Production System Simulation
Calculation Model for Local and Line Production Systems

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Abstract

The main purpose of this thesis was to create a general theoretical calculation model based on real practical case, where a company that produces its product in local cells plans to partially change the system to production line and requires calculations to be done in order to compare and evaluate optimal variants.

Achievement of the objectives was a matter of observation and testing. The model was designed in Microsoft Excel environment and required knowledge of VBA programming language.

In order to test the usability of the program and ability to make all calculations correctly as well as to get the idea for the necessary functionality information was collected in a practical case, which belonged to a production factory. The case of the company was interesting since it was a task of renovation of the system and making it more efficient by saving resources such as time, space, human resources etc., which is one of the most important challenges of industrial management.

During research a lot of useful data was collected that improved the quality of the theoretical calculation model and that was used to improve the company processes in overall. As a result theoretical model was created and tested and final product can be beneficial beyond the frames of this specific project.

CONTENTS

APPENDICES

1. INTRODUCTION

The topic of my thesis is "*Production system simulation – a calculation model for local and line production systems*". It belongs to the field of development of manufacturing systems and the main purpose of the study was to create a general theoretical calculation model based on real practical case, where a company that produces its product in local production cells plans to partially change the system to production line and requires calculations to be done in order to compare and evaluate optimal variants.

The actual case study was performed in the real production factory. The company specializes in the manufacture, sale and marketing of high-quality heating systems. Since the company has great variety of products, one of the main aspects of the project was to choose the product type which would be most beneficial to concentrate on for the company and the project in overall.

Present production system of the product inside the local assembly cell creates a lack of space and as a system is complicated to be controlled in terms of time. The lead time cannot be measured and classified very specifically and it varies widely so that scheduling is complicated. More capacity of the production and better control are necessary. The case of the company is a task of renovation of the system and making it more efficient by saving resources such as time, space, human resources etc., which is one of the most important challenges of industrial management.

The project was started as a part of the course "*Development of the manufacturing systems*" conducted by our teacher Mr. *Jarmo Pyysalo* in March, 2013. First draft of the theoretical calculation model was presented to the Managing Director of Case Study Company on the April, 12th of the same year and he approved the feasibility of the project. Leka-Project organization also found it interesting to be developed further. All three organizations - Leka-project, Case Study Company, and *Savonia UAS* –are potential client organizations that are currently interested in the development process.

Initial design and coding process of the model was carried out in Savonia UAS computer laboratories during April, May and June, 2013. The data for testing purposes was collected during internship in June, July and August, 2013 in the company's factory facilities. The necessary equipment for the project was generously provided from all three parties of this project.

1.1. Project description

The main idea was to create a general theoretical calculation model (also referred to as tool or program) that allows evaluating current production system in the local cells and design a well-balanced production line that is based on the collected data. The design and functionalities of the tool had to be so, that they could be tested with information collected in the given practical case but at the same time would be helpful to many other similar cases. Testing was necessary in order to exclude the errors in the code, insure that the program performs all the calculations correctly. Also there was a theoretical research made on the Toyota production system (TPS) to define necessary functionalities for the tool.

The main goals of the project were:

1. To design a calculation system (tool), that will allow collecting necessary data in a convenient way on the present local system in order to simulate a line production system.
2. Test the tool on the real practical case that is presented above and prove that the model is useful.

Research and analysis covered wider area of company's interest, but information for the test was collected as a consequence of this study.

Achievement of the objectives was a matter of observation and testing. The model was designed in Microsoft Excel environment and required knowledge of VBA programming language. In order to test the usability of the program, information was collected by recording videos of the manufacturing process. Videos were observed and analysed with the help of video editing software. Collected information was sorted and used for testing of the model. Main product of this research method was important data such as names of operations, their order and operation times, which was necessary as an input for the model testing. Statistical methods were used to narrow down the diversity of production to the specific type of stations that would be more beneficial to work on. Parallel statistics were used to determine weak points of the production time estimations.

At the same time data collection process brought some good results specifically for the purpose of the partner company, and additional report was created to underline the results that were specifically beneficial for the company itself.

1.2. Initial objectives of project implementation

In order to achieve the final goal certain objectives had to be obtained on the way. They were:

- Evaluating the products of the company in the way they can be classified in certain groups and the suitable cases for the line production can be defined.
- Determining operations of both systems and evaluate their value.
- Evaluating time requirements of both systems calculate and compare the values.
- Assigning materials to certain operations track the material need and create a smooth flow.
- Creating visual demonstration of the processes.
- Creating a system that will allow manipulating stations in order to determine the best options.
- Calculating capacity benefit of the line production system.
- Estimating space requirements of the systems.
- Defining benefits of change supported by the data and calculations.
- Creating a general theoretical calculation model based on real practical case.

Additional objectives of the project that were outlined during the internship specifically for Partner Company were:

- Collecting the data on the structure of two circuited heating substations.
- Making new time evaluations for processes through statistical methods and by collecting real time values and change time in the calculation program for certain accessories, pipe sizes or standard components in order to minimize error in the plan.
- Systematizing the assembly process through flow chart in order to describe the process flow and make it more visual and understandable.
- Determining what the most frequently/rarely used accessories are.
- Finding out how late/ fast the production in total is for the given period of time.
- Estimating how pre assembly increase the efficiency of the production.
- Estimating how many percent of efficiency consumes the avoidable non-value adding time.
- Pointing out the problematic areas of the production and analyse the priority of the necessary changes.

At the same time the learning process was an essential part of the whole project and led to the final result:

- Implementing several fields of knowledge into one project, such as programming skills, knowledge of Microsoft Excel environment and knowledge gained in the field of the operations management.
- Learning how to implement statistical methods in practice and what the benefits of this method are.
- Connecting theoretical knowledge to the working life. Getting a practical experience of how things work inside real company.
- Comparing the benefits of both systems (production line vs. local production cell) and realizing what the practical challenges of both implementations are.
- Mastering gained knowledge to make a future learning process more efficient and progressive.

The advantage of this work is that it gave an opportunity to implement several fields of knowledge into one project, such as programming skills, knowledge of Microsoft Excel environment and knowledge gained in the field of operations management. It was also a task of good implementation and combination of the software engineering and industrial management skills.

1.3. Leka project

The LEKA was a project managed by Savonia University of Applied Studies. Its main goal was to bring together the strengths of UAS, universities of technology, vocational colleges and development companies and industry in order to work on new innovations, development of current products and improve cost efficiency through building a research unit and technology transfer network for North Savo.

Since metal and engineering industries are a major part of the region's business life, LEKA project has its focus on the area of machine building, metal and engineering industries. Major founder organization of the project was Regional Council of Pohjois-Savo.

LEKA united proactive minds together for the common good. It believed that today it is important to learn or find new innovative ways to get more value from already existing resources and emphasizes the importance of cooperation between educational organizations and industry of North Savo, so that multidisciplinary scientific and applied research can be united with practical implementation.

