



Jaana Koistinen

**AUTOMATION OF PRE ASSEMBLY CELL AND IMPROVEMENT OF MATERIAL FLOW**

Nokia Networks, Oulu

## **Automation of Pre Assembly Cell and Improvement of Material Flow**

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## **FOREWORD**

Automation of a pre assembly cell became as my Master thesis subject after working over 19 years in many kind of tasks in Nokia Networks base station production Oulu.

During these years I saw very closely different production phases to many kind of products. I practiced first to do all the preassembly parts considering this thesis by myself. They were all done by soldering iron this far and the purpose of this thesis was to automate all the production phases and then improve the material flow to the production line.

Automation was not strange to me. I had made several years temperature profiles to Metcal- and Zevac- rework stations. My bachelor thesis consisted of infrared heat usage in rework process for all kind of components on multilayer Printed Wired Boards. Ersa IR rework station was the machine during the research then. Being several years as a soldering trainer and a quality facilitator too, gave me good back round knowledge and capability to get a qualitative results by different machines.

I would like to thank Mr. Aleksi Jämsä, the Filter Production Manager, for trusting me and getting this wide and interesting subject as my thesis and Mr. Mika Kaivola, MS Test Engineering Manager who supported me among all the automatic equipment by giving me competent employees for the help with the machines.

My dear husband Kari earns the biggest thanks and all my love for supporting me during all my studying for several years. Without his support and encourage would this thesis perhaps never be done.

## **ABSTRACT**

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Nokia Networks Corporation is an independent organization inside the Nokia. This factory is located in Oulu Finland. It produces base stations among other electronic equipment as filters for them. Filters need small assembly parts, which must be first assembled together by the soldering iron. The parts were made by several hand assembly operators in different shifts and in a separate pre assembly cell. Some filters needed even six of these small parts and their assembly took a lot of time because of their big amount. The main subject was to change all the hand assembly work as automatic as possible with the existing automatic machines in Nokia Oulu.

There is Toyota Lean manufacturing system used in Nokia production that had to be considered through the thesis especially in the material flow improvement plan at the end. The Lean manufacturing culture by Toyota Way was studied very enthusiastic and so learned a lot of its qualitative and responsible manufacturing process. The force of all employees committing to Lean principles together was deeply assimilated Lean tools were used to get to the best result in the just-in-time production considering material flow improvement.

Optional choices for automation was SMD area with many reflow ovens, Selective Wave Soldering machine, "Zevac" and "Metcal" -hot air rework stations, different kind of dispensers and a new soldering robot that had bought to Oulu. The implementing of the robot will be inspected closer than other equipment in this thesis. The quality of all assembly had to fulfill the accepted requirements of IPC-A-610 quality standard system. The soldering profiles had to fulfill the ROHS requirements for the lead free soldering process too.

As the result of the automation there was got a lot of cost savings. The savings concerned operator resources, material costs and working time. The quality of the soldering results became much better and work time (takt time) more standardized by the automation. All the hand assembly phases will be now checked in Oulu to see if there is a possibility to make something else more automatically.

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Keywords: Lean manufacturing, soldering robot, hand assembly, material flow, automation

## **INTRODUCTION**

Nokia Networks is a wide spread global company manufacturing equipment and software used in information technology as in the base stations. It began to work as independent organization 1 April 2007 and has factories in Oulu, China, India and Germany. In addition has other functions in 150 countries and even 55 000 employees. In Finland Nokia has 7000 employees whereof 2200 are working in Oulu. This thesis is made to Nokia Networks Oulu factory.

The thesis aims to get cost savings by automating as many hand assembly phases as possible considering a small pre assembly cell. The automatic machine situation is good in the factory and their usage was taken account in this thesis. Furthermore the first soldering robot arrived to Nokia during this thesis time and it had to be implemented to the production. The soldering robot is a whole new equipment in Oulu and so the machine is inspected very closely. There is a material flow problem too that has to be solved in this thesis and take the needed actions in use.

The other subject thesis is focused to is the Lean Manufacturing system. The Lean was studied quite deeply by thesis writer and it gave many enlightenment moments during reading the Lean books. Lean is described often as a house with all basic bricks consisting of different Lean tools in manufacturing. When doing all kind of changes to production one has to be careful not to collapse the structure. In addition in this thesis had to be considered the fact that there are many other factories in Nokia where the changes might be adopted. This induced more accountability to thesis author.

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# 1 INTRODUCTION OF LEAN MANAGEMENT

## 1.1 Lean Manufacturing

Lean is usually introduced everywhere in books and internet pages like this:

*"Lean is a continuous improvement philosophy which is synonymous with Kaizen or the Toyota Production System. The history of lean management or lean manufacturing is traced back to the early years of Toyota and the development of the Toyota Production System after Japan's defeat in WWII when the company was looking for a means to compete with the US car industry through developing and implementing a range of low-cost improvements within their business."* (26).

According to Lean manufacturing there are the five principles of it based on the *Value* that customer specifies. Other principles are identifying and creating the value stream from raw materials to customer, making the value flow smooth without any storage or delay, guide the production value without pushing it, only by pulling, and striving for perfection (see figure 1). "Value is the inherent worth of a product as judged by the customer and reflected in its selling price and market demand" (54). Some of the production phases have value for customer and some not. E.g. walking, material transportation and reworking have no value for him. This thesis aims to perfection by doing assembly as much automatically as it could and making the value flow smooth without any delay. In addition by improving the material flow to production line from the pre assembly cell, will the timing be striving to more perfection time.

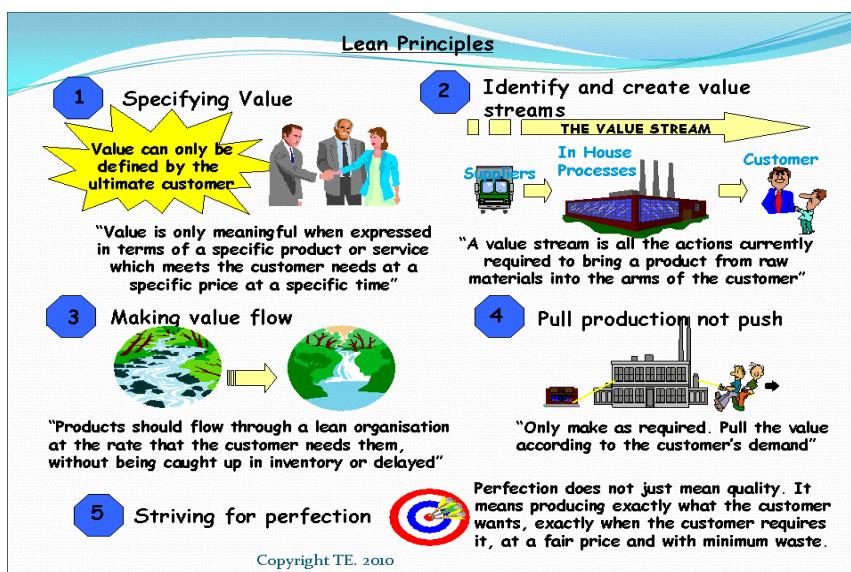


FIGURE 1. Lean Principles in manufacturing (26).

## 1.2 Kaizen culture

*Kaizen* is the Japanese term for “Good Change” (see figure 2). When used in the business sense and applied to the workplace, *Kaizen* refers to activities that continually improve all functions and involve all employees from the CEO to the assembly line workers (21, see figure 3). *Kaizen* culture is in use in Nokia and even in Oulu has employees made usually in minimum one thousand *Kaizen* every year. *Kaizen* are made through all organizations and job levels by all production operators and managers from all levels.



**Kai = Change Zen = Good**

FIGURE 2. *Kaizen symbol* (21)



FIGURE 3. *Kaizen is continuous improving* (20)

When operators are not making any *Kaizen* meaning improving suggestions considering their work, tools, working methods, ergonomics etc. is it a root cause for all seven wastes.

*“This is result of employees not taking part in design of manufacturing processes. Only in this way the ideas can develop, which are needed to eliminate and avoid the other seven waste sources.”* (31).

### 1.3 Seven Waste

There are seven kind of different losses that is called waste (see figure 4). Waste is something that does not add the value to the customer (25).

- Overproduction against plan.
- Waiting time of operators and machines
- Unnecessary transportation
- Waste in the process
- Excess stock
- Non value-adding motion
- Defects in quality

Waste is divided to three categories. One is called *Muda* and it means non-value-added-tasks. These could be e.g. stacking, many walking steps and long reaching distances. Other waste is *Mura* meaning inconsistency in the process and the third one *Muri* which is excess stress or strain to the employees. All these waste categories take time in working without any value for the result and that is not what customers want to pay off .There is taught by Toyota Lean system how to eliminate the waste by going to the very root of a problem. (32.).

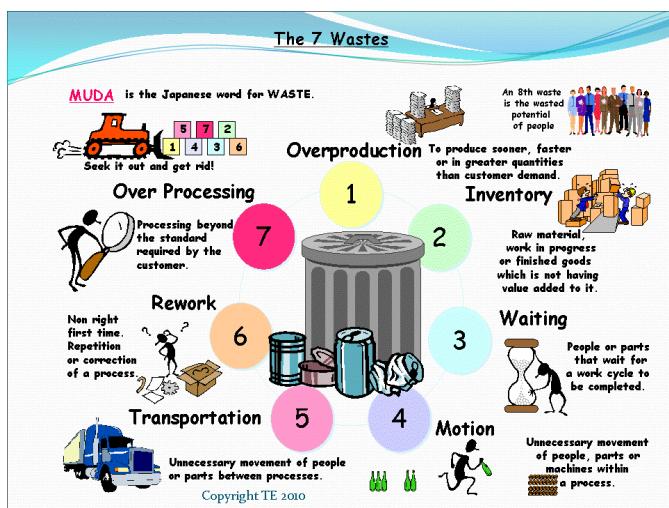


FIGURE 4. The seven waste in the production (50)

## **1.4 Eighth Waste**

Waste is something that has to be considered at the beginning of the planned change. When producing something faster there might appear waste e.g. by doing excess stock, over production or even defects in quality. There exists furthermore the eight waste too and it is explained by Lean so: “*An extremely important form of waste that is not represented within the Seven Wastes is unused human potential. This form of waste results in all sorts of lost opportunities e.g. lost motivation, lost creativity, and lost ideas*” (47).

## **1.5 Different kind of loss**

By this thesis was found out that one kind of a waste was in addition the waiting time and utilisation loss what appeared when some parts had ended too soon from the assembly line. Assembly operators can not do their best then and that is called performance loss. Other loss to be considered is Method Loss. Toyota system explains it like this: “*Method Loss is the responsibility of engineering and management across the organisation. For example, if a product was not designed to be easily manufactured then this would be the R&D team's responsibility*” (31, Appendix 1).

Two more opinions considering the working process can be added here. If the method is not standardized and operators in the production do the same work phase by many different ways, will there become additionally some method loss. The work phases should be standardized and everybody teach to make the work phases by simplest and the most effective way. When doing the phase every time by similar way will there come after some time more routine and the work will be faster. We will then produce more in the same time. The Thesis writer opinion is that when counting the working phases by a Stop Watch it should always be done between the best and the worse way and then taking the average between different operators. By this way (including the quality assurance acceptance) will the manufacturing be most effective and without unnecessary waste.

## 1.6 Just-In-Time (JIT) manufacturing

Just-in-time producing is explained by Toyota philosophy so that it means: "*Making only what is needed, when it is needed, and in the amount needed!*" (19). Elements of *JIT* includes continuous improvement (*Kaizen*), eliminating waste, inconsistencies, Setup-time reduction and leveled / mixed production. *Kanban*, *Jidoka* and *Andon* system are part of this system. These avoid temporary stocks and excess material keeping on the production line. "*The assembly line must be stocked with required number of all needed parts*" (19). On the other place earlier was additionally said that material must be the right amount that is needed for the assembly. This gave an idea of a possibility to change the material flow in the production so that it will decrease the amount of the faulty assembled products. There were often some small parts forgotten to assemble on the assembly line or they were mixed up together.

When having a lot of different small parts in the production is a *KIT* a good choice for not forgetting to assemble something. There is exactly the right amount of everything for e.g. one or even three different parts with the assembly instructions on a pallet. When there is a bigger part that needs several small parts to be assembled in to it could the part pallet with the illustrated instruction be brought to the assembly line with the big part together. *JIT* is something that must be understood deeply. Factories with their manufacturing and material handling easily get stuck into their systems and can't see the possibility of a change. It is safe feeling when having e.g. a little bit overproduction than aim to the perfection with material storages is directed in many Toyota Way Lean sources. Some mistakes are easily forgotten to investigate. It should always be as a habit to search the root cause for even small mistakes.

In a Finnish Toyota Lean book (51, 123) was said that when having more than two similar kind of different parts to assemble on the same place will the parts be easily mixed. This happened when Toyota had five parts in their assembly line on the same place. That is why assembly phases should have only a couple of small parts because faulty products keeps dropping up too often. Assembly places for all phases should only be then more.

## 1.7 5S

"JIT" also demands good 5S system meaning clean workplaces and organization (25). Keeping environment clean and tools in order helps trolleys moving and employees work phases fast and safe. This system can even reduce bad quality. The environment (5S) needs some checking weekly or at least monthly in the production. Usually in Nokia this check is done by supervisors and area managers. They report the findings to the line supervisors and then will responsible persons set everything in order (see figure 5). When implementing 5S there should be 5S teams from the same working area considering 5-12 people, steering committee of 5-15 members, 5S coordinator and a management champion (2).

