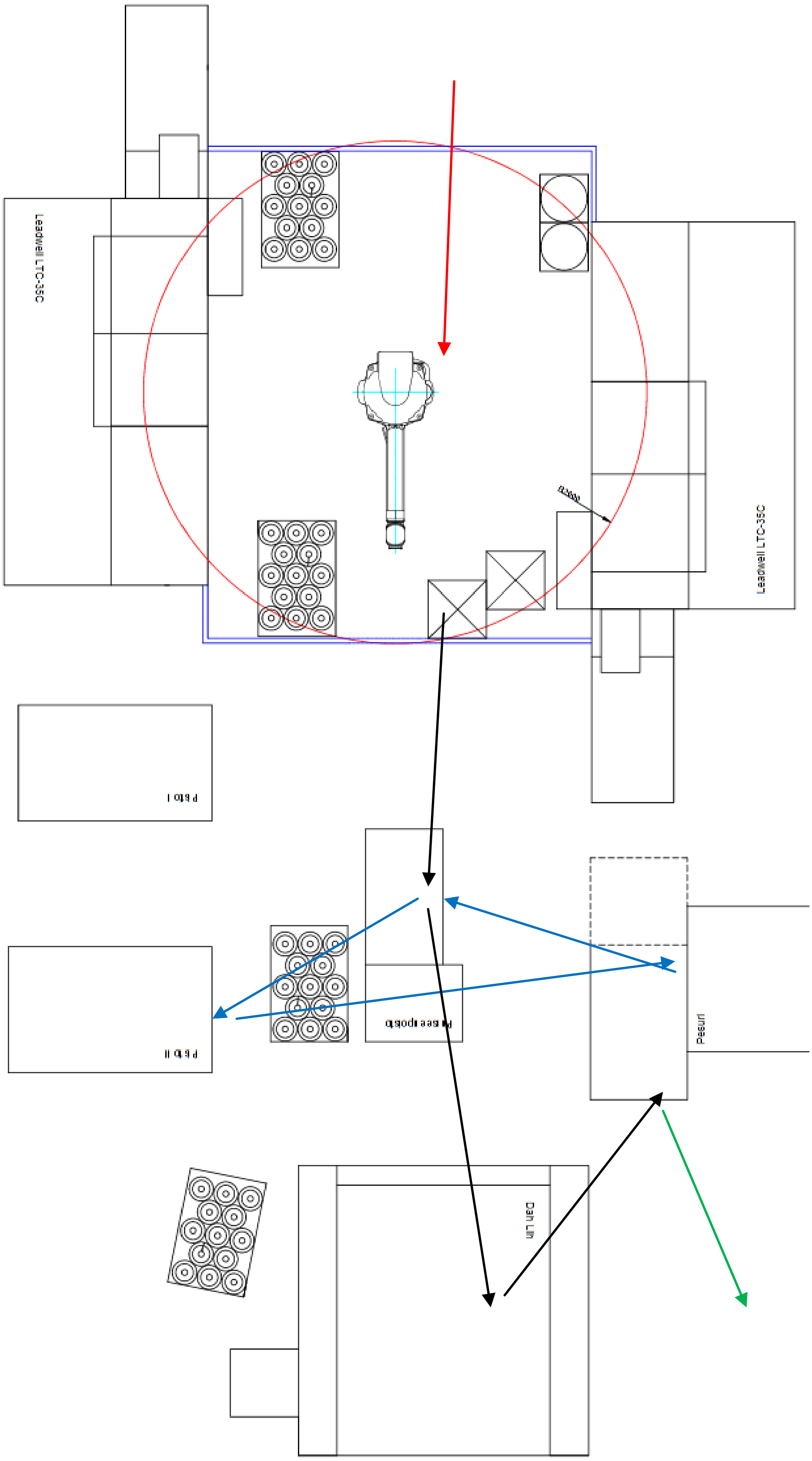