The goals of the project were:

- Reducing the risk of weakening profitability of the companies and risk of decreasing employment
- Helping the companies to find the access and actually stay competitive on international markets
- Improving cost efficiency of the products
- Avoiding the transferring of production to lower cost countries
- Building the possibility for international research partners

Through the project, expertise was offered for the practical needs of the company for emerging research topics, the content of which was planned with the company. Thus, concrete entireties were formed to be implemented in part in a corporate environment

The operation focused primarily on centrally managed research units, in which researchers, corporate personnel, teachers as well as students work, which makes possible the integration of the research into the operational activities of the company. The work of the project's research units was spread throughout the whole of North Savo. The priorities for Savonia´s mechanical and production engineering research are the development of productivity, as well as digital work tools and methods in networking production in view of product lifecycle management and business.

With the work of the LEKA project the competitiveness of the North Savo technology businesses on the domestic and international markets has improved, expertise and cooperation between the different operators has increased as well as the availability of skilled labour has been partly ensured.

From a company`s perspective the results of the project were research and development support , technology transfer, production of prototypes, piloting of product ideas, improved cost efficiency and manufacturability as well as other matters relating to the development of production. Through the project the companies were receiving rapid access to large-scale development resources. Through the research the expertise achieved in the LEKA project is transferred to teaching. From this the companies will benefit by getting better qualified workforce.

2. PRODUCTION SYSTEMS

The theory presented in this work is here to support the user of theoretical calculation model with the ideas that are relative to its purpose. Concepts and tools described below present my personal choice of the Toyota Production System (TPS) that I was guided by during the design of the model functionality and which I would take as an example to set a production line. The intention was to note what has to be considered and what are the target conditions of the process design. The tools described in these chapters represent only a part of TPS, but are the most relative to make the concept and notions of the theoretical calculation model more understandable.

2.1. Why TPS?

Chapter is here to prove the importance of the concepts and tools that will be described further in this work. It is about a company that was established in the country with almost no own natural resources, the country, where most industries were destroyed when it was decimated by two atomic bombs in August 1945 and put it even more far back on the industrial progress scale. But only this environment of few natural and technological resources and almost no capital could create perfect conditions for the Toyota company rise and its unique approach to the manufacturing – Toyota Production System (TPS).

Toyota's leaders first visited Ford and GM in 1930s. The goal of the visit was to study their assembly lines, test their conveyor system and precision of machine tools. To illustrate the gap between Toyota and U.S automakers at that time it is enough to mention that the productivity of US auto line was 10 times higher, so that they could produce 9000 units per month while Toyota would produce only 900 units [1].

Ford's production was designed to produce limited number of models in huge quantities. They had lots of cash, large US and international markets. Toyota on the other hand had no cash and operated in a small country, where consumer demand was too low to support such system of assembly line per one model. They needed to manufacture low volumes of different car models on the same assembly line and needed to turn cash quickly. So what they needed was to adapt the mass production system to achieve "simultaneously high quality, low cost, short lead time and flexibility" [1].

In 1950 Eiji Toyoda and his management team had a second 12-week study tour of US plants. They were expecting to be amazed by their 20 years manufacturing progress but instead were surprised that development of mass production techniques very much stayed the same as they had been in early 1930s [1].

Instead of studying operational excellence of their American competitors this time they learned about many bad practices that surfaced over the time and inherent flaws [1]:

1. Unreasonable amount of equipment

2. Big inventories of finished products and WIP(work in progress) waiting for the next process

3. Interruption between the steps

4. Overproduction

5. Uneven flow

6. Workers kept busy

7. Defects hidden in the large batches (could go undiscovered for weeks)

8. Disorganized workplaces out of control

They saw the opportunity to catch up and they did. Using Ford's original idea of continuous material flow (assembly line) Toyota developed an efficient system of one-piece-flow that flexibly changes according to the customer demand. After the Henry Ford's mass production Toyota Production System (TPS) has become a next major evolution in efficient business processes [1].

TPS was already a powerful philosophy in 1960's but it was only taught to the key suppliers of Toyota. 1973 first oil shock sent the world into a global recession. Toyota went into the red zone for less time than other companies and came back to profitability faster, which proved the efficiency of the TPS firstly to the Japan government and eventually to the whole world [1].

All those process flaws that were discovered by Toyota team in the U.S. factories among the other reasons led to the fact that in 1982 the Ford Motor company was seriously flirting with bankruptcy. On the same year the University of Michigan U.S. as an effort to help U.S. companies started a Japan automotive study research to learn from Japanese automakers.

Toyota launched its first luxury car in 1989, when Mercedes-Benz three models had no rivals in the U.S. market. In one year 2.7 times more Lexus (one model) cars were sold than all three of those well-established Mercedes combined [1].

By the early 1990s all of the "Big Three"[1] [2] auto producers concluded that Toyota and its Japanese quality was the company to compete [1].

Toyota's consistent performance is result of their operational excellence that started as a set of techniques and later was organized as a Toyota Production System (TPS). It is partly based on tools and quality improvement methods, such as just-in-time, kaizen, one-piece flow, jidoka and heijunka. Quality improvement techniques, such as jidoka has taken many forms and is largely beyond our scope, but all other tools will be discussed in the next sections of this document to indicate the key techniques that can help in intelligent designing new production process [1].

It is also important to realize that behind Toyota' success is far more than set of tools and methods. It is also about deeper business philosophy based on its understanding of people and human motivation and ability to cultivate leadership, teams, and culture to devise strategy, to build supplier relationship, and to maintain a learning organization. The Toyota Way is a philosophy and set of tools that must be appropriately applied to your situation [1, 4].

2.2. Value-added versus non-value added time and operations

Realization that if you make lead time short and focus on keeping production line flexible, you actually get higher quality, better customer responsiveness, better productivity, and better utilization of equipment and space has become a critical discovery. One of the obstacles on the way to shorten lead time is actually waste or *muda* [1].

Mass production idea about eliminating waste was concentration on running labour and equipment as hard as possible to get a better utilization of resources. Radically different approach was that waste has little to do with it and everything to do with the manner in which raw material is transformed into final product [1].

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1   In this case the "Big Three" is used to refer to General Motors, Ford, and Chrysler as the largest automakers in the United States and Canada at that time.

When the value is defined though the customer's eyes, the only thing that adds value manufacturing process (as well as in marketing or a development process) is the physical transformation of that product into something the customer wants [1].

If we draw the path of material through the process (such as casting, machining or assembling) on the layout, then map the value stream, calculate the time and distance travelled and stretch it to the point that the value added is barely recognizable, it most probably will become a big surprise to see that in reality an actual value of converting raw material to a finished product added by only few steps of the individual process, and these are the only steps that a customer is willing to pay [1].

In the traditional approach, effects in the processes improvement were gained from focusing on the improving of value adding steps, but if to rely on the fact that there are relatively few value adding steps, improving those will not amount to much. But there is a huge opportunity for reducing waste by eliminating or shrinking non-value-added steps [1].

So it is very essential to observe the process and separate the value-added steps from the non-value-added steps, in other words, to identify activities which add value to the raw material and get rid of everything else. When some of the non-value-added steps are necessary, the point becomes to minimize the time spend on such steps [1].