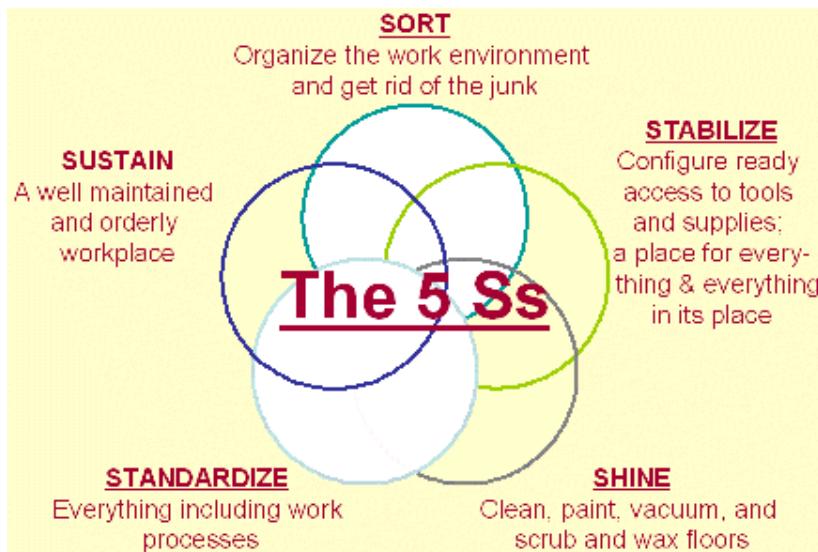


FIGURE 5. 5S explanation (1)

## 1.8 Small-batch-production and One-piece-flow

Small-batch-production and one-piece-flow are known as a part of *Toyota Lean production system*. Small batches cause in the manufacturing less mistakes and scrap parts, but less additional time too because there is no need for sorting or stacking in the middle of the work phases. It keeps so the cycle time low but quick. Products should move through production as one piece at the time in small batches what keeps the amount of faulty products in minimum. The main vision

is that the products will pass through in all material flow overall only once. A lay-out of one-piece-production can be seen in figure 6.

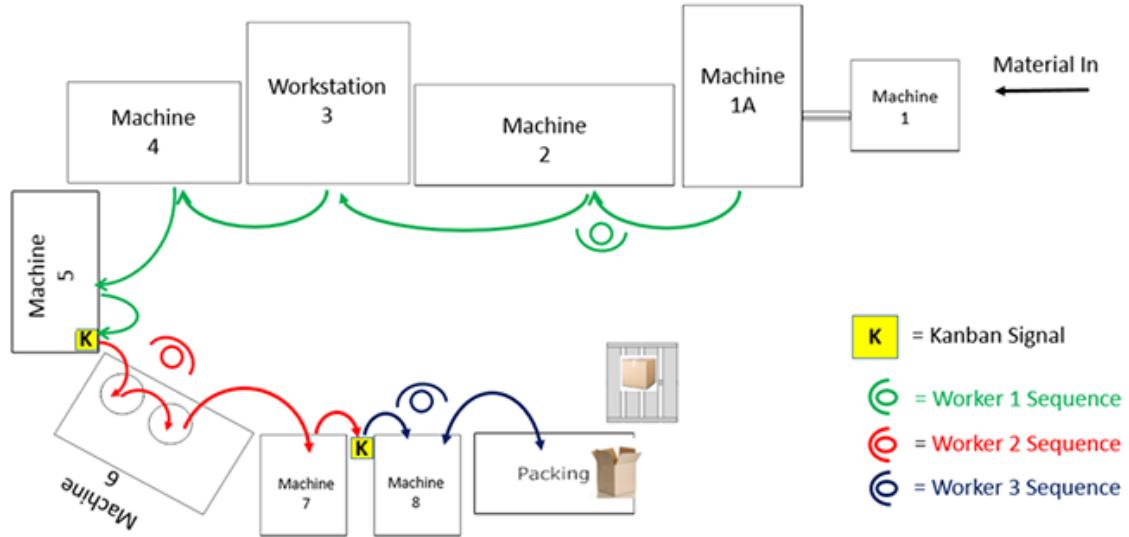


FIGURE 6. One-piece-flow cell (35)

### 1.9 Jidoka and the Andon lights

The origin of the *Jidoka* is the Type-G Toyoda Automatic Loom (figure 7). It is, the world's first automatic loom with a non-stop shuttle-change motion,. It was invented by Sakichi Toyoda in 1924. This loom automatically stopped when it detected a problem such as thread breakage (17).



FIGURE 7. The origin of Jidoka (17)

If there turns up some error phase in the manufacturing process e.g. because of a broken machine or tool causing bad quality will the *Andon lights* be turned to red and the process stopped immediately. This avoids of more coming faulty products. If the batch is big there is always a

chance to get a big amount of faulty products. This *Jidoka* system is in use in Nokia and that must be considered with the material one-piece-flow flow when planning the material flow to small assembly parts (33).

*Andon lights* were also helpful with solving the problem of material flow. It showed that the rate time on the production line considering small parts amount did not match with the time of the material train. This was because people work in different rhythm in every shift and additionally it took very long period, despite with the help of *Andon* lights, counting to get the right amount of the parts to be enough according to *JIT*. This had to match with the material train cycle too. “*Andon is a principle and is also a typical tool to apply the Jidoka principle in Lean Manufacturing – Jidoka is also referred to as ‘autonomation’, which means the highlighting of a problem, as it occurs, in order to immediately introduce countermeasures to prevent re-occurrence*” (5). *Jidoka* with *Andon* lights is a very good system in *JIT* and used overall in Nokia production where are machines and material consumption. Swithing the lights to red will stop the production as long time that the problem has been solved (see figure 8). In machines they can also be switched automatically.

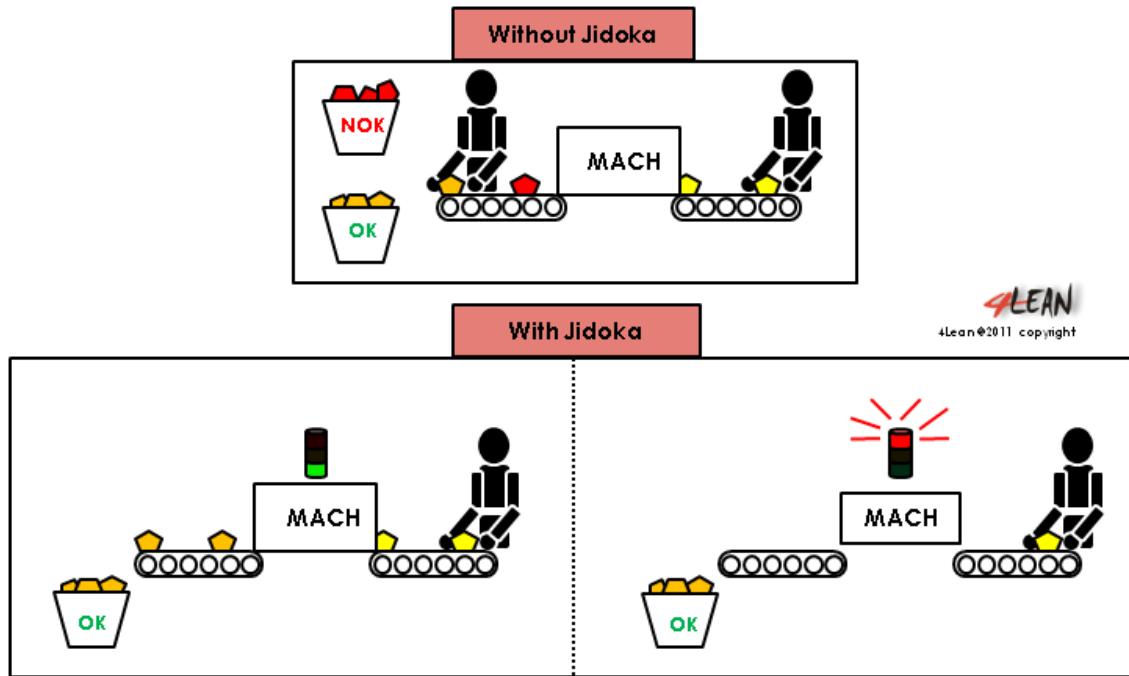


FIGURE 8. *Andon* lights interrupting the faulty production (6)

## 1.10 Gemba and Genchi Genbutsu

The production places, working places in the factory; where all constructing happens is called *Gemba*. It is very important that all engineers, supervisors and even CEO:s visit the *Gemba* time by time to see how everything works there. This visit is called *Genchi Genbutsu* what means "go and see!". This had to be done very often during the thesis to see how the problems had to be solved. It can't be striving enough to any firm by running improvements and suggestions only by phone and e-mailing. In Nokia is normal that e.g. Oulu factory manager and other managers are visiting the production or even checking some manufacturing phases by working them through. There are so many short and odd words in Toyota Lean Manufacturing system for new readers so there is put an appendix (Appendix 2) with them at the end of the thesis.

## 1.11 Heijunka

There is always fluctuation in the production brought about of customer demand. When many various product (mix-models) must be produced at the same time *Heijunka* facilitates Just-in-Time. It improves production efficiency by levelling fluctuations in performance in the operation. (28). *Heijunka* can be balanced by a help of a visual chart. As seen in the *FIGURE 9* has the work load between different operators put in balance quite well.

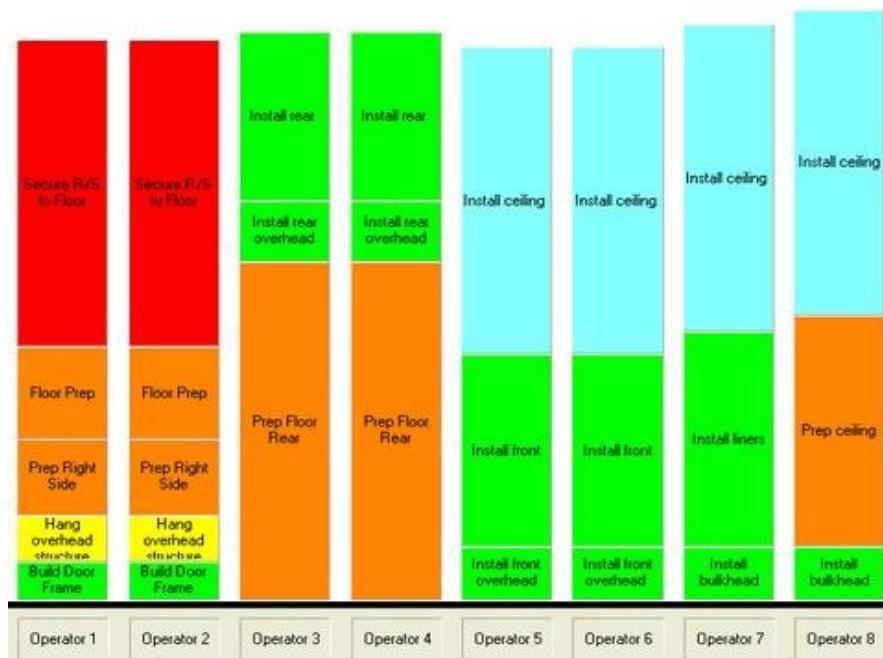


FIGURE 9. *Heijunka* planning chart (11)

## 1.12 Yamazumi

Yamazumi chart is a great help when balancing tasks between assembly operations. It can be seen in figure 10 that big boxes are big tasks and take a lot of time. There is now easier to begin to move some work load from other task onto other task for balancing these manufacturing phases reducing at the same time the work overload and stress. The material flow plan needs to consider the work balance between different machines and parts. Some kind of weekly yamazumi could be done in the future.

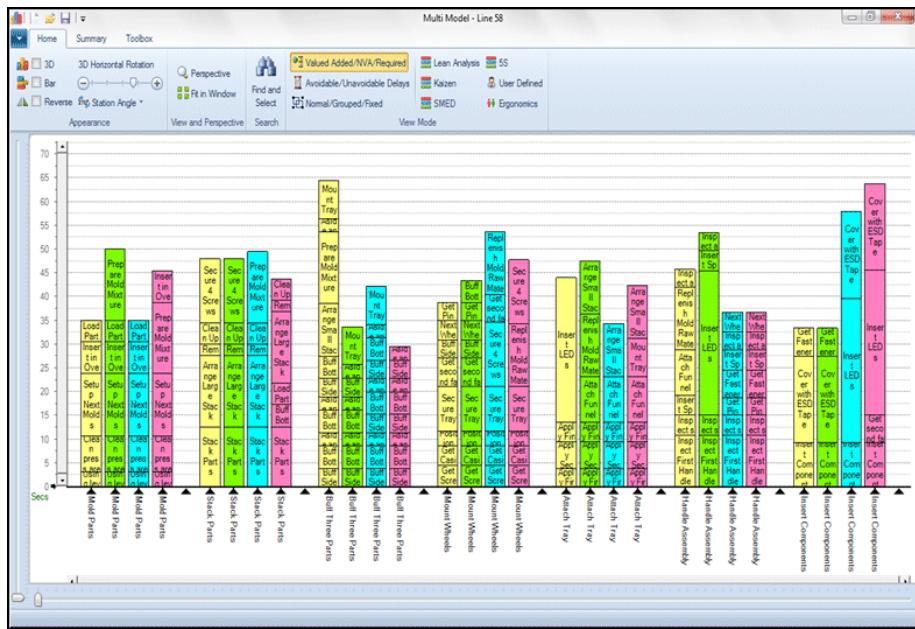
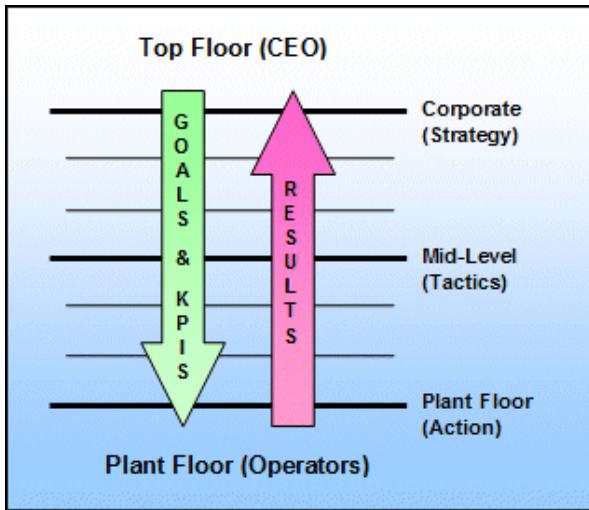


FIGURE 10. Yamazumi operation chart (60)

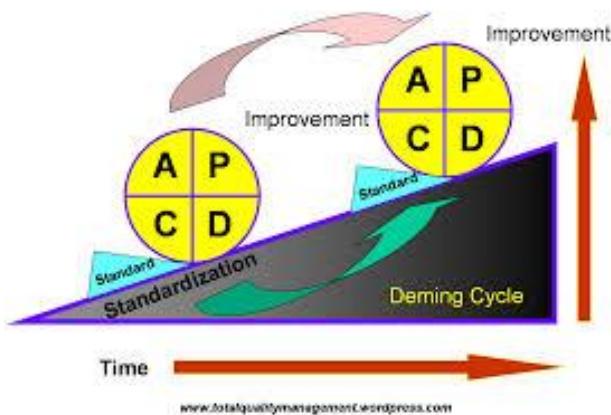
## 1.13 PDCA and Hoshin Kanri

When work is standardized the waste be in minimum level through Kaizen system. In Lean manufacturing there is a ten and five years planning vision system for managers. This vision must be seen through all levels in the company. This needs *Hoshin Kanri* (see figure 11) for help. *Hoshin Kanri* (called a Policy Deployment too) is a method for ensuring that the strategic goals of company drive progress and action at every level within that company. This eliminates the waste that comes from inconsistent direction and poor communication (13).