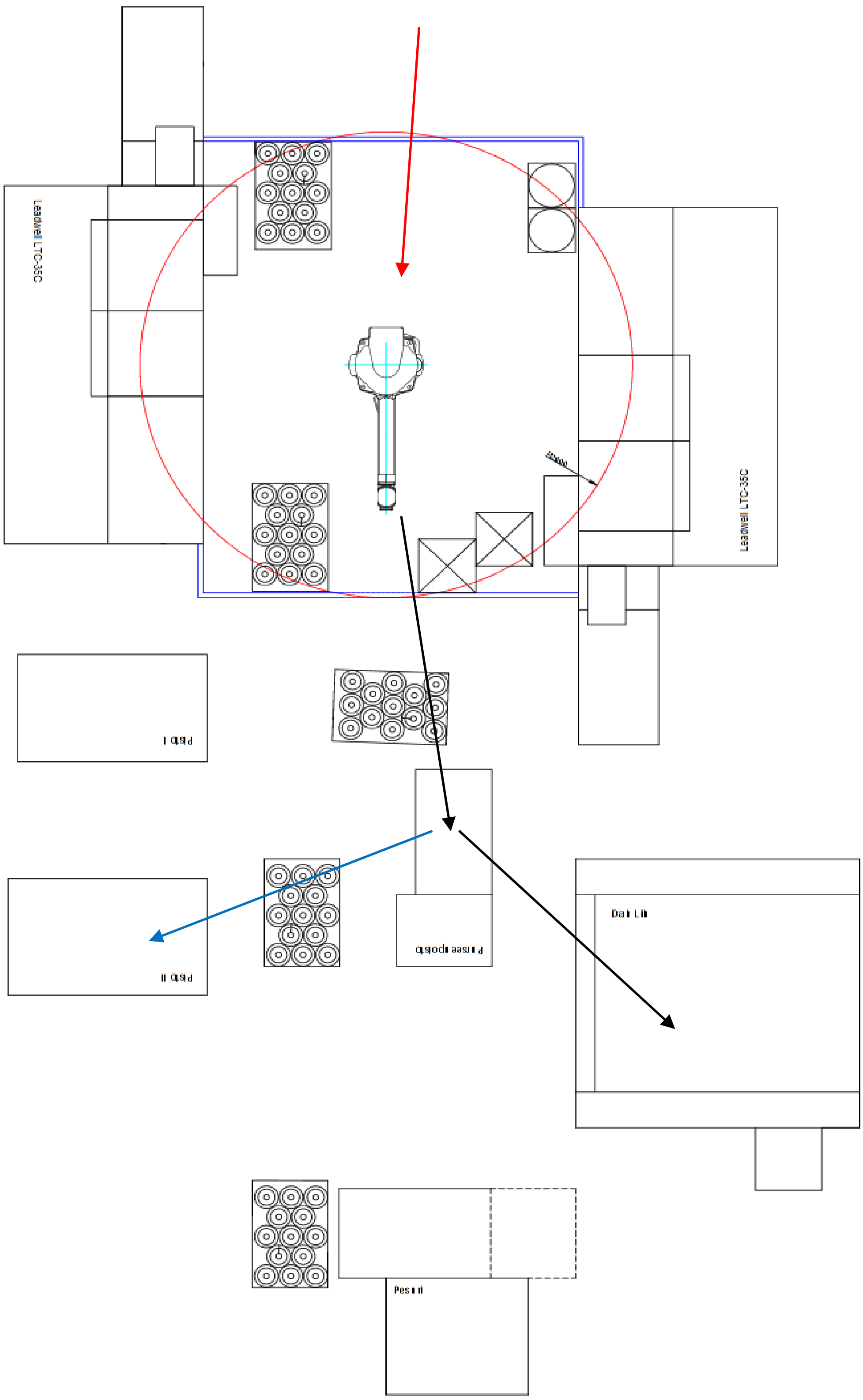