If to identify value adding steps is rather easy, waste on the other hand has a bit more complicated nature and has much more variations. According to the Taiichi Ohno (former president of Toyota) there are 8(eight) wastes, that are supposed to be eliminated in any production [1].

The 8 (eight) wastes are:

1. *Muda of overproduction.* It results from getting ahead of the schedule, which in just-in-time system is regarded as worse than being behind the schedule. It often appears with the temptation to produce more than necessary in order to be on the safe side or when the efficient utilization of an expensive machine is favoured more than the actual requirement for the number of the products demanded. What it actually does is [3]:

   - Consumes raw materials in advance

   - Creates wasteful input of man power and utilities

   - Adds extra machinery

- Takes up space for inventory

- Adds transportation and administration costs.

According to Ohno, overproduction is a fundamental waste, because big buffers (inventories between processes) also lead to other suboptimal behaviour. When the inventory level is high nobody gets serious enough to deal with problems, like [1]:

- Continuous improvement of operations and right quality from the beginning

- Preventive maintenance on equipment and reduction of machine downtime

- Absenteeism

2. *Muda of inventory*. While excess raw materials, WIP, finished products stay in inventory no value is added, but the cost is added from [3]:

- Occupied spaces

- Additional equipment requirements(e.g., forklifts, conveyor systems)

- Additional facilities requirements (e.g., warehouses)

- Additional manpower for operation and administration

In addition to extra costs excess inventory causes longer lead time, obsolescence of storage, damaged goods, extra transportation, delays. Inventory is often compared to the water level that hides production imbalance, late deliveries from suppliers, defects, equipment downtime, and long setup time. Large batches of material that are produced create waste if then they sit in the storage and wait to be processed further [1].

3. *Muda of repair/ rejects*. Rejects either require expensive rework or if discarded, become a waste of effort and resources. They not only interrupt the production, but may also damage expensive equipment. The right design is one of the basic ways to avoid defect [3].

4. *Muda of motion.* To be unproductive is considered any wasted movement that the employees have to perform during the course of their work that is not directly related to adding value (e.g., looking for, reaching for, unnecessary walking,

stacking parts, tools). In addition any action that requires great physical effort like heavy lifting also represents waste [3].

5. *Muda of processing.* Inefficient processing will cause defects and poor tools or design will create unneeded steps to process the parts and unnecessary motions. Also it is important to understand that providing higher quality products than necessary is also generating waste, as well as unwise dividing of operations that creates new steps [1].

6. *Muda of Waiting.* Waiting for the next processing step, tool, supply, part etc.(line imbalances); lack of work to do because of stock outs, lot processing delay, equipment downtime, capacity bottlenecks, basically any situation when the hands of the operator are idle. Even when the operator is just monitoring the machine that performs the value-added work [1].

7. *Muda of transportation.* Production cannot go without any kind of transportation, therefor it is essential part of operations, but moving materials or products adds no value. Carrying work in progress (WIP) long distances or using inefficient transport only adds to the waste, but the damage that often occurs during transportation makes it even worse [3].

8. *Muda of unused employee creativity.* Not listening to the employees will lead to loosing time, skills, ideas, improvements, and learning opportunities [1].

Nowadays there is a need for fast, flexible processes. Focus on eliminating wasted time and material from every step of the production process will help to give customers what they want, when they want it, at the best quality and affordable cost [1].

2.3. Traditional Mass Production Thinking

The goal of traditional mass production is to reach economy of scale, which means that out of every piece of equipment or every worker in a manual operation it is important to squeeze the most production possible at the lowest cost per unit [1].

Similar machines and similarly skilled people are grouped together, so that departments, such as mechanic engineering, electrical engineering, accounting etc. can be set up. This method allows having only one machine for a certain process to meet needs of the whole factory. The smallest capital cost per piece of equipment is considered as an advantage of this system as well as greatest asset utilization [1].

When you put all same skilled workers, for example welders, together at one department it is easier to schedule their work to any work that comes up. Scheduling the operation goes by organizing it into separating processes and to send individual schedules to each individual department. The decision on what to make each day is based on the idea to optimize equipment and utilize people for that week. A lot of WIP inventories are produced by this method. The faster equipment will build up the most of it [1].

Mass production system guarantees overproduction with all its negative effects. In real case of the large batch operation there could be weeks of work in process between operations. If defect occurs and is passed to the next process without notice, it can take weeks – months for it to be discovered. In order to prevent defect in the future the root-cause should be defined, but by the time the defect is discovered it is almost impossible to truck down and identify why it really occurred in the first place [1].

It is hard to determine how many people are really needed to produce certain number of units, when operation productivity is not measured by the value-added work. When people overproduce parts, storing this overproduction, tracking down the defective parts and components, repairing finished products, nobody has an idea of how much productivity is lost [1].

Product being made for a customer moves across departments to become what customer wants. Each time the product enters a new department, it causes a delay. In traditional shops where machines are organized by type, product is moving everywhere with no coordination of the product across departments, so it is impossible to have a stable control [1].

2.4. One-piece-flow Cell

Usually customer has to wait months for the order to be ready, but manufacturer knows that it doesn't mean that the order is being processed all this time. In most cases it just sits in parts in the factory's inventories in the queue to be processed [1].

Common assumption is that the process takes from days to weeks to be complete, but reality is that value-added work like an assembly is taking hours at most, which means that everything else during the time customer is waiting is a waste [1].

Flow means that when customer places an order, this triggers immediate chain of actions. First, the raw materials needed just for this particular customer's order are

obtained. Second, the raw materials flow immediately to the supplier plants, where workers quickly fill the order with components. Then components flow immediately to the plant, where workers assemble the order, whereupon the completed order flows immediately to the customer. The whole process should take a few hours or days, not weeks or months [1].

According to Taiichi Ohno, the ideal batch size is always one. The fastest way to reduce the batch size is to create work cells that are grouped by product, rather than by process [1].

One-piece-flow (1×1 flow) cell is a close arrangement of people, machines or workstations in a processing sequence or in other words in one-piece flow you physically line up the processes in the sequence that will produce the customer order in the shortest time. Product flows through the various operations (welding, assembly, packing, etc.) one unit at a time, at a rate determined by needs of a customer, with the least amount of delays and waiting. [1] The other name for it is cellular manufacturing that refers to a group of machines that manufacture a particular set of parts. [5]

In 1×1 flow work pieces are moving from one processing step directly to the next one and do not pass through any buffers in between. The operators must be fully loaded to the current planned cycle time (defined in the next section) and there are no extra operators. One of the conditions of one-piece flow is to have a correct number of operators. [4]

Equipment has to be organized to follow the flow of materials as it is being transformed into a product. Particularly good layout for efficient movement of people, material and good communication is U shaped, also can be straight line or L. It helps to reduce material handling, increase worker interaction, and minimize travel distances and inventories between machines. [5]

One-piece flow implies that same amount of products is finished faster than in batch production and the first product is ready for shipping significantly faster due to the fact that it goes through the production without waiting between the operations. And this result is always the same no matter what scale is used just because the logic of the process is improved [1].

There is a direct relation between the lead time and WIP (work-in-process). Longer lead time means longer time between orders launching date and its due date, correspondingly more orders are in the shop at one interval of time [5].