*FIGURE 11. Goals and KPIs (Key Performance Indicator) travel from the top down, while results are returned from the bottom up (13)*

For making this succeed is there a “PDCA” - system rolling around all the time (see figure 12). By “PLAN”, planning the improvements via *Kaizens* will then come “DO” phase and after that “CHECK” before “ACT” again. By rolling this system will there be *Kaizens* made all the time and improving for the production processes and work phases including tools continuously. For example if balancing the work load between different tasks must there be used this “PDCA” system for getting improvement through. After planning the improvement must then begin to do whatever needed to get to the needed point. The system must be inspected from the affects of improvements and act if needed to begin to improve something again or modify the made change.



*FIGURE 12. Plan-Do-Check-Act (36)*

When all actions considering the thesis has been done should the “Lean system house” in Nokia be still stable and not collapse. Figure 12 shows all the important bricks to take care of in the Lean manufacturing system and their place when making some changes to production.

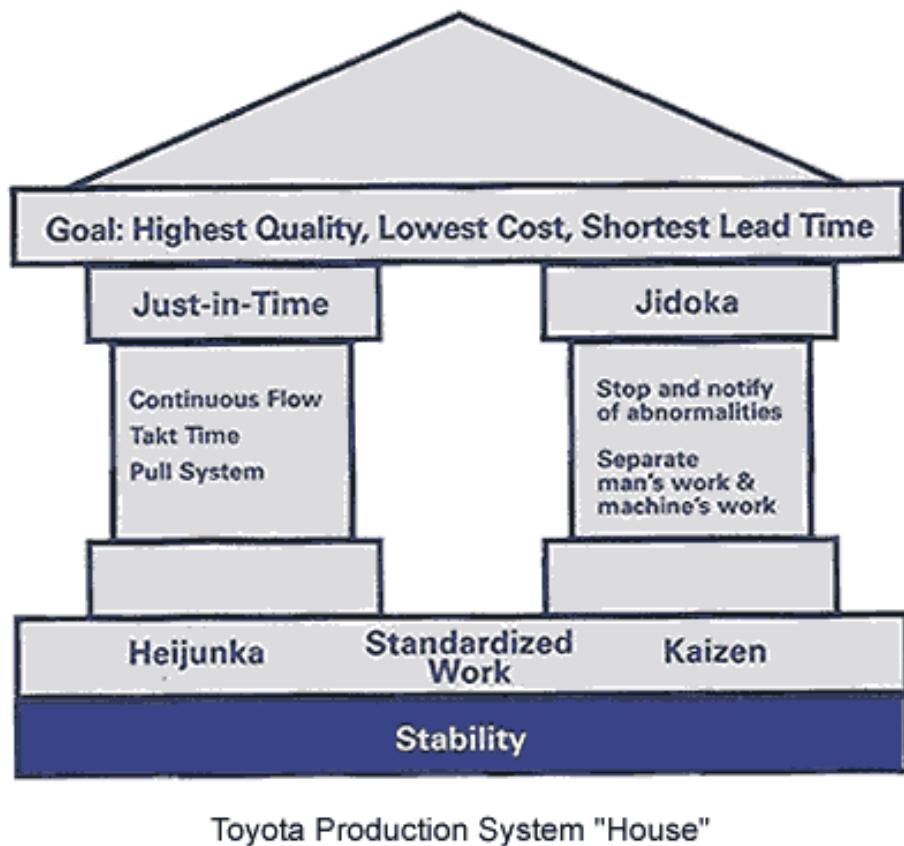


FIGURE 13. Lean system house in balance (28)

## 2 INTRODUCTION OF PRE ASSEMBLY CELL

### 2.1 Cell layout

Lean manufacturing prefers cells because there work phases and tasks can be easily balanced. They are additionally flexible for variety of products and the number of assigned operators (8). Everything there is close and communicating with each other is smooth because of employees are close to each other. The amount of input and output material is easy to calculate too. Cellular layouts (figure 14a) require less space too. It has been found out that they increase material velocity through the plant and improve service levels. If some product needs many assembly phases it just moves around the cell stopping on every table a short time and then it is ready after the last phase. If this was done on many straight lines would the products be put to many queues between every line to get the processes through. This option would take a lot longer (9).

*"They reduce inventory and the myriad costs associated with it; and they achieve both manufacturing flexibility and team accountability for product and process performance. The biggest benefit is Manufacturing cost reduction and increased plant competitiveness, as a result of the combination of all of these benefits."* (7)

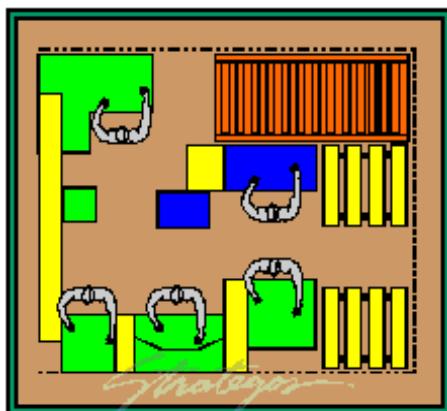


FIGURE 14 a. A cell lay-out (9)

Cells can be constructed to U shape too (figure 14b). Moving there closely from right to left reduces the amount of steps and time including floor space. The most used U shaped cells are often made only for one person (e.g. post office, packing place or even a shoemaker). They reach then easily from left to right and straight ahead, up and down easily by hands for collecting arti-

cles, without unnecessary walking at all. There is also clear input and output place for products and counting and visual control including the tact time is easy to see.

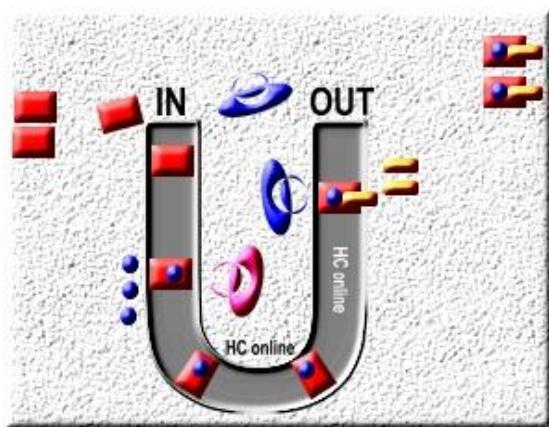


FIGURE 14 b. U shaped workcell (53)

## 2.2 Lay-out in Nokia production

In Toyota factories there are in use both cellular and line lay-out for different products. By looking at commonalities in process routings will the layout of equipment and workstations achieve optimum flow (24). In Nokia are some layouts straight lines opposite each other. They are although in the same cell where is made the same product from the beginning to the end. The next "customer" for these finished products are then usually bigger units what these are part of. So these finished parts will then be pushed in a trolley to other line for assembling them together. There is a possibility to connect cells together by making of them a long stretched assembly line. In cells there are various kind and size of parts to be assembled including the different material storage places e.g. trolleys, pallets, bins and modules in racks. Material must be brought to the assembly lines smoothly to all assembly places. There are sometimes testers in the middle of the cell and their failed products must be able to take away from testing places and some reworked products get in to testing inside the cell too. This is the environment where all the pre assembled parts are going after assembling and where from the empty pallets are brought out.

## 2.3 Pre Assembly Cell

Pre Assembly Cell is a small area inside the Filter Production line. In the beginning of this project it consisted of five assembly tables, two shelves with assembly parts, an "empty pallet" table, table for empty bins, and a rack area for small modules. All was done by hands by even five as-

sembly operators in each shift. The only used electronic tool in the cell was a soldering station that was on every working table.

## **2.4 Pre assembly parts and tools**

Assembly parts were all made of metal, mainly of copper and other metal. The soldering heat to them was nearly always in the soldering station at the end of the tip 425°C. The tips did not last very long time because of using 24 hours whole week. The cost of the tips was quite huge even monthly. Soldering wire consisted of Pb -free tin and silver with flux. Some modules needed some extra flux too in the soldering process. A soldering paste tube was also in use. Some parts needed some pre soldering paste before their soldering process. Other tool used with the soldering iron was different type of jigs. Small parts to be soldered were first put into the jig and then soldered together in right angle.

## **2.5 Workload in the cell**

Depending on the amount of the units per week was the pre assembly cell sometimes very busy. Even five hand assembly operators there were too little in one shift. They were in a rush whole eight hours all the time when there was a high peak in manufacturing. Empty pallets were brought to the “empty pallets” table for getting more parts. A shelf had ready parts, but there had to do more all the time. Some products consisted of three and some of six similar parts and there were nearly 20 different kind of assembled parts together. Very many of assembled parts were assembled even over a thousand pieces every week.

## **2.6 Assembly instructions**

Assembly instructions were in front of the all assembly tables hanging there as paper versions. Same instructions were found from every place so that assembly for all products was possible on every place. The problem was that when they were in paper versions were they not easily automatically updated. This was a subject that needed some automation too. All parts had assembly instructions. There stands the component part codes, jig number, recommended soldering tip and quality requirement criteria for the assembly result.

## **2.7 Scrap material**

When parts were made a large amount in a rush every week were often new helping hands needed from other departments. Soldering parts by a new assembly operator affected to the amount of the scrap material because of practicing and disapproval by the quality facilitator. The soldering itself caused weekly quite much scrap material anyway. The thin metal parts twisted easily and when the solder spread too wide was it difficult to solder again to the limited small area. The good point here is that they were quite cheap.

## **2.8 Material flow in the pre assembly cell**

*“One-piece-flow will help a manufacturer make quality parts in the correct quantity at the right time. It works most optimally in combination with a layout where all the necessary equipment is located in a cell in the sequence in which it is used”* (33). All the needed material for the assembled parts were in one shelf inside the area. Beside this shelf was other shelf waiting for the finished parts. When a pallet got empty in the production line, was it brought by the material person to assembly cell on the “empty pallet” table. The hand assembly operator took it and the needed parts from the shelf including jig, and soldered the parts together. When the material ended up in the pre assembly cell was the bin or the pallet put on the “empty pallet table” to get more. All codes were marked on the side of the shelf. There was a label on the pallet too for controlling the amount of needed parts and right material codes. When the pallet was full was it put onto “ready parts” shelf.

The material person takes the full pallet from the “ready parts” shelf and when bypassing by the train the assembly line puts it on the exact assembly place. All the places are marked from the both sides in the assembly line. The pallet was taken from the shelf only if it was ordered to the production line by putting the empty pallet first from there on the “empty pallets table”. The empty pallet was a part of a *Kanban* system, a sign for asking more material.

## **3 PLANNING THE AUTOMATION**

### **3.1 Manufacturing phases**

If possible it would be very helpful for first learn to do all the assembly phases by self. It would fasten very much the automation project. In addition by seeing very closely the hand assembly operators work for each component assembly is important. Very many different kind of parts and assembly jigs, the width of the tip and soldering wire and the quality issues must be considered. Soldering itself consists of many phases. There is preheating, soldering, post heating and cooling time. These must be considered when choosing the automatic equipment. The right temperature time with the right amount of solder causes the best quality to soldering joint. Because all parts are quite small must they be soldered with the help of a jig. Jigs assure that the parts will be soldered exactly to the right place with the other part in the right angle. All parts must use a jig in the soldering process. This had to be considered in the automation plan for example they could not be set in the oven if they are made of plastic etc. Automation implementation plan consisted of all assembly phases with the right larger jig for the automatic machine, the new way of automatic soldering and at last the quality check approval. The other parts will be automated just after first parts successful implementation.

### **3.2 Assembly part groups**

All the small parts that needed automation were divided to small groups. Same kind of parts consisted typically of the same kind of assembly phases, tools and jigs. This made the sorting more simple when taken account the heat length and tip width to the same automatic choice.

#### **3.2.1 Metal parts**

The fact that e.g. copper changes its colour when getting too much or too long time heat had to be considered in automation. All metal parts had other part made of copper. In addition the fact that plastic jigs did not last too much heat had to be taken into account when ordering jigs and choosing the automation option.

### **3.2.2 Small modules**

The other group consisted of small PWB modules with long pins. The other module needed two pins and the other only one. They were soldered by soldering iron until this and with the help of jigs. The pins had to be soldered in 90 degrees angle. Their quality criterion demanded additionally X-ray inspection from inside the soldering to assure that it was wetted 360 degrees around the pin and also 50% from the height of the soldering collar was full of solder.

### **3.2.3 Coil nuts**

The third group that needed automation was small coils. The soldering was already melted in a reflow oven, but the coils which consisted of small nuts got the soldering paste put by a dispenser with a foot pedal and by hands. So the phase solder paste dispensing needed to be automated.