Appendix 6



Appendix 7

THE ONE-LATHE SETUP

Despite of its high cost, the dual spindle setup has many attractive features. This machine configuration model includes just one multipurpose CNC lathe served by an industrial robot or a gantry. Offers have been recieved for a DMG CTX gamma 2000 and Nakamura_Tome Super NTX. As in the second proposed model, the cross shaft drill is run by the operator on Dah Lih. This setup would require far less floor space and would allow a smaller, and thus cheaper, robot.
Source: http://www.nakamura-tome.co.jp/e/products/atc/super-ntx.html

The process flow varies from to the two-lathe setups only in the automated phase. With dual spindle machine, the parts are done by running batch of halves.

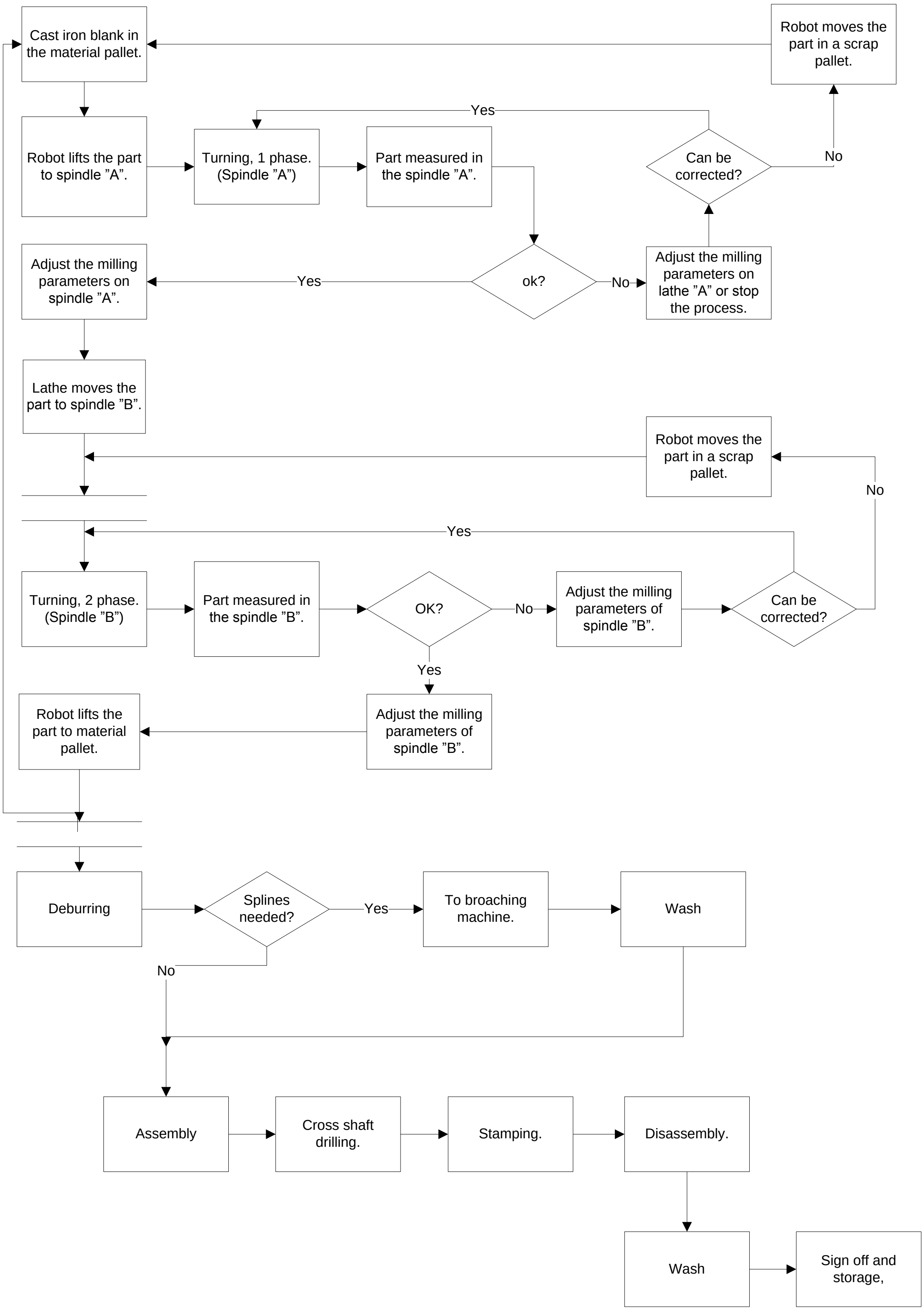
It is possible, depending on the machine chosen, to do the broaching in the new machining centre. This would allow deletion of the broaching machines and simplify the process even further. In this case, there would be no need for the mid process washing – the final wash would suffice.

The one CNC-machine setup is technically less complicated to implement. As much of the material handling can be left to the CNC machine, less configuration and data transfer between the stations is required.

On a dual spindle machine the orientation data can be preserved between the spindles. This allows the drilling to be divided between the phases to level phase times and thus provides much better utilization rates than two separate lathes ever could.

Appendix 8

PROCESS FLOW OF A ONE-LATHE SETUP USING TOOL PROBES



Appendix 9

LAYOUT OF A ONE-LATHE SETUP