According to Toyota executives, "*the right process will produce the right result*". Faster production speed in the flow does not compromise the quality, instead it improves it. In the large batch by the time the problem is discovered there is already big amount of parts in process that might also have the same problem. It takes much longer time to discover it. Usually the product has to go all the way to the test department, and it takes a long time for the first product to get to the test stage of the production, since it waits for the whole batch to be processed in previous stages. In the one-piece flow production the defect can be discovered faster, because it was moved to the test in a very short period since it was made and by that time not many other products will be able to inherit the same defect [1].

Positive effects of the flow are listed and explained in the Table 1:

Table 1. Benefits of the flow [1]

Build in quality	Every operator works to fix any problems in station before passing them on.
Real Flexibility	Short lead time gives more flexibility to respond to the customer demand. Almost immediate changing over to a different product mix to accommodate changes in customer demand. If demand changes you change the amount of people proportionally to the change.
Higher productivity	In one-piece flow cell non-value-added activities are minimized, it is visual who is busy and who is idle, easy to figure out how many people are needed to reach certain production rate. *Toyota Supplier Support Center reported that every changed mass-production supplier to a TPS style line gained at least 100% improvement in the labor productivity.

Free Floor Space	In a cell, everything is pushed close together and very little space wasted by inventory.
Improved safety	Smaller batches of materials are moved-no forklift tracks, no hard lifting and moving.
Improved morale	See the actual results of their work gives sense of accomplishment.
Reduced cost of Inventory	Frees up capital from inventory, no carrying costs, no inventory obsolescence.

There is a cost to creating flow. It creates need in cross-trained workers who are able to with different manufacturing processes. Whole cell will stop production if one piece of equipment breaks down. If one process takes longer than expected it delays the whole cell. And it requires investment to bring in-house the process that is currently sent outside to supplier.

Creating a flow of materials through shortening the elapsed time from raw material to finished goods will lead to the best quality, lowest cost and shortest delivery time. It also tends to force implementation of a lot of other lean tools such as preventive maintenance and built-in quality (jidoka).

Lowering the level of inventory exposes the problems that you have to deal with, exposes inefficiencies that demand immediate solutions. Traditional business processes hide the inefficiency so that nobody notices.

It motivates everyone concerned to fix a problem or inefficiency because otherwise the process will shut down. Linking together operations brings more team work, rapid feedback on earlier quality problems, control over the process and direct pressure for people to solve the problem, think and grow.

The ideal of one-piece flow is not a reality in many cases, but as always it provides a clear direction to improve. There should be no forcing of one-piece flow where it does

not fit. Inventory buffers must be used judiciously where continuous flow is not possible today.

2.5. Takt time

Takt – (German for rhythm or meter) is a rate of customer demand for the group (family) of products produced by one process [4]. It is a value that demonstrate the pace at which customer is buying a product [1].

The use of continuous flow and takt time can be extended in any repeatable process. Takt time is equal to effective operating time of process (e.g. shift, day) divided by the quantity of items customer requires from the process in the same time period:

$$\text{takt time} = \frac{effective\ operationg\ time}{quantity\ customer\ requires\ per\ shift}, \qquad (1)$$

where "effective operating time" is available time for production without lunches, breaks, cleanup, team meetings and plan maintenance. But changeover times and downtime are still included, since these are the variables that must be reduced, not ignored [4].

Figure 1. demonstrates how to calculate takt time on the Excel spreadsheet. In this particular example, based on the available time the production has per one shift, on average customer is currently buying one unit every 35 sec.

	A	B	C
1	Demand per month	15000	
2	Days/month	20	
3	Hours/day	7.33	
4	Sec/day	26400	'=B3*3600
5	Everyday demand(units/day)	750	'=B1/B2
6	Takt time(sec/unit)	35.2	'=B4/B5

FIGURE 1. Takt time per unit calculation

If this would be a true one-piece flow system final product has to be ready every 35 sec, which would mean that every separate cycle of the assembly should be finished at the same 35 sec, so that the cycle at which the unit is produced is synchronized with the rate customer demands it – sell one, make one [4].

Takt time represents an ideal repetitive cycle for an assembly process as an exact pace the product has to be produced. Takt time is a target condition that is used as something

to strive for. Going over takt time is overproduction, going slower creates bottleneck departments. Takt time can be also used to alert workers whenever they are going to slowly or two fast. It also shows that activities must be coordinated. One extra efficient department can create excess inventory and bottlenecks on the next stages [1].

Since the ideal conditions are hard to reach and smooth process can be delayed by changeovers and downtime, planned cycle time is usually used instead of takt time, which is actually less (faster). This allows compensating for the time lost during unexpected delays [4].

Planned cycle time answers the question of how many seconds per piece the process should be cycling at. This value gives a target condition for the process. By producing consistently to a planned cycle time it is possible to develop a stable process and to eliminate unnecessary fluctuation. It is easier to make improvements when the process is in control [4].

Once the process cycle is stable it is possible to go further and try to reduce the gap between the takt time and planned cycle time, by setting a new target condition for the process that includes the target planned time only 15% less than a takt time [4].

2.6. "Pull" system

As it was already said, one-piece flow is ideal, but not always achievable right away. Where one-piece flow is not possible to create, the next best option will be to design a pull system that allows some inventory [1, 4].

The way production is regulated traditionally is that each process in a value stream gets its own schedule that is based on the prediction of what the next process will probably need in the future. This approach is called "push system" for the fact that it pushes materials on toward the next process whether needed or not. Results of it are the inventories of parts and products that nobody needs to use immediately [4].

The fact that the production of goods is initiated by a plan that has been made in advance means that both purchase orders and production are based upon projected customer order. In situation when customer demand can change frequently and unexpectedly building to the schedule can cause lots of problems and create waste [1, 4].

As an alternative to it, pull system makes sure that customer receives the items only on demand. For our case it is important to remember that American quality pioneer, W. Edwards Deming has broadened definition of "customer" to also include internal customers - "the next process is the customer". According to him person or step in a production line or business process should be treated as a "customer" and should be supplied with exactly what was needed, at the exact time needed [1].

Concept of the "pull system" was inspired by American supermarkets. Supermarket is just like a warehouse, but it is operated in a particular way. Specific amount of inventory is kept on the store shelves, based on past purchase patterns and expected future demand. Material replenishment is initiated by consumption. Customers pull items off the shelf that are replenished as each item begins to run low [1].

In the case of shop floor, it means that step 1 in a process shouldn't make (replenish) its parts until the next process after it (step 2) used up its original supply and it is down to a small amount of "safety stock". In TPS, the actual need of parts of next process triggers a signal (kanban) to previous process asking it for replenishment of what was taking away. On the contrary if the process does not use a part it sits there and the buffer is not replenished. The preceding process must do what the subsequent process requires. This way last process gets some form of production instruction first and "pull" continues cascading backwards to the beginning of the manufacturing cycle [1].

As was already mentioned, kanban is a signal that the assembly line has used the parts down to the safety stock and it needs more. Kanban is created for managing and ensuring the flow and production of materials in just-in-time production system [1].