### **3.2.4 New design needed parts**

The forth group consisted of two metal parts that were soldered together with the help of a jig as every other metal part in the cell. There was one similar type of the component compared to this that needed any soldering process at all. There started so a process for possible change to all other quite similar type of components. This concerned then even nine different product. The part needed only a new design from the other end of it. Buyers and designers began to find out if this possible change could get to these parts. The saving costs of making this possible could give huge savings per even a week.

### **3.2.5 Metal parts with a plastic “hat”**

There were two different kinds of copper parts that should be assembled with a small plastic part “hat”. The other was done only by hands by pushing the “hat” onto copper. There was a locking place in the middle that made assembly a little difficult. The other was two metal parts soldered together and then the “hat” pushing on it afterwards. It was no benefit of any kind of a jig because they were already after the soldering process standing on a jig. The only helping option to make the “hat” pushing safe was a new good assembly tool. No automation was so needed for “hats”.

## 4 AUTOMATION CHOICES

The options for pre assembly part automation in the SMD area were a reflow oven, a selective wave soldering machine, soldering robot and an automatic soldering paste dispenser used together with SMD reflow oven.

### 4.1 Soldering paste dispenser change for coil nuts

There were even 160 nuts per one pallet. These pictures were taking after the soldering paste put first by hands (figure 16a) and then automatically by a dispenser machine PVA650 (figure 16b). When the soldering paste was put automatically was the amount of it very same everywhere. Figure 15a on the left is pasted by hands with the help of the foot pedal. There is the amount of the paste very variable when comparing to the automatically put soldering paste on the figure 15b.



FIGURE 15 a. Soldering paste put by hands



FIGURE 15 b. Automatically put soldering paste



FIGURE 16 a. The old hand assembly dispenser



FIGURE 16 b. The new automatic dispenser

#### **4.2 Small modules with long pins**

Small modules needed a jig to support the pins against the PWB. The supporting jig needed to be both upper and other lower for making pin dropping by hands fast and straight into holes before the soldering process. The new automatic assembly way for them is a Selective Wave Soldering machine (figure 17). It is a machine where a soldering nozzle puts liquid solder exactly to the right programmed places from the underside around the component leg. Components soldered by this machine must be a certain type with “pins” through the PWB. They are called “Through Hole” components.



*FIGURE 17. The selective wave soldering machine*

#### **4.3 Design change for similar kind of parts**

The design change takes so much time that it will be get through all processes after this thesis is finished. Assembly time from one minute per part is after the change only one second. This part is the most used quite similar part for every product and they are needed over one thousand per week. All the soldering for this part will end soon and the part being assembled just by pushing two parts together.

#### **4.4 Copper parts assembly with other metal part**

If copper part is heated too long time or by too high temperature will its colour has changed. This had to be considered and that is why e.g. reflow oven and soldering paste dispensing together was not a chosen option. The new soldering robot was a chosen automatic option for all metal parts that had to be soldered because there was not any surrounding heat inside it. Soldering was only using nitrogen which makes always the soldering joint brighter and nicer than plain air.

## 5 NEW SOLDERING ROBOT IMPLEMENTATION

A new soldering robot (see figure 18) was bought to Oulu factory. Automation is something that must be inspected with great curiosity to find out where it can be implemented to make the quality better in some processes and at the same time manufacturing faster.(This is the Lean Principle nr 5: Striving for Perfection). Automatically made work phases will lead to less scrap material and assembly time. Counting the output and management for the production is additionally easier when cycle time in assembly operation is always the same.

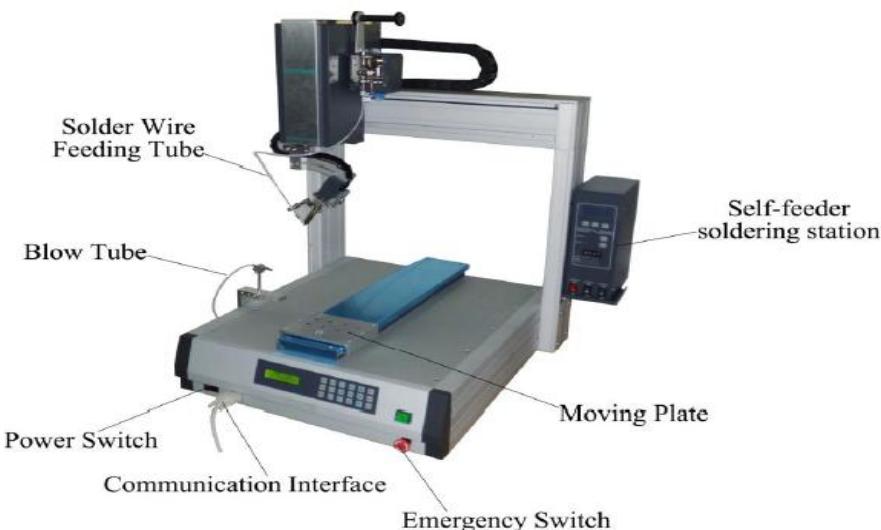


FIGURE 18. Quick Soldering Robot ET9434NA

### 5.1 Soldering robot accessory

Special soldering wire Almit 48S SR-37 3,5% 0,50 mm was ordered to the robot. Tip number 2 (911G-30DV1) was smaller than number three that included in to the package and because the soldering tip with 1,88 mm wide end was mainly used in soldering iron were smaller tips ordered too.

## 5.2 Moving pallet

Before ordering any larger jigs for the parts, needed the soldering robot at first a bigger moving plate (figure 19) so that there was possible to fasten big jigs on to it. There is no benefit of a soldering robot, if it soldered only some funny parts instead of soldering e.g. 50 at the same operation. The small including moving plate inside the robot was left on its place and attached inside to new big moving plate from bottom side where was modified a cavity for it. That dropped the height from the moving pallet and made possible to attach higher jigs onto it. The moving pallet size was ordered as big as possible considering the robot axis movement limits and it was even 370 x 450 mm.

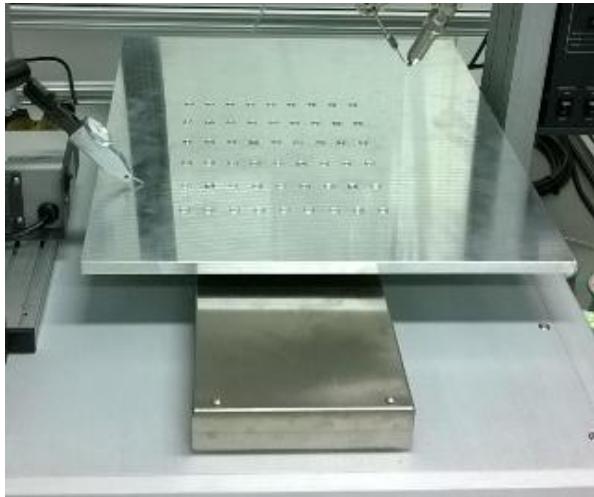


FIGURE 19. New moving plate

## 5.3 Phases for the automation

When the big jig was got from the manufacturer was the first step to make a soldering program for the first chosen pre assembly part. After accepted soldering result (visually) was the quality of parts checked by the quality facilitator. Parts were done several trays before accepting the soldering process to the production assembly line. Material flow was then forced to be planned again because the soldering robot was not physically inside the pre assembly cell. Two hand assembly operators in every shift had to be trained to use the soldering robot. In additional there had to be done the assembly instructions including the simplified user manual for the robot users.

### **5.3.1 First part with the assembly jig to the robot**

The first jig was subcontracted from the same manufacturer that had also made smaller jigs to assembly operators need. The first chosen pre assembly part for the robot soldering was the most consumed part from all the pre assembly parts. Hand assembly jig had six places for this part but to the robot was decided to get 35 places to them. Furthermore there had to be left some space for the fastening clamps and guiding pins around the jig.

### **5.3.2 Right temperature and time for the soldering programs**

The soldering robot uses milliseconds in its programs and the best and fastest way to make a soldering program to these first parts was to copy the times from the soldering phases from the soldering iron. While the hand assembly operator was soldering, was the time clocked at the same time by a stopwatch with a millimeter counter. There was the preheating time, the soldering time, post heating time and tip backing off timing. The length of the soldering wire and the tip size was easily got from parts soldering process. The soldering time was very much similar by the soldering robot and there was also used the same soldering wire diameter and the same width of the soldering tip.

### **5.3.3 Analysing the parameters in TABLE 1**

As seen in table 1, is in the “TestB” the feeding time zero ms . This is because the pre heating time is longer. No solder is then attached. The heating time is still continuing 5 ms longer than in “TestC” because the soldered pin is long and thick there (1<sup>st</sup> Delay). More solder will be attached after this because of the large soldering collar. Preheating time is the 2<sup>nd</sup> Delay and that is shorter in “TestB” because of the long preheating time.

**TABLE 1.** The soldering robot parameters for two different parts

Test B	Test C
Height: 5mm	Height: 5mm
1 <sup>st</sup> Feed: 0 mm	1 <sup>st</sup> Feed: 5 mm
1 <sup>st</sup> Delay: 15 000 ms	1 <sup>st</sup> Delay: 10 000 ms
2 <sup>nd</sup> Feed: 015.0 mm	2 <sup>nd</sup> Feed: 010.0 mm
2 <sup>nd</sup> Delay: 02000 ms	2 <sup>nd</sup> Delay: 03000 ms
Feed speed 010 mm/s	Feed speed 010 mm/s

### 5.3.4 Soldering program

When beginning the work with a new automatic equipment must first think carefully how to name, and where to save, all the soldering programs. They must be easily found later on and they must have a back up place somewhere too. It could be e.g. a spreadsheet for the different kind of parts for later usage. By copying the width of the tip and the diameter of the soldering wire, temperature parameters and soldering time from different phases to the similar type of the components will the program making be fast. Choosing first the certain tip and soldering wire diameter to the similar part or component from the sorted spreadsheet will the programming be fast without any physical tool exchange in the middle of the programming.

### 5.3.5 Lead free temperature profile

The soldering profile should be according to the directed profiles in the figure 20a and 20b. When soldering happens by the soldering robot will the heating temperature and the cooling time be similar comparing to the soldering iron behavior. The Lead free (ROHS) Criteria finds at here: [http://leadfree.ipc.org/RoHS\\_3-2-3.asp](http://leadfree.ipc.org/RoHS_3-2-3.asp).

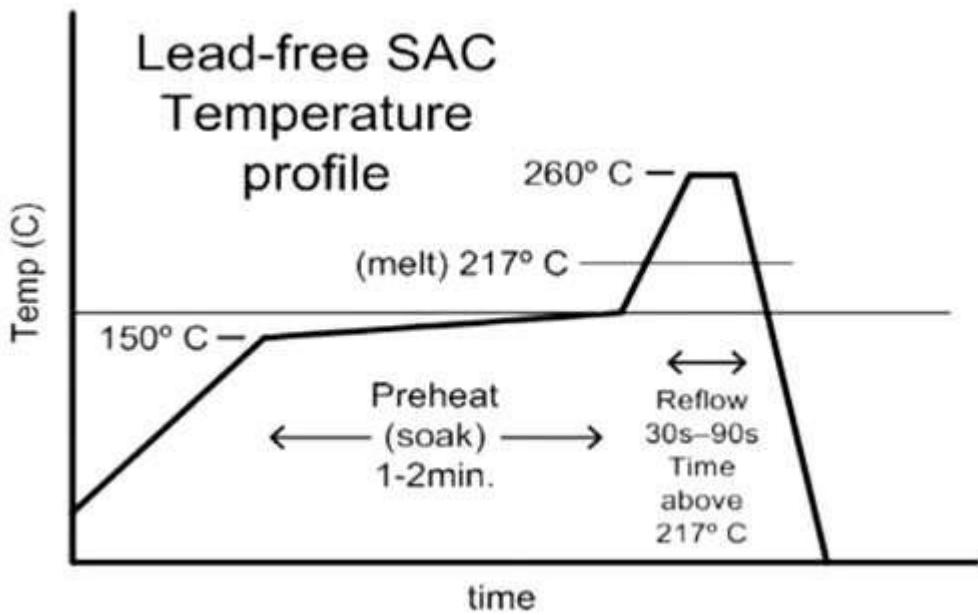


FIGURE 20 a. Lead free temperature profile (38)

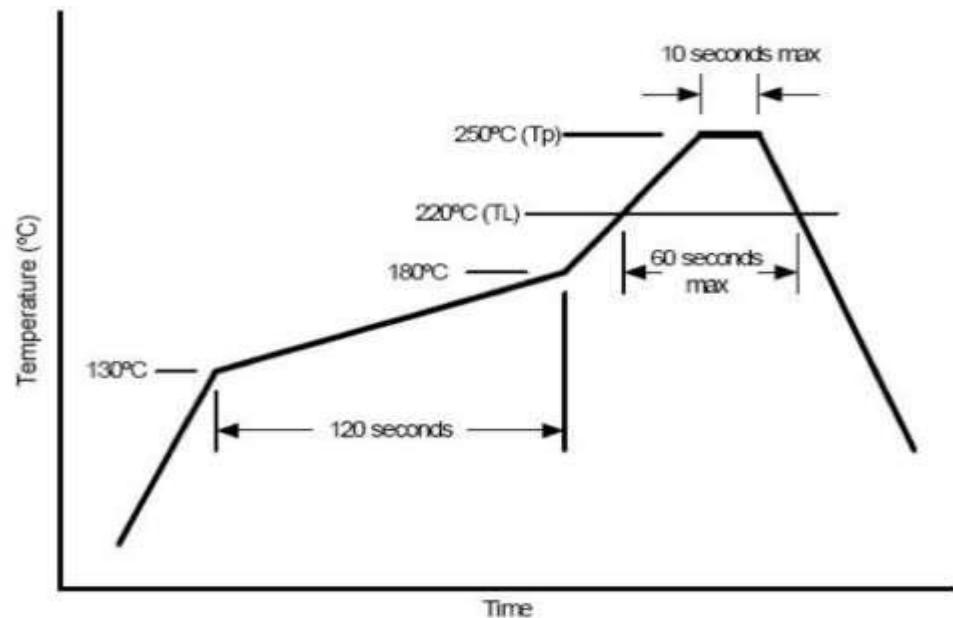


FIGURE 20 b . Soldering time for different phases (38)

## 6 QUALITY ROLE AND TOOLS USED IN THE PROJECT

### 6.1 Quality tools

The inspecting tools for the pre assembled parts in this thesis were microscope (Leica) and X-ray machine. After the soldering process were all the parts brought to the quality facilitators for checking the soldering quality. They checked the parts visually and by the microscope and sometimes with a X-ray machine.