In practice kanban has to be simple, effective and highly visual. It could be a card, an empty bin, empty cart, more broadly a signal of some kind that is self-explanatory and specific. When some kind of container is used as a kanban it means that it should be refilled with specific number of parts and send back. Card with detailed information about the part and its location can also be send all the way back to the inventory and then even to the suppliers. Responsible employee will collect the cards and fulfill the orders accordingly [1]. Very common practice is to paint the floor that holds a specific number of components, so that when the space is empty, the producing department is authorized to make parts to fill the space up [5]. Companies are turning away from sophisticated computer schedules because kanban is a very common sense system that is cheap to execute, adapts well among workers and gives very precise results [1].

Kanban/ pull system works better than a schedule system in the most business situations, but it is still depends on small buffers and according to Taiichi Ohno inventory

is waste. Many companies confuse this well organized system of inventory buffers with something to be proud of, but in fact it is something that the factory has to eventually get rid of. The challenge is to find a way to reduce and finally eliminate the number of kanban and hence reduce and finally eliminate the inventory buffer. [1]

The most obvious purpose of kanban is to provide a way of regulating production between the processes so that it producing only what customer needs when it need is [4].Leanest imaginable system would be if the manufacturer could take in a customer order and make a single product just for that order using a one-piece flow production cell, so that there is 100% on-demand work and zero inventory [1]. But just like in case of one-piece-flow cell, "pull" means the ideal state of just-in-time (JIT) manufacturing and invisible purpose is to provide a target condition for the process improvement by definition of desired systematic relationship between processes. So by striving to achieve the perfect "pull" all the problems will be brought to the surface. Pull system gives the flexibility to respond to the unpredictable customer behavior, but it takes away the flexibility to ignore the problems [4].

2.7. Leveling the production schedule

The paradox of the pull system is that, without constant production level there is no way to apply pull system and balance the production line, which means that in most of the cases it is not possible to build only to order [1].

In fact strict build-to-order model creates lots of waste. Build-to-order production system problem is that customers are not predictable and actual orders are vary significantly from time to time. If you build product as it is ordered you may be building huge quantities one week, paying overtime, stressing people and equipment, and if next week orders are light – people have little to do and equipment underutilized [1].

Unevenness in the production levels means that even if the average requirements are much lower, it will be necessary to have on hand the equipment, materials and people for the highest levels of production. Since there is no way to know exactly how much to order from the supplier, the maximum possible amount of each item the customers might possibly order is stockpiled. Piles of excess inventory make factory disorganized if not chaotic [1].

Some of the risks of the unleveled schedule [1]:

9. Unexpected buying decision for unusually large amount can create very big troubles to the factory

10. Risk of unsold goods

11. Unbalanced use of resources. For example, different labor requirements throughout a week

12. Bullwhip effect (increasingly amplified behavior backwards through the supply chain). Placing an uneven demand on upstream processes, will cause that suppliers also would have to be prepared for the worse scenario and hold big inventories

Toyota found out it can create the leanest operation and ultimately give customer better service and better quality by leveling out the production schedule and not always building to order [1].

Toyota Way document refers to "elimination of *Muda, Muri and Mura*", which is also known as three M's (FIGURE 2).

Muda – Non-value-added, wasteful activities that lengthen lead time, causing extra movements to get parts or tools create excess inventory, or result in any type of waiting [1, 3].

Muri – Overburdening of people or equipment by pushing the machine or person beyond natural limits. Overburdening people result in safety and quality problem, overburdening equipment – breakdowns and defects [1, 3].

Mura – Unevenness that results from an irregular production schedule or fluctuating production volumes due to internal problems, like downtime or missing parts and defects [1, 3].
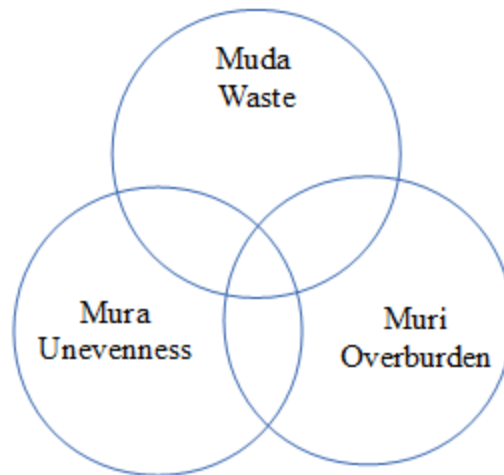
FIGURE 2. The Three M's [1]

Eliminating *muda* is relatively easier than stabilizing the system and creating "evenness". But it is only 1/3 of achieving flow and if concentrating only on eliminating waste, system will fail itself due to the spikes in customer demand that force people and equipment work harder than they effectively can [1].

Toyota does not assemble the vehicles in the same order in which customer buys them. [2] Building to an actual sequence of orders causes you to build parts irregularly. On the example of the labor work, sometimes you have to pay the overtime, sometimes you have to send your workers home early. Many companies deal with this situation when they need to add a large number of temporary workers in a peak season and when the business drops dramatically for the rest of the year; people had to be laid off [1].

Heijunka means leveling out the work schedule. Achieving Heijunka is fundamental to eliminating mura, which is fundamental to eliminating muri and muda. It levels production by both volume and product mix [1].

Company that implements heijunka does not build products according the actual flow of customer orders, which can go up and down widely, but for a certain period takes total volume of orders, that correspond to actual customer demand, determines the pattern of volume and mix, and built a leveled schedule every day so that the same amount and mix are being made each day [1].

When an item is pulled from the finished goods inventory the signal for replenishment is not directly sent to the assembly process. Instead it goes through some kind of sorter that typically sorts two things: mix and quantity (volume) [4].

- Leveling the mix.

It is a task of sorting of customer orders into a predefined sequence by item type. The sequence could be selected in a beneficial way, so that the total changeover time is the minimum or large batches of demand are distributed across the day or reduce any other concerns of the factory [4].

If frequent changeovers are possible and the plant can produce each type of the product during the day ("every part very day") then the lot size of any item is one day worth [4].

- Leveling the quantity.

The sorter also defies the maximum quantity of each item that should be produced on one pass through the sequence. It is based on the production lot size and the rate at which customer demands the item. If the production goes through the sequence in one day, it means that lot size of the item is worth of one day of customer average demand for this item and this quantity is a maximum that the process should produce [4]. Full-mix production in a short time interval allows building up fewer inventories for each model. It also provides an opportunity to respond to actual customer demand conditions faster [5].

The leveled demand for a period of time is compared to the real demand that kanban signals for today. If kanban requires replenishing more items for one product type than it is allowed by heijunka level, this item is will pass through the sequence next time. This way there are no demand spikes on upstream processes. Heijunka quantity represents an average daily demand rate, which assumes that over a period of time one extra item bought today will result in one less item bought in the future. If to produce the extra item right away it will send a demand spike upstream [4]. Level output requires keeping the schedule firm (frozen) for some reasonable time to provide a stability of the production and balance a work flow [5].

Benefits of Mixed-model assembly line:

- Serve the variety of customers in the short lead time. Whereas short lead time gives flexibility to make what the customers wants when they want it and reduced inventory [1, 4].