All soldering acceptance was based on the accepted criteria of the quality standard system "IPC" (14) considering ROHS manufacturing where solder is totally lead free.



*FIGURE 21. X-Ray picture of two nuts having too much soldering paste inside*

## **7 INTRODUCTION OF NEW PRE ASSEMBLY CELL**

### **7.1 New lay-out inside the cell**

The new assembly cell was totally modified to a new kind of an automatic cell. The old cell had five working tables with several soldering stations, but only one soldering station was left for a possible solder repairing or parts removing (e.g. wrong parts) on the table beside the soldering robot. The assembly cell was changed for an automatic assembly cell filled of machines. The pressing machine for the mechanics, the automatic dispenser and the soldering robot were all gathered there together in a circle with their working tables and computers with displays.

Now when small modules are made by Selective Wave Soldering machine are their storage place there near the machine. Their unused buffer place was left in the pre assembly cell floor being reserved for the same “ready” modules after soldering process. When the pin soldering has happened in the SMD area will the racks be brought to their buffer with the finished assembled parts. They only need an operator to cut all the modules to trays. The material train will then handle the material flow from there to the production line as before.

### **7.2 Trays instead of pallets**

Component shelves stayed in the pre assembly cell. All the material flow works on the same way than before except the amount of the parts made by soldering robot is larger and the pallets have changed to bigger trays. The “finished good” shelf has been removed because of the trays keeping in racks. The ready parts trays are so now on the floor in tagged buffer inside their racks. Racks are marked by their products (four places to each part) and product colour label. The first parts should be done in every shift total four trays to be enough for the need of one and a half shift.

### **7.3 Digital Instructions**

All the assembly machines have got all the needed assembly instructions on their computers, and the displays are naturally there in front of the table. Instructions for using the soldering robot, antenna connector machine and PVA automatic dispenser has been made there for users.

## **7.4 Quality Assurance register for soldering robot**

Because assembling the small parts will be done by different operators in many shifts must there be a register for following the assembly quality and giving feedback. The register is in a form of a spreadsheet on the computer beside the soldering robot. All trays have been named as the production line number with other number that is counted from the beginning of the assembly line e.g. F4\_1A, F3\_2B etc. (Filter line number 4 and place one on the assembly line , Filter line three and second assembly place there etc.). The letters from A to D are explained below in chapter 7.5. Material persons have now it easy to bring full trays back to the production line on the right assembly places. It is additionally easier and faster for bring and collect the trays with the numbers than with the names of the parts.

## **7.5 Traceability of small parts**

When the parts are being assembled will there be the traceability of their versions and vendors found afterwards. If there drops up for example a quality problem with the poor substance or the part is even the wrong version could they be found and blocked easily away. When parts are brought to the assembly cell must they be in their original unopened package. When assembly operator begins to work with the parts, will the batch number and vendor information be collected from the packages by a barcode scanner into the "Soldering log" -spread sheet on the computer (Appendix 3). That is why trays have letters from A to D. Because trays are making the round in the production all the time in FIFO principle (first in and first out where the oldest inventory is used first), will trays be able for tracing inside 24 hours when the possible version or quality change was happened. The new pre assembled full trays are put in their racks so that the FIFO is actualized. Material persons will be advised by an instruction to take always the next letter (from A-D) next to the returned empty tray letter from the rack. If the empty tray is C must the next one taken to production be tray D.

## 8 MATERIAL FLOW TO PRODUCTION LINE

### 8.1 Kanban used in the production

The pre assembly cell has an empty pallets and bin system used as a Kanban. “*Kanban underpins Toyota's "just-in-time" (JIT) production system. It works on the basis that each process on a production line pulls just the number and type of components the process requires, at just the right time. The mechanism used is a Kanban card. This is usually a physical card but other devices can be used*” (23). This “device” is in Nokia a pallet or one of a different size of material bins. Kanban system is called as a supermarket method in Toyota system. There is a warehouse with all codes marked on the shelves in Nokia and it makes it easy to find the needed parts quickly. When all the pre assembly parts on the production line were used from the pallet was the pallet brought back to the pre assembly cell by the material train. When the material person drove the next round by the material train was the full pallet returned to the assembly line. The train brings more parts from the warehouse to the pre assembly cell when needed. The parts are put on the right tagged shelf here too.

### 8.2 Kanban signs and colours in use

The empty pallet worked as a sign to assembly operators to begin to assembly more of these parts. Flags are used as a *Kanban* in the production. When trolleys of mechanics, units or modules end up will there be turned a flag up on that assembly place. Flags are made by different colour of carton. The flags colour are green, yellow and blue depending on the requirement of *Kanban*, if it is modules or some mechanics that is needed. In addition a red colour is used to indicate the faulty products collecting to the rework area. When a trolley has three faulty products will the flag be pulled up. Train is not handling these. Material person collects those faulty products in the beginning of every shift once. (The operator pulls the flag from vertical to horizontal position from a rope). The train takes three rounds in one hour and one round is longer so red is handled only then. The train cannot handle all the colours on the same round. This is because train would be otherwise too long and so unsafe to drive in the production. Furthermore some material must be brought in separate trolleys and they need different kind of wagons in the train. This system is good according to the *Kanban* definition. “*Each process (area, cell) on the produc-*

tion line has two Kanban 'post-boxes', one for withdrawal and one for production-ordering Kanban. (16). See Kanban used in figure 22.

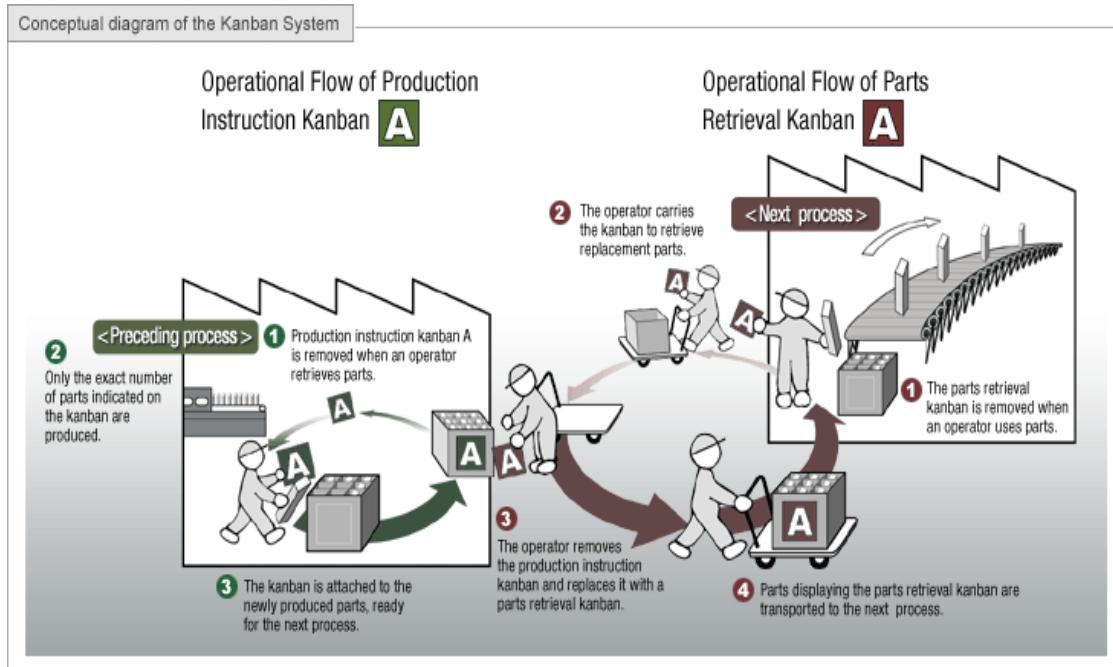
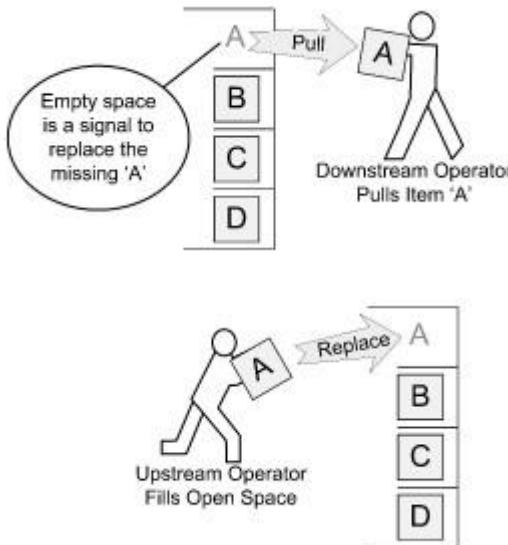


FIGURE 22. The concept of Jidoka and Kanban (17)

When manufactured items moves from other cell to an other line it is difficult to keep an empty manufacturing place as a part of a *Kanban* system (see figure 23). Products can be easily mixed up. If the assembled part of the product is made inside the same cell/line is this a very easy *Kanban* system to use. If assembling has been divided e.g.in to 6 different sections there are for example four operators is the material flow pulled by an empty place between them. There are still two empty places to give some flexibility to help the others if there comes some problems.



*FIGURE 23. Empty place used as Kanban (10)*

### 8.3 Instruction Kanban

Toyota has in factories a *Kanban* system for the instructions too. When material is brought to production line are always the assembly instructions included with them. If there are various products and several assembly phases is this a must system to assure the quality in assembly.

If material were in a KIT could there be instructions within them too. Other option is to have the instructions waiting on the exact assembly place. In Nokia where products have their own manufacturing lines are instructions always hanging as paper versions there for operators to see them. Work instructors and quality facilitators take care of having always the latest updated versions there. When having e.g. several hundred employees working in the production it is not a wanted situation to get access for everybody to the server. This is why the so called "volume lines" use paper versions in the production. The new automatic pre assembly cell got all the instructions put into computers. There is so few users that this is possible.

## **9 IMPROVING SYSTEM BY “VALUE STREAM MAP”**

### **9.1 Value stream mapping (VSM)**

Sometimes there is a compulsive situation to get cost reduction e.g. because of the bad situation on the market. The first subject where to begin to chase the waste is the factory. (Though eliminating the waste should be part of the company behavior every day by Toyota). With the help of a value stream map (VSM) it is easy to see what process gives value and what does not. Then the "future state" VSM can be created without as many non-value-adding activities as possible (56).

In this thesis when many assembly chances was replaced by machines and new operations was a Value stream map good help for using as a guiding chart. There was seen all the processes and then made a future map of the future situation. This gave Kaizen ideas to new pre assembly cell and other existing pre assembly operations there. Non value operations like too many moving phases to assembly operators and material persons were cut off.

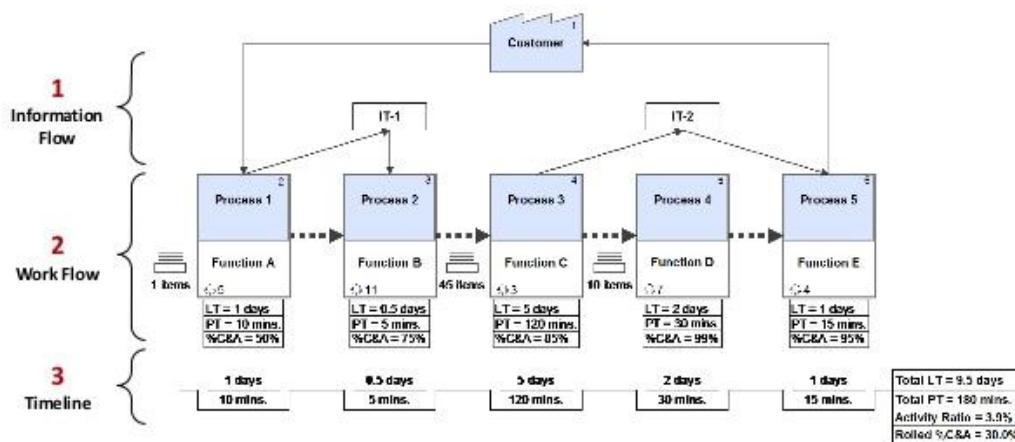
Value stream mapping according to Lean is something that everyone must be able to do. It represents the material and the information flow from customer to production through whole organization. It will be difficult to analyze all kind of the problems like delays in the production without it. When making The VSM first time it is recommended to make with a pencil to a large A3 paper together with other employees involved on the mapped area (59). There is given referred symbols for the VSM at the end of the thesis. (Appendix 5)

When first “The Current Situation” of the VSM has been made is the second phase to analyze the time, the amount of processes and functions. According to Toyota Way Field book (37) improving isolated processes seems to come more naturally than improving flow across value streams. Improving the isolated processes happens through *Kaizen* system. Karen Martin with her group has made two very good examples of Value Stream Maps (below). They can have asked the five why questions there like “Why do we have five processes here or “Why does this take so long time?”.

Here is seen that after the Basic Current State value stream mapping was the amount of all processes reduced from five to three. There became standardized work time to all functions. In addition the manufacturing time for products has dropped with several days. Information flow (IT) began to have connection to IT2 and before there was no connection at all between them. There is seen that IT1 and IT2 took different roles at the same time. Activity and Rolling ratio have in-

creased a lot too. If this production system had some machine would its usage been improved a lot and so payback time e.g. for new machine come sooner at the end by getting all the benefit of its usage.

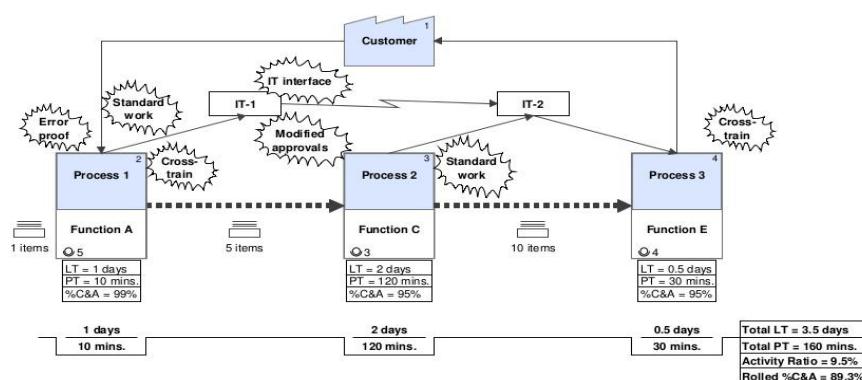
## Basic Current State Value Stream Map



18

FIGURE 24. A picture of a Current Value Stream Map (55)

## Basic Value Stream Map: Future State



8

FIGURE 25. A picture of a Future Value Stream Map (55)

## **9.2 Value Stream mapping the “Current State”**

There are seven good tips given by Toyota Way Field Book (52 , 39 – 41) for the mapping.

1. The current state map must be used as it is without any changes, as a foundation for the future state system. Fixing anything is strictly forbidden except safety or immediate quality issues.
2. The wanted achieved concept must keep in the future state map.
3. Facilitating help from some lean expertise should be used when doing this.
4. When the future map is ready it is time to make an action plan and not only satisfy to the ready drawing.
5. There should be made a plan for only one family product and only just then when it is needed.
6. Some responsible managers considering the mapped area must be with the mapping process.
7. Don't stop mapping when all actions are done. P-D-C-A (Plan-Do-Check-Act). Then Find then one more current map being mapped then to future state system map.

## **9.3 Value Stream mapping the “Future State”**

The seven needed elements for the future mapping according to Toyota system (52, 46 - 47) are listed here below

1. Flexibility requires a finished good “supermarket” system at the end of the process. It shorter the time between order and delivery. See that the customers need meets the leveled manufacturing schedule.

2. Short lead-time is a key characteristic value in Lean. This can be strategically reduced by putting the location of supermarket components after the first flow loop. The inventory level is then at the lowest possible level. Material will move then faster without any waste.
3. Use FIFO lane in processes when connecting them. Triangles, squares and circles are also illustrating connections and so indicating a “sequenced flow” between processes.
4. The supermarket delineates the beginning and the end of a flow loop. The next loop is always a customer to the other and it must be satisfied. The consumption from the supermarket represents the demand. Sometimes there is only one flow loop e.g. having high variety or a custom producer. Then the customer in the beginning and in the end is the same.
5. All the needed external and internal information flow within the stream should be simplified. In the map there is a “voice of a customer” representing the external information that flows to the process. That dictates what must be done and when.
6. Actual physical awareness (instead of only on the scheduled papers) of the customer requirement is demanded on the work area. *Kanbans* and physically defined connections are needed between operations.
7. A pacemaker is a must in every value stream and within each flow loop too. That will dictate the pace for all operations, but the supermarkets role is to divide the flow loops and thus require a separate pacesetter.

#### **9.4 Creating a flow**

At the beginning when creating a better flow is not the main issue to aim the perfection. The first target is to get a good flow in one phase and then create the others step by step. The improving comes then afterwards by linking and connecting each phase dependent on the other (52 , 49).

Continuous improvement is a cycle where after creating a flow comes standardizing, then level incrementally, stabilizing and then the next flow creation again. Rushing to short-term gains will end in disaster warns the Toyota book.

According to it, it is crucial to focus on the depth of skills within the organization than on a short term dramatic push to results (50). All the processes must be set in a time frame representing the customer requirement in weekly, daily and at the end even hourly schedules. By doing this will the process with the greatest weakness i.e. most waste being appeared.

When a customer visits the company should the production flow introduction begin from the end and not from the beginning on the production line. Customers want to see from their side how the pulling happens from their demand so from the end to the beginning in the manufacturing.

## 10 PROBLEM SOLVING BY THE TOYOTA WAY

Sun Tzu's *The Art of War* (figure 26) is the most studied and the oldest book (2000 years) in the world on business strategy. This book takes a process driven approach to problem solving. Its main strategy is to use this process:

### **Sun Tzu's Five Things Process**

Therefore measure in terms of five things, use these assessments to make comparisons, and thus find out what conditions are. The five things are the way, the weather, the terrain, the leadership, and discipline.<sup>1</sup>

FIGURE 26. Sun Tzu's Five Things Process (45).

#### **10.1 Finding the reason by different ways and tools**

Searching the root cause is done by Lean manufacturing asking first five times "Why?". This is told to be the fastest way to find the reason for a problem. In addition Toyota use the "A3" system where is plain A3 size paper and pencils for the problem demonstrating. Very often in Toyota history have A3 reports been required by managers in a big problem situations. This is not only "writing and drawing on the paper although they say so in Toyota Way Field book (52). Even in their book there are 14 pages handled this issue (376 – 390) and telling how to make a good A3 report. Toyota factories employees are trained to use this reporting system and the basic problem solving system. There is even two days lasting classes for learning A3 reporting in internet (3). Problem solving is very wide subject to study for using all the tools and for understanding it deeply. There are used only a couple of Lean problem solving tools in this thesis.

There are three good tools that Lean pages and books recommend to use. "Root Cause Analysis" answers gets by using "Brainstorming", "Ishikawa Diagram" (fishbone diagram) or "Cause and Effect Diagrams" (49). There was used a mind map and found it a very good tool too.

### 10.1.1 Root Cause Analysis

When some of problem solving tool is taken to use is time to find the root cause to problem.  
Lean manufacturing gives there some good advises.

1. Define the problem
2. Divide the big problem into the right subproblems
3. Find the root causes of each subproblem
4. Find the high leverage points to resolve the root causes
5. Development and implement solution elements to push on each high leverage point.
6. The system runs now in a new mode -> PDCA

Root Cause Analysis as RCA is a tool to get rid of the problem cause for good. There should be first doing three steps where first is to determine what happened, second where it happened and third step what should be done for it not likelihood happening again. RCA system assumes that systems and events are interrelated. By tracing one area triggering the other it will be easy to find the cause to the system. There are usually three causes for this and they are physical cause, human cause and organizational cause. There is no use for going too far when investing the problem. The area must be specified carefully.

### 10.1.2 Ishikawa Diagram

After this diagram (figure 27) is filled with all team members will there be taken only top three (by voting) for closer inspection and find root causes for them. Then can team members use five whys for each to solve the problem.

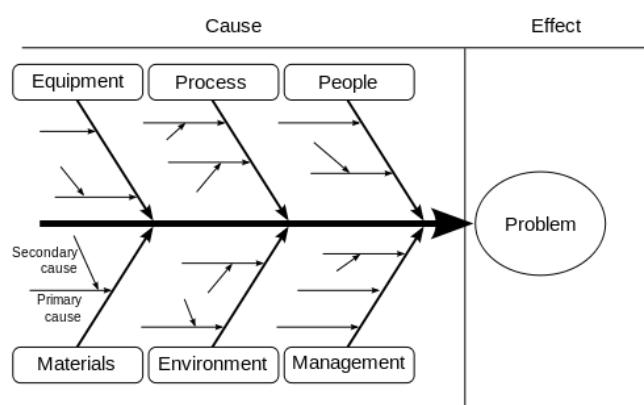


FIGURE 27 The basic Ishikawa Diagram (15)

### 10.1.3 Brainstorming

Brainstorming is something that can be done alone or together with other people. The main purpose is to speak loud and write down all thoughts even the "stupid" ones considering the subject. The goal is to see all the alternatives and get them all the time better by only speaking and writing them together.

### 10.1.4 Mindmapping tool

The problem can be visualized by making a mind map (see figure 28) of the problem. Here is shown the map when inspecting the material problem in the production. The reason was that the counted material was not enough when the shift output rose e.g. from 19 units to 47. In addition a material map was used for learning to use the Microsoft Office Visio 2007 software (Appendix 4.).

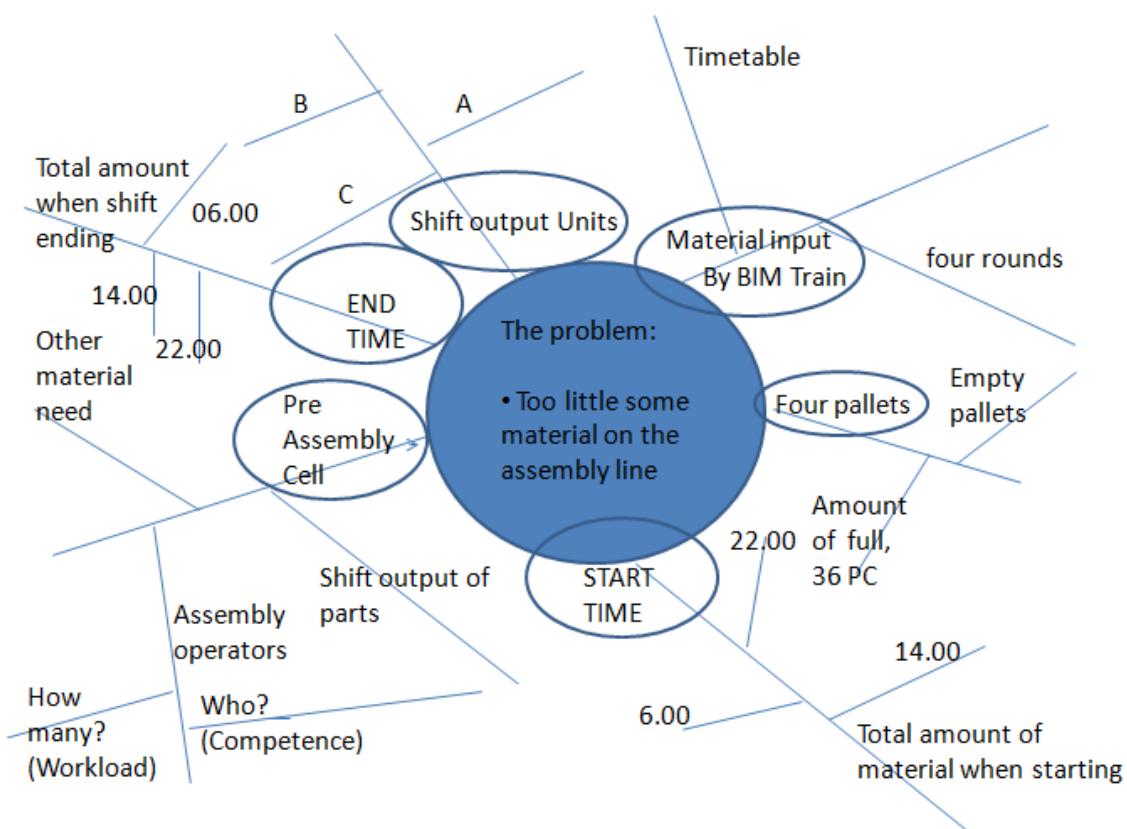


FIGURE 28. Mind map made of the thesis problem material flow.

## 10.2 Problem solving methods

The problem solving should happen very fast when *Andon* sign has called help to the line. Sometimes this is not enough and there must go must beyond the basics of solving problems. According to the Toyota Way Field book (52, 308) some thorough evaluation and reflection and consideration of various options must be carefully considered. This is called long-term strategy development where can happen new product launch, process improvement or policy deployment at the end. This method encompasses a critical and logical thinking process. This is recommended to use e.g. when purchasing new equipment, to cost reduction activities, when correcting weakness in skill levels and development of a training plan, tem improvement activities like Kaizen events and quality circles, productivity and process flow improving and to annual planning and strategy development..

This was done during the thesis for the part that needed change by the designers. It took even three months with discussions and standardizing the specs to this part for all products but the savings were even hundred Kilo Euros per every coming year after this change. The main question based on this change and to all other processes considering the automation plan was that “Could this be done some other way?”. In addition there is Lean Six Sigma tool for problem solving. It needs a lot of practice and training if want to be able to use it for problem solving. (See references 40, 41, 43).

## 10.3 8 D problem solving

The Ford company used 8 D problem solving system (Eight Disciplines Problem Solving) during WWII to describe the actions for repairing the manufacturing process when there were found errors. The eight “disciplines” are seen in figure 29.

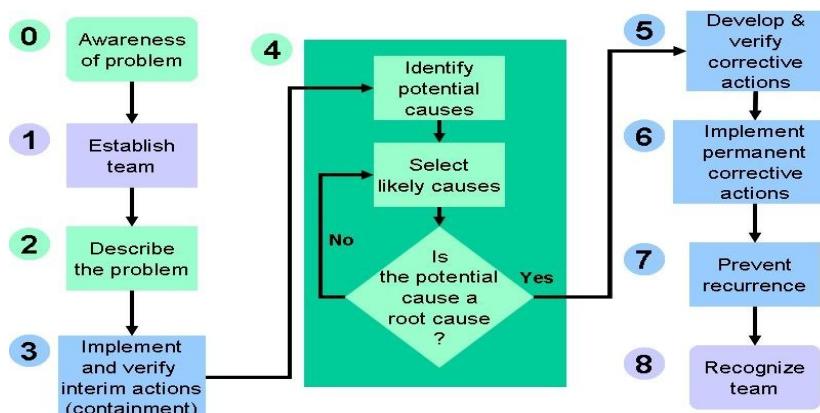


FIGURE 29. The chart visualizing 8 D problem solving (47)

## 11 Material flow problem

It was taught at the first place that the root cause for this was that the small assembly parts were counted too carefully to match to the need of the production line. When the parts ended up too soon was material person called by the phone to get more parts to the production line. The amount of the parts was counted to six products considering the cycle of the material train and the shift output time. Albeit there were even too pallets on the assembly line the material train timetable did not match with the cycle of the shift output. Was the *Jidoka* system in *JIT* (just-in-time) followed then too carefully here and the root cause so right?