- Reduced risk of unsold goods. The plant mostly produces only what the customer orders [1].

- Balanced use of labor and machines. The plant can create standardized work and level out production by taking into account that some products will require

less work than others [1].

- Balanced and manageable workload over the day [1, 4].

- Smoothed demand on the upstream processes and plant suppliers. Stable and level set of orders for suppliers [1, 4].

Sometimes company has to selectively add some waste, by building selected product to store away. Especially it concerns the companies that are highly season dependent. When supplier must satisfy customers whose demands fluctuate significantly, TPS experts are often recommend keeping at least small inventory of finished goods (even though inventory of finished goods is more expensive than inventory of raw material) and build at a leveled pace to replenish what the customer takes away in a pull system [1].

Companies that have successfully applied TPS often schedule their production with combination of building to order and maintaining pre-determined level of finished goods inventory. For example, building high-volume seasonal products to hold in inventory and then building other products to order. This combination allows leveling the schedule over the year, having a smooth flow, and building most of its products to order. When real time orders are low, workers can build to the seasonal inventory or to replace any safety stock [1].

A small inventory of finished goods is often necessary to protect a suppliers' level production schedule from being jerked around by sudden spikes in demand. Living with the waste of some finished goods inventory, you can eliminate far more waste in your entire production process and your supply chain, by keeping your production level [1].

To level the mix of products built every day changeovers must be quick. In batch-processing mode, the goal is to achieve economies of scale for each individual piece of equipment. Change over tools to alternate them between making different products is considered wasteful, because nothing is being produced during changeover time and operators do not work, while still being paid. The logical solution in this situation is to produce large batches of one product before changing to another, but this is not allowed in for heijunka [1].

SMED is a single-minute exchange of die. This concept states that all changeovers can be done in less than 10 minutes [5]. It was expressed by Shigeo Shingo, who in his time studied and analyzed the set up process for large stamping presses, and proved that eliminating most of the set up time for the changeover is possible in every circumstance.

During changeover most of the work is either muda or it is something that can be done while the machine is still running, in other words "external setup" can be performed. As oppose to external setup "internal setup" is work that has to be done while machine is shut down. When all the waste from internal setup is eliminated, a many hours changeover process turns into process to be done in matter of minutes. Since that time Mazda supplier of stumped door panels has won a prize in national competition for changing over a several-hundred-ton press in 52 sec [1].

3. DESCRIPTION OF THE DATA COLLECTION PROCESS AND DESIGN STEPS

Calculation model allows analysing the current manufacturing system of the company by several parameters and through use of initial data can assist with design of a new system. Not only line production system can be achieved with its help, but also some simpler designs. The model makes the design process more visual which is one of the factors that is very convenient. At the same time it provides all the time value calculations automatically and assigns tools and materials to the operations it belongs, which helps to balance the system first theoretically in order to do it in more efficient way in practice.

3.1. Worksheet layout design

The first step was to design a model structure in Microsoft Excel environment including most of the functionality of a final product. It was achieved by enabling macros in a regular MS Excel workbook and using VBA programming language to create buttons and support it with functionality.

It was intended to create a layout that would be easy to use for the regular user that isn't very familiar with the VBA programming and maybe even not very experienced with MS Excel working. The program is operated by buttons and dialogue windows that communicate with the end user and put inserted parameters in the right place of the tables and make all the necessary calculations.

Because each company that can benefit from this tool is different and for sure has their specifications, the model needs to be adjusting for each case. Tools and materials need to be added to the lists and also the amount of subassemblies; stations and operation number limit has to be adjusted for every case separately.

During the design process fake test information was used to check the functionality of the tool. When the layout design of the tool was completed it was important to check how well it actually performs in practice with the real data. This was important in order to find the mistakes in calculations that could occur under certain circumstances.

3.2. Detecting the suitable product type

The real practical data was collected on the factory floor. Since the case study company has a very wide range of different products that they offer to their customers, our aim was to find a product type – object that is most suitable for the purpose of the project.

The data was collected on the substations that were manufactured during period of time starting in November 2012 till the end of May 2013. This data was originally collected during production process and stored in the company's database for the purpose of statistical analyse and forecasting. It included names of the projects, type of the substation (parallel coupling, two step connections), pipe size, plan time for the assembly and actual time used, accessories list for each substation.

The initial goal was to find out what is the type of substation that would be most beneficial for making a video for a further analysis. For this purpose some criteria were supposed to be managed first. Criteria were chosen in such way that the collected data would both benefit the project and the company in overall.

Criteria:

1. *Production volume of the product.* We were looking for a product type that has a big production volume, first of all because it had more sense for the production on a line and at the same time because collected data could be useful in many other ways to improve the current processes.

2. *Product structure.* It was not possible to choose the product which had too complex structure. The components of the station had to be most common. Also since it was decided that the data analysis will be made by video recording of the manufacturing process we were limited by the equipment abilities (recording time, memory capacity).

3. *Accessories.* Each product had different combination of accessories that depend on the customer order. It was also one of the issues to decide which accessories are in the scope of interest for the further analyse.

4. *Usability of output.* One of the criteria of the company was to choose substations video recording which will reveal some problematic areas of the manufacturing process or structure.

Decision was made that we continue to work with two circuited heating substations. This type of substation has domestic hot water circuit and heating supply circuit. After the

decision was made, data on all objects for the period of time from 1.11.2012 to 31.05.2013 was collected.

Collected data was analysed and sorted in the way it was possible to see what pipe sizes are the most common, which connection type and what accessories are most regularly ordered as the part of the substation. With this information gathered we could find the station video recording which will bring the widest range of valuable information.

Statistical tools of the MS Excel were used to perform calculation on the time difference between the plan time and actual time, standard deviation and average of these values. Also through the known time for the accessories that is given in the time calculation program tool of the company, the total accessories time for each substation was calculated and plan time without accessories.

All generated data was used to point out problematic areas of this type of substations and choose an object of further study.

3.3. Video recording

The video recording of the production process had its difficulties. It was important to choose a convenient time of production, since there were some technical limitations that had to be considered, such as memory capacity of the camcorder and its battery life. Charging the camcorder on place raised the issue of safety regulations regarding wires on the floor. Safe positioning of the camcorder itself away from sparks and so that it does not disturb the operator was important. At the same time willingness of the employer to be on video had to be taken into account.

In total it took 20 hours of recording time to collect visual data on three stations. Video was made for both pre-assembly and assembly.