### 11.1 Finding the root cause

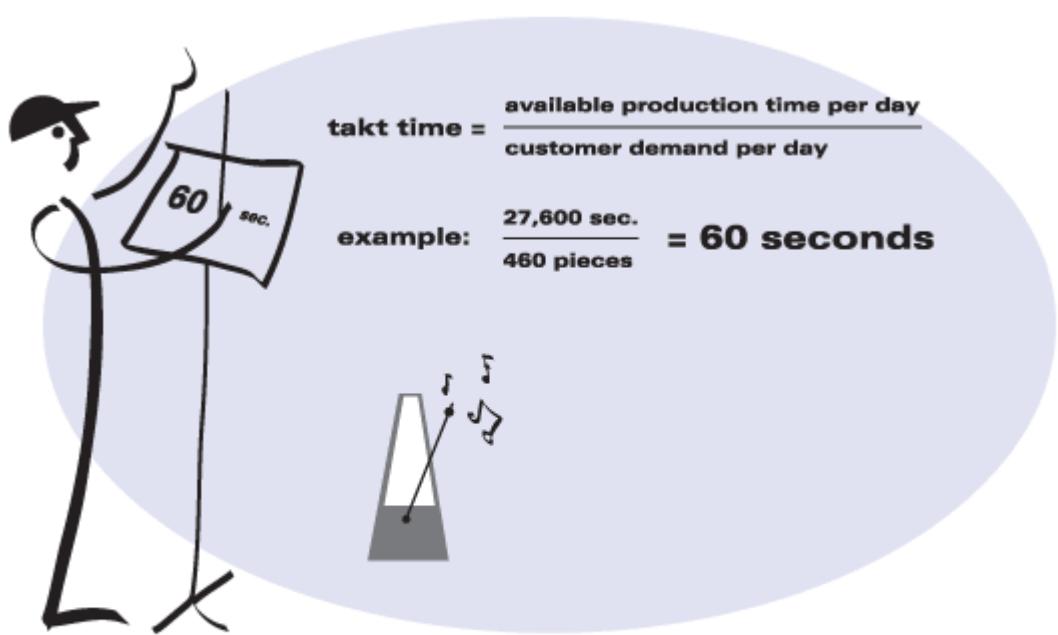
The root cause to this was found with the help of a LEAN tool and in this case there was use Value Stream Mapping (VSM) and from there only a small part of it. It was made a map of timing and the amount of material consuming which is only an individual process chain in VSM (Appendix nr 4).

Sometimes the shift output was 19 and sometimes 47 products depending on the production levelled plan. This made a part need from 57 to 141. The producing and consuming cycle could so not match with the material train time table because when e.g. 47 products was done were there more people doing the job and the takt time different. It would have been very easy to increase the amount of the needed parts as much as wanted. It would not have been then the Toyota way of handling the material process because of overproduction.

The first choice was to check the amount of maximum shift output. Because of the soldering robot was going to begin to solder the parts will there be easy to grow the amount if needed. Pallets were anyway changed to bigger trays to grow the amount and perhaps having less trays. There was left too options either to get more pallets or make the amount of the parts larger on one pallet. Three pallets would have been too much on the production line because they did not fit on the assembly line places and they could not be put as a tower there (high parts).

## 11.2 Right quantity of parts

Because the small parts are very small and cheap they could have easily been counted to be the minimum amount for getting the shift product output that one shift need in one day. There was not counted the fact that the amount of product might be bigger even over doubled. If the production line produces usually e.g. twenty units in one shift the need of the parts should be minimum so much that they suffices to minimum twenty units. Now when the line output was even 47 products should the small part amount been counted to be enough for the maximum output. The takt time was different and so it did not match to the material train timetable at all. The takt time should have measured or only the output maximum been divided by train timetable cycles. In electronic manufacturing the plans for the amount of manufacturing might change very easily. When customers want to have some new telecommunication system must the manufacturing begin quite immediately. So there must be at least some overall parts for the changed manufacturing plan (30) for increased amount of products. See figure 30 of counting the takt time.



An example of calculating takt time.

FIGURE 30. Takt time formula (45)

## **12 BENEFITS, COSTS AND SAVINGS OF THE PROJECT**

The change to an automatic dispenser gave results in next issues:

### **12.1 Dispenser change for nuts**

- The soldering paste time for each nut dropped from 5 - 6 seconds to 1.5 second.
- One operator made even three days those before, now only one operator is needed for one day.
- Extra costs are 770 euros because the machine was already available in the factory and only some fastening accessories for the paste tube had to be ordered.

### **12.2 Change of the design for similar parts**

- Soldering process changed to assembly process. Time savings are nearly 99%.
- Extra costs became around 10% to the price per part. This still compared as a winner against the hand assembly time and soldering work because parts were cheap. The saving from this is over one hundred Kilo Euros per year.

### **12.3 Small modules to the Selective Wave Soldering machine**

- A large amount of small modules were done at the same run. This was a very good choice for the pin soldering.
- Extra costs consider only the jig because the machine was already available in the factory.

### **12.4 Copper and other metal parts**

- All the parts are made by the soldering robot much faster than before. Big amounts by the same run without expensive soldering iron tips usage and several operators work time was the best benefit of this change. The work changed so that operators only put the parts to jig and collect them off. This made very much savings and was the main automation change to hand assembly phases.

## 13 IMPROVEMENT OF MATERIAL FLOW

### 13.1 Problem in the material flow

The main problem between the Pre Assembly Cell and the Production line was to synchronize the rhythm of the assembly of different shifts and operators with the amount of the pre assembly pallets. The pallets could not be too large because of the lack of room on the production line and the pre assembly cell shelf. There had been counted that four pallets of all these should have been enough to all filter products. Still was the material person called several times in a shift to bring some more pre assembly parts to the production line. The root cause according to Toyota manufacturing policy is the discipline lack of the production line. *“The just-in-time method demands a very disciplined assembly-line process, says David Dobrin, an analyst at Surgency Inc. in Cambridge, Mass. The entire factory has to be in sync to successfully exploit its methods. Manufacturers can afford fewer errors in the delivery of the supplier’s component; if a part isn’t there, the assembly line stops, and that can result in the loss of manpower and cash”* (18).

### 13.2 Improved way for material flow

Because the pallets were changed to the two times larger trays was there no need to increase the amount of the “pallets”. Four trays will definitely be enough for all small metal parts and modules because the amount now is nearly twice as much as before. The trays fits very well into racks (where keeps usually PWB modules). One product has its own rack with all the trays filled with the needed small parts in the Pre Assembly Cell. There is always two trays on the production line and two in the pre assembly cell and so the system was not changed. When one is empty is it in the material train or under the work for getting new parts. The both trays will not be empty at the same time from the production line so there is always enough components for assembling. When the tray gets empty will it be put behind the other tray waiting the material train to change it to a full one. All trays have the amount of small pre assembled parts and modules counted to be enough for ten or twenty products. This depends on the fitting size of the part on the tray.

### **13.3 Material traceability taken in use**

All assembled parts in pre assembly cell are some code version. Versions are usually from A to E. When some version will be updated to other must it be able to count and then make the change after the proposed time to other version. How to trace the versions of small metal parts when the version difference cannot see by eyes? There became a new system for this. When material persons this far brought the parts on pallets as some amount only, was this now directed to bring on the pallet only unopened packages. The trays were labeled by their assembly line and place e.g. F4\_1A, F4\_1B.....F4\_1D. The last letter was the pallet number what made possible to follow the versions in the soldering register. Soldering register was in a computer beside the soldering robot (Appendix 3).

### **13.4 Manufacturing process to Selective Wave Soldering machine**

All small modules were soldered with their pins in a big SMD Selective Wave Soldering machine. Common assembly operators could not use that machine and the modules were put as a part in a SMD manufacturing process to a manufacturing log. When modules were soldered were they waiting in that SMD area in their racks. The racks were then brought to pre assembly cell and small modules cut off from the bigger PWB board when they were needed. The modules were put on to trays by hand assembly operators where material person could find them easily. The trays were marked among all the other trays with their line number, assembly phase and tray number.

### **13.5 Manufacturing process to parts inside the cell**

There were several issues to be taken account in this process. This far was all the small parts made according to *Kanban* system. When empty pallets dropped in to the pre assembly cell was the manufacturing process started automatically by hand assembly operators. The question was that will it still continue in the similar way or because the amount is now larger will there be some manufacturing “hours” or even “days” perhaps? For keeping using a soldering robot as a good skill in every shift was it decided to go on with the same system. Trays will be as Kanban and when they arrive to pre assembly cell will there begin the manufacturing of the needed parts.

## **14 CONCLUSION**

There were several issues to deal with in this thesis: to get the new soldering robot in use, substitute the hand assembly soldering iron with some more automatic equipment and additionally improve the material problem flow and make it more accurate. If standardizing the work manufacturing methods, not only time and operation, there would be even more accurate results for counting the shift output.

The soldering robot is in use for all metal parts being soldered together and also for other bigger components that do not last any kind of soldering oven. Nuts of coils got an automatic dispenser and the small modules with pins are being soldered by a selective wave soldering machine in the future. Thus, the objective of the thesis was accomplished. The thesis result gave a lot of savings to Nokia in manufacturing time, employee resources and material costs. It gave a lot of efficiency to all processes, too.

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We can typically look at the waste within a business process by considering the labour and equipment effectiveness. For example for labour, there's usually a stark difference between the paid time for a resource and the time that the resource is actually adding value for the customer. We can define this difference through a series of losses.

Labour Effectiveness			Equipment Effectiveness		
PAID TIME			AVAILABLE TIME		
SOCIAL LOSS	PRESENT TIME		LOAD TIME		PLAN LOSS
UTILISATION LOSS	PRODUCTIVE TIME		OPERATING TIME		STOP LOSS
PERFORMANCE LOSS	STANDARD TIME		NET OPERATING TIME		SPEED LOSS
METHOD LOSS	VALUE-ADDED TIME		VALUE-ADDED OPERATING TIME	QUALITY LOSS	

**Social Loss**, for example losses due to meetings, is typically the responsibility of management

**Utilisation Loss** is generally the supervisor's responsibility, and may occur if parts are not available or the operation is not setup such that the operator can perform at their best.

**Performance Loss** is the operator's responsibility. This includes not meeting standard times and not following standard operating procedures.

**Method Loss** is the responsibility of engineering and management across the organisation. For example, if a product was not designed to be easily manufactured then this would be the R&D team's responsibility.

We're often also interested in the availability and effectiveness of equipment being used.

## **LABOUR AND EQUIPMENT EFFECTIVENESS**

**Plan Loss** results from scheduling equipment not to run

**Stop Loss** results from a changeover or breakdown

**Speed Loss** results from running equipment below the design speed of the machine

**Quality Loss** results from producing defective parts and materials

Analysis of equipment effectiveness is especially important to focus on when dealing with high-cost equipment, such as in drilling, mining or the airline industry. In these cases a business is only making money or providing value when its equipment is operating.

(25)

## 25 ESSENTIAL LEAN TOOLS

## APPENDIX 2

The following is a collection of 25 essential lean tools. Each tool is distilled into a simple description of what it is and how it helps.

Lean Tool	What Is It?	How Does It Help?
<b>5S</b>	<p>Organize the work area:</p> <ul style="list-style-type: none"> <li>▪ Sort (eliminate that which is not needed)</li> <li>▪ Set In Order (organize remaining items)</li> <li>▪ Shine (clean and inspect work area)</li> <li>▪ Standardize (write standards for above)</li> <li>▪ Sustain (regularly apply the standards)</li> </ul>	Eliminates waste that results from a poorly organized work area (e.g. wasting time looking for a tool).
<b>Andon</b>	Visual feedback system for the plant floor that indicates production status, alerts when assistance is needed, and empowers operators to stop the production process.	Acts as a real-time communication tool for the plant floor that brings immediate attention to problems as they occur – so they can be instantly addressed.
<b>Bottleneck Analysis</b>	Identify which part of the manufacturing process limits the overall throughput and improve the performance of that part of the process.	Improves throughput by strengthening the weakest link in the manufacturing process.
<b>Continuous Flow</b>	Manufacturing where work-in-process smoothly flows through production with minimal (or no) buffers between steps of the manufacturing process.	Eliminates many forms of waste (e.g. inventory, waiting time, and transport).
<b>Gemba (The Real Place)</b>	A philosophy that reminds us to get out of our offices and spend time on the plant floor – the place where real action occurs.	Promotes a deep and thorough understanding of real-world manufacturing issues – by first-hand observation and by talking with plant floor employees.
<b>Heijunka (Level Scheduling)</b>	A form of production scheduling that purposely manufactures in much smaller batches by sequencing (mixing) product variants within the same process.	Reduces lead times (since each product or variant is manufactured more frequently) and inventory (since batches are smaller).
<b>Hoshin Kanri (Policy Deployment)</b>	Align the goals of the company (Strategy), with the plans of middle management (Tactics) and the work performed on the plant floor (Action).	Ensures that progress towards strategic goals is consistent and thorough – eliminating the waste that comes from poor communication and inconsistent direction.
<b>Jidoka (Autonomation)</b>	Design equipment to partially automate the manufacturing process (partial automation is typically much less expensive than full automation) and to automatically stop when defects are detected.	After Jidoka, workers can frequently monitor multiple stations (reducing labor costs) and many quality issues can be detected immediately (improving quality).
	Pull parts through production based on customer demand instead of	Highly effective in reducing inventory levels. Improves cash flow and reduc-

<b>Just-In-Time (JIT)</b>	pushing parts through production based on projected demand. Relies on many lean tools, such as Continuous Flow, Heijunka, Kanban, Standardized Work and Takt Time.	es space requirements.
<b>Kaizen (Continuous Improvement)</b>	A strategy where employees work together proactively to achieve regular, incremental improvements in the manufacturing process.	Combines the collective talents of a company to create an engine for continually eliminating waste from manufacturing processes.
<b>Kanban (Pull System)</b>	A method of regulating the flow of goods both within the factory and with outside suppliers and customers. Based on automatic replenishment through signal cards that indicate when more goods are needed.	Eliminates waste from inventory and overproduction. Can eliminate the need for physical inventories (instead relying on signal cards to indicate when more goods need to be ordered).
<b>KPI (Key Performance Indicator)</b>	Metrics designed to track and encourage progress towards critical goals of the organization. Strongly promoted KPIs can be extremely powerful drivers of behavior – so it is important to carefully select KPIs that will drive desired behavior.	<p>The best manufacturing KPIs:</p> <ul style="list-style-type: none"> <li>  Are aligned with top-level strategic goals (thus helping to achieve those goals)</li> <li>  Are effective at exposing and quantifying waste (OEE is a good example)</li> <li>  Are readily influenced by plant floor employees (so they can drive results)</li> </ul>
<b>Muda (Waste)</b>	Anything in the manufacturing process that does not add value from the customer's perspective.	Eliminating muda (waste) is the primary focus of lean manufacturing.
<b>Overall Equipment Effectiveness (OEE)</b>	Framework for measuring productivity loss for a given manufacturing process. Three categories of loss are tracked: <ul style="list-style-type: none"> <li>  Availability (e.g. down time)</li> <li>  Performance (e.g. slow cycles)</li> <li>  Quality (e.g. rejects)</li> </ul>	Provides a benchmark/baseline and a means to track progress in eliminating waste from a manufacturing process. 100% OEE means perfect production (manufacturing only good parts, as fast as possible, with no down time).
<b>PDCA (Plan, Do, Check, Act)</b>	An iterative methodology for implementing improvements: <ol style="list-style-type: none"> <li>1. Plan (establish plan and expected results)</li> <li>2. Do (implement plan)</li> <li>3. Check (verify expected results achieved)</li> <li>4. Act (review and assess; do it again)</li> </ol>	Applies a scientific approach to making improvements: <ul style="list-style-type: none"> <li>  Plan (develop a hypothesis)</li> <li>  Do (run experiment)</li> <li>  Check (evaluate results)</li> <li>  Act (refine your experiment; try again)</li> </ul>
<b>Poka-Yoke (Error Proofing)</b>	Design error detection and prevention into production processes with the goal of achieving zero defects.	It is difficult (and expensive) to find all defects through inspection, and correcting defects typically gets significantly more expensive at each stage

		of production.
<b>Root Cause Analysis</b>	A problem solving methodology that focuses on resolving the underlying problem instead of applying quick fixes that only treat immediate symptoms of the problem. A common approach is to ask why five times – each time moving a step closer to discovering the true underlying problem.	Helps to ensure that a problem is truly eliminated by applying corrective action to the “root cause” of the problem.
<b>Single Minute Exchange of Die (SMED)</b>	<p>Reduce setup (changeover) time to less than 10 minutes. Techniques include:</p> <ul style="list-style-type: none"> <li>▪ Convert setup steps to be external (performed while the process is running)</li> <li>▪ Simplify internal setup (e.g. replace bolts with knobs and levers)</li> <li>▪ Eliminate non-essential operations</li> <li>▪ Create standardized work instructions</li> </ul>	Enables manufacturing in smaller lots, reduces inventory, and improves customer responsiveness.
<b>Six Big Losses</b>	<p>Six categories of productivity loss that are almost universally experienced in manufacturing:</p> <ul style="list-style-type: none"> <li>▪ Breakdowns</li> <li>▪ Setup/Adjustments</li> <li>▪ Small Stops</li> <li>▪ Reduced Speed</li> <li>▪ Startup Rejects</li> <li>▪ Production Rejects</li> </ul>	Provides a framework for attacking the most common causes of waste in manufacturing.
<b>SMART Goals</b>	Goals that are: Specific, Measurable, Attainable, Relevant, and Time-Specific.	Helps to ensure that goals are effective.
<b>Standardized Work</b>	Documented procedures for manufacturing that capture best practices (including the time to complete each task). Must be “living” documentation that is easy to change.	Eliminates waste by consistently applying best practices. Forms a baseline for future improvement activities.
<b>Takt Time</b>	The pace of production (e.g. manufacturing one piece every 34 seconds) that aligns production with customer demand. Calculated as Planned Production Time / Customer Demand.	Provides a simple, consistent and intuitive method of pacing production. Is easily extended to provide an efficiency goal for the plant floor (Actual Pieces / Target Pieces).
<b>Total Productive Maintenance (TPM)</b>	A holistic approach to maintenance that focuses on proactive and preventative maintenance to maximize the operational time of equipment. TPM blurs the distinction between maintenance and production by placing	Creates a shared responsibility for equipment that encourages greater involvement by plant floor workers. In the right environment this can be very effective in improving productivity (increasing up time, reducing cycle

	ing a strong emphasis on empowering operators to help maintain their equipment.	times, and eliminating defects).
<b>Value Stream Mapping</b>	A tool used to visually map the flow of production. Shows the current and future state of processes in a way that highlights opportunities for improvement.	Expose waste in the current processes and provides a roadmap for improvement through the future state.
<b>Visual Factory</b>	Visual indicators, displays and controls used throughout manufacturing plants to improve communication of information.	Makes the state and condition of manufacturing processes easily accessible and very clear – to everyone.

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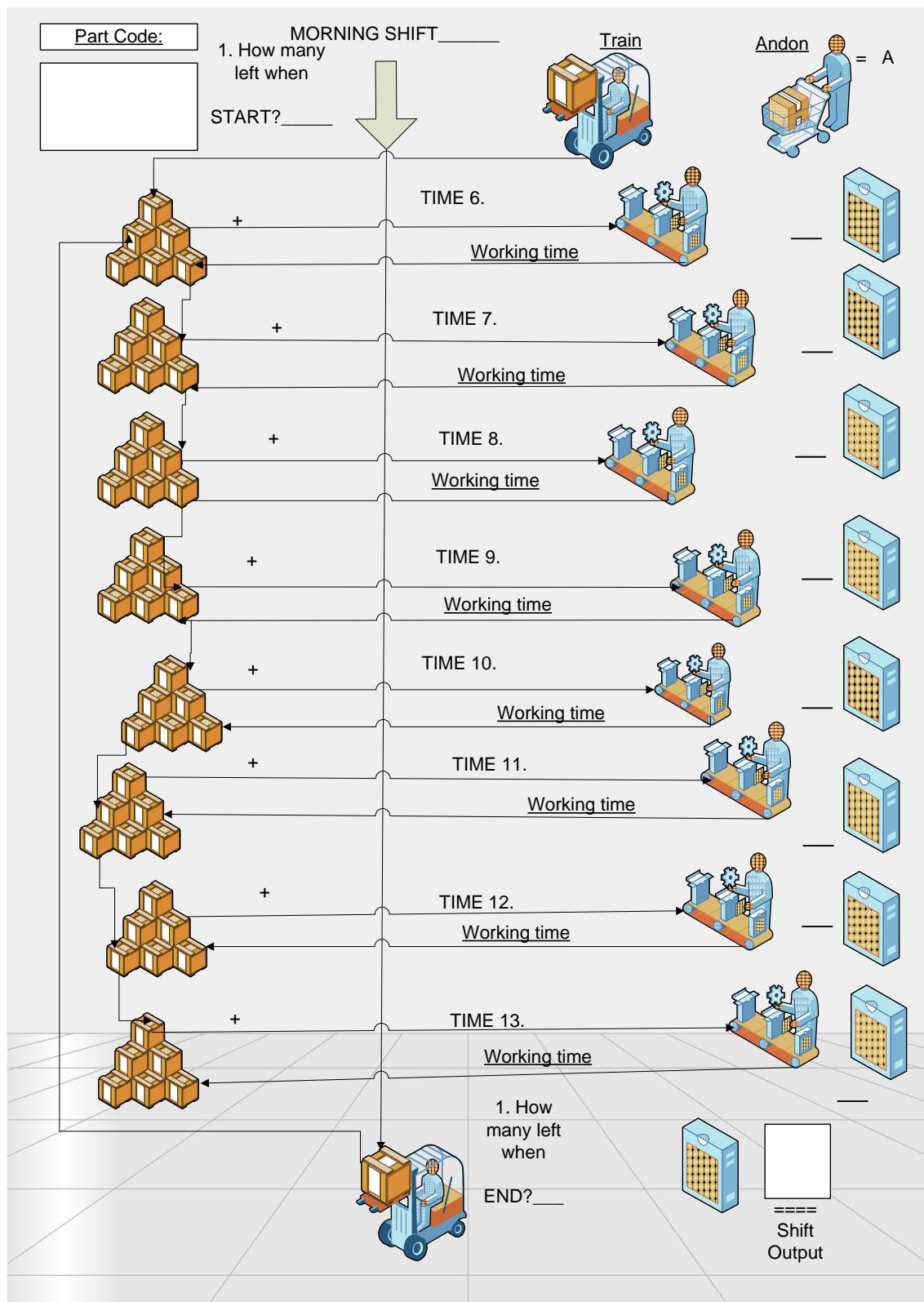
## MATERIAL TRECEABILITY LOG

## APPENDIX 3

	A	B	C	D	E	F	G	H	I	J	K	L
1	SOLDERING LOG					Use the Barcode scanner For "INSERT COMMENT" FROM THE PACKAGE: VENDOR AND TRECEABILITY				SMALL MODULES: TAKE ONE NUMBER FROM ONE LABEL TO PART 1 AND WRITE THE VENDOR NAME TO PART 2		
2	OPERATOR NAME	SHIFT	DAY	TIME	THE TRAY INFORMATION	PART 1	PART 2	PART 3	PART 4			
3										<- PART NUMBER HERE		
4										<- PART NUMBER HERE		
5										<- PART NUMBER HERE		
6										<- PART NUMBER HERE		
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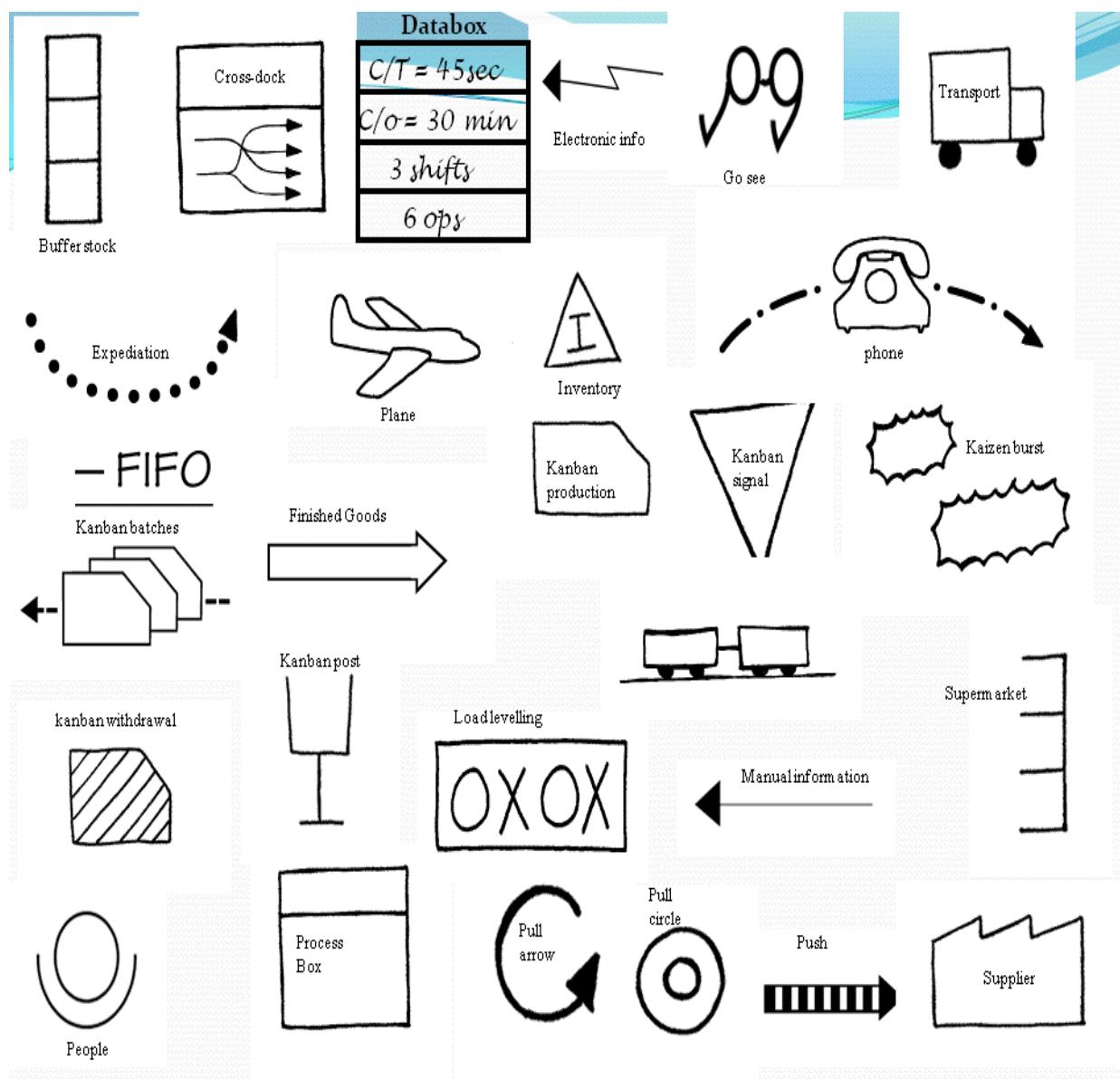
**MATERIAL COUNTING MAP** (material consumption in morning shift)

**APPENDIX 4**



## THE VALUE STREAM MAP SYMBOLS

## APPENDIX 5



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