The figures below (FIGURES 3, 4, 5) present the subject substations and include description of specific features.
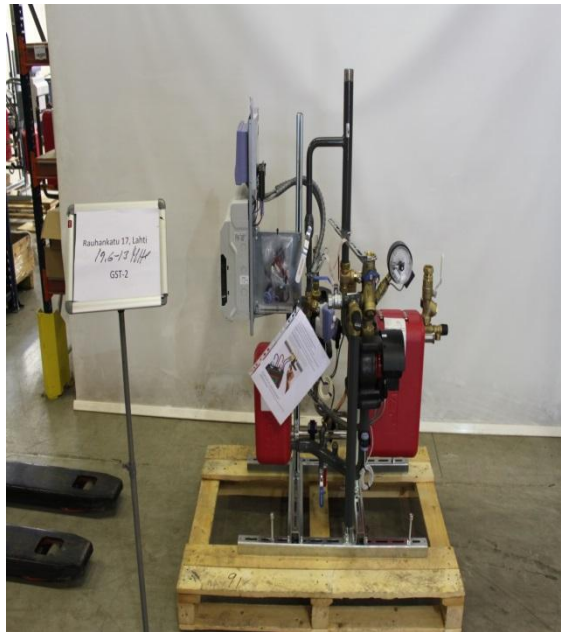
FIGURE 3. Two step connection heating substation, DN 32, safety valve, and service valve, substantially standard

FIGURE 4. Two step connection heating substation, DN 65), Airvec Normal, two safety valves, service valve and two control valves in District Heating Supply

FIGURE 5. Parallel coupling heating substation, horizontal structure, DN 65, four-point measurement in heating secondary side, safety valve, thermometers, gauge block for energy meter and pressure gauge in DH Return, two point measurement in DH Supply

3.4. Video Analysis

Analysis of the video was made with the help of free software - Windows Live Movie Maker. This software allowed breaking down the video to pieces and by that split the time of different operations. The downside of this software is that the structure of the folders that have the videos and pictures inserted in the media projects can't be changed. If the address path of the file folder was changed, as for example, the directory of the file folder was changed or folder was transferred to another computer, program cannot find the video files within the Movie Maker project. To fix this you need to:

1   Right click on the file(video, picture that is giving an error message)

1. Correct target

2. Choose the file from the folder (should have same file name).

Benefits of the video analysis were so that it allowed:

- to view and study the total manufacturing process,

- to determine process complexity and operation sequence,

- to estimate the real time for the components assembly,

- to reveal what are the non-value adding operations(avoidable-non avoidable),

- to describe the process flow

Video analysis gave an opportunity to gain a deeper understanding of the manufacturing process of the substation which became very beneficial when the data was being processed and prepared for input into the model.

Three videos were made in order to estimate more times for other accessories and find average values for same processes. Also it was made with a perspective to find continuous process that will involve most of the functionalities of the calculation model, so that can be tested.

3.5. Model testing

Collected data was organized and processed in the Microsoft Excel worksheet. Documents that had time calculation of preassembled parts separately for all three substations were created and tables were combined so that it is possible to see how time for same components can vary (preassembly, assembly, total).

Operation lists have approximate chronological order of the operations and their times. In the first two cases the order is more precise due to simpler structure. In the third case there were more accessories that needed attention in different stages of assembly. All the collected data was analysed and different ways of input were tested. Then one station was chosen and the test and data was inserted in the model.

Two worksheets of the tool are dedicated to the design of the flow charts. One is supposed to describe the current production system and the purpose of second is to make a more visual representation of the future system. Due to this fact the attempt to build a flow chart that describes a present way of production was made and proved itself as an effective method.

Design flow chart described the flow of assembly of two step connection substation and was based on the experience gained from the analysed videos. It also showed points

where the preassembly meets assembly and where the additional preparation work is needed such as welding.

In order to use the calculation model, a lot of theoretical material needs to be collected and the processes must be learned well. The information collected in this case helped to identify many issues with the model that were not visible at the development stage and correct them. Performed studies helped to develop the final product so it can be beneficial beyond the frames of this specific project.

4. CALCULATION MODEL

4.1. Description of functionality of the calculation model

Link to the video presentation: https://www.videosprout.com/video?id=e30801e9-0935-4c73-a11c-9875a93cc6c3

As it has been mentioned already above the tool was created in Microsoft Excel environment and, just like it was initially planned, it is built in such way that each worksheet represents a step of the designing process of the future layout. One of the main issues was to create an interface that would be user-friendly and have efficient usability level. The program will be operated by buttons and dialog windows that will communicate with the end user and put inserted parameters in the right place of the tables and make all the necessary calculations.

Benefits of chosen approach are:

- Saves time of input by making all the formatting automatically.
- Provides new calculations after each addition to the table, which allows tracking the current situation.
- Makes it possible to renew the calculations after every change made to the content of the tables.
- Eliminates human factor errors.
- In many cases transports necessary data across the worksheets, so that no repetitive work is needed.

Possible issues of the chosen approach:

- Possibility of the bags that were not eliminated during the development stage.
- Some adaptation of the system is possible only with the knowledge of VBA.

Tool consists of worksheets named:

- Instructions,
- Visual Presentation,
- Product,
- Local Production System,
- Flow Chart 1,
- Flow Chart 2,

- Main Assembly,
- Subassembly A,
- Subassembly B,
- Station development
- Final Assessment.

Before each worksheet is described it should be noticed that additional worksheets were added that were not mentioned in the project plan: Product and Station development. The idea of these two worksheets was gained later in a process and purpose of them will be described below.

4.1.1. Functionality of the buttons

Calculation model is mostly operated by buttons. Each button represents series of actions that will be made automatically after it is pressed. In order to successfully use a model it is important to understand these functionalities.

Create Operation:

- Adds the row of certain format (colour, borders of the net),
- Asks all the parameters (operation order, operation name, time, detail code etc.) and inserts them in the right column.
- Sorts the operations by the order number.
- If the operation number already exists, then the program will still put the operation in the right place, but change the following operation order number to the next one.
- Evaluates the time values and condition them by colour from smallest to biggest value
- Calculates total values

Change Operation:

- Asks the operation order number of the operation to be changed
- Checks which parameters should be changed(by clicking Enter it is possible to skip the parameters that are not to be changed)
- Recalculates the total value

Delete Operation:

- Asks the order number of the operation to be deleted
- Deletes the entire operation

- Changes the order number of the following operations
- Recalculates the total values

Renew Calculations:

- Checks the total calculations and renews the values if necessary(recommended if manual updates were performed)

Save:

- Saves the whole document

Content description:

- Gives a short description of the worksheet process

Design Template:

- Takes the names of operations from the local production system list and uses it to create an automatic template for the flowchart.

Back to Main Assembly:

- Automatically leads to Main Assembly worksheet

Add Operations (Station Development):

- Asks user to input the start order number and the end order number of operations that are intended for the station.

4.1.2. Visual Presentation

Worksheet named *Visual Presentation* shows in more demonstrative way approximate plan of how the system will be affected. One of the examples was created to demonstrate the working principle, but in practice it can be done in any way user believes is convenient. The worksheet does not have any special functionality but it is present as an extra explanatory method in order to provide a good start point.

Our visual model (FIGURE 6) displays present system where all 100% of products manufactured in the local assembly cells and future system where 50% of the production is turned into assembly/production line. By clicking the buttons *Open Operations List* it is possible to go straight to the operations of each production system.
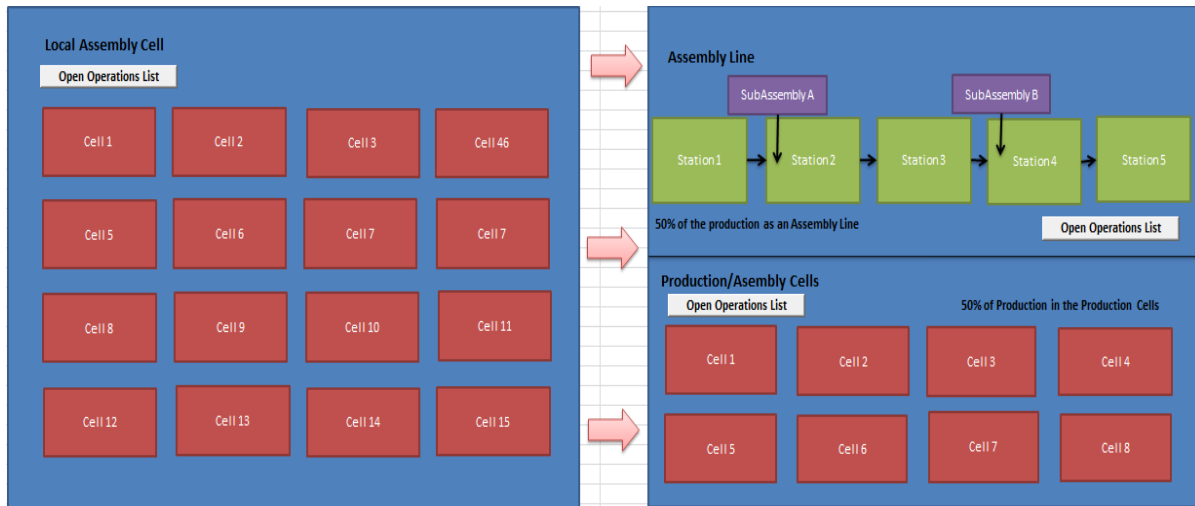
FIGURE 6. Visual presentation example. Present and future model of the studied production system

4.1.3. Product

This field is reserved for the product(s) specification information. In our specific case it is a heating substation, manufactured by Case Study Company. All the data, images of the product(s), links to the video demonstrations that are useful for the purpose can be included in this worksheet. It is a way to organize-related documentation for the convenient use later in the process.

4.1.4. Local production system

Worksheet *Local PS* (Appendix 1) is designed in order to analyse present system. The idea is that if the present system is well understood it can lead to the better future design that will take into account all the advantages and disadvantages of the current ways of implementation.

Videos of the manufacturing process made during research stage of the project were used to collect information for the table test during this project. Processes and its time consumption were evaluated separately from each other. This method in practice proved its efficiency and provided us with a lot of information, which is beneficial even outside of the scope of this specific project.

By filling up the given table, it is possible:

- To find out what are the operations and list them down
- To identify the order of the operations
- To learn how much time each operation takes
- By assigning the Part Name(s)/Code(s), amount of these details and the necessary tools for each value-added operation to be done, we can also trace the material flow and follow at which stage of assembly the specific part or equipment is needed
- To evaluate the necessity of each operation. The program will ask is the operation value-added or non-value-added. In the case of value-added operation it will create an importance indicator "Necessary" automatically. If the operation is non-value-added the program will give an opportunity to tag the operation as "Avoidable" in order to draw attention to this type of operations and evaluate its influence on a total process

As a summary of the listed information there are automatic calculations done in three time units: seconds, minutes and hours, so that the user will get three levels of precision. The values indicate total runtime and calculate value-added and non-value-added time of the manufacturing process. Non-value-added time is also divided into two categories: pure (or avoidable) and required (necessary). Required it the non-value-added time that we can't get rid of completely for now, but the goal is to reduce it as much as possible. Pure non-value-added time is the one that has to be liquidated before moving to the production line design so that no waste is transferred to the new system.

This table helps to collect the necessary data and think it though first and only then use to plan a new system. All collected information for this table will be useful for the next operations of the model such as creating a flow chart and listing down the operations for main and sub- assemblies of the new design of the production flow.

4.1.5. Flow chart 1

Next step is to create a flow chart of the manufacturing process of the product in the local production system, which is possible on the next worksheet created for this purpose named *Flow Chart 1*.

Flow chart, also known as flow sheet or flow diagram, is a symbolic representation of the successive steps (operations and equipment) though which material passes, as in manufacturing process [6].

Another way to describe a flow chart is pictorial algorithm of the decisions and flows that create a process from start (input) to end (output). Examples of decisions can be production, storage, transportation. Examples of flow can be movement of information and materials [7].

The figure below (FIGURE 7.) presents an example of most common symbols that are used to create such flow chart.
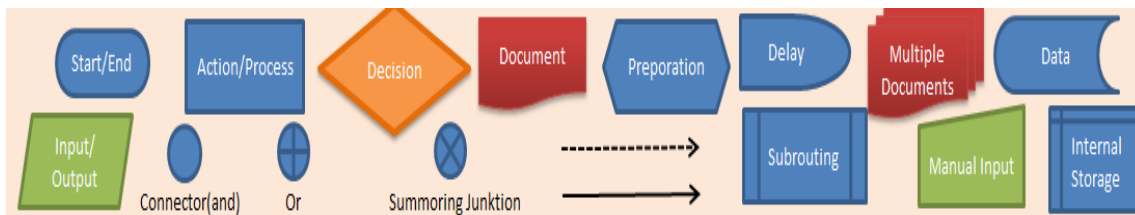

FIGURE 7. Common flow chart symbols

This step will make it easier to visualize the current process and will prepare the basis for the design of the flow chart for production line system (*Flow Chart 2*). During this phase it is possible to visualise the process as it is now, before any modifications are made. A well designed flow chart usually gives a very good idea of the process standard steps.

The model offers an easy way to start the chart. By the click of one button it will create a template of the chart that will have blocks with all already listed operations in their chronological order. This template can be easily modified. All necessary shapes and their meanings are always in the view range in order to:

- Assist user with design
- Help observer to understand the chart

After changes are implemented to the system, another useful application of this chart would be to store information about initial system in order to reference it in the future if needed.

The flow chart designed during the project proved to be beneficial in the way it describes the current process and simplifies the way it can be demonstrated to other participants of production and organization process of the company.

4.1.6. Flow chart 2

Flow Chart 2 can be based on the *Flow Chart 1* and the purpose of it is to design the schematic representation for production line system. During building process of the flow chart for the production line we can divide the whole process on the main assembly and subassemblies — some preassembly work or preparation work that can be done externally from the main assembly. The chart can demonstrate where the subassembly should meet the main assembly process, as well as help to organize storage(s) and material flow.

4.1.7. Main Assembly

As the whole process is designed it can be followed by listing down all the operations and issued parameters separately for the main assembly (Appendix 2.). In the document the subassembly can be automatically hyper-linked to the certain operation where these two processes meet in the main assembly. For this purpose each subassembly can be assigned by certain code. In our case Latin letter is used, but it can be also numeric code, specific name etc. for each subassembly process.

Now time of each operation is treated differently. Program request to input a start time of operation and the time operation is finished. The purpose of such change will be explained below.

Programming code automatically calculates the duration of each operation, runtime after each operation and total runtime, as well as total space. Also it asks is there a subassembly process that needs to be attached to current operation. By choosing the subassembly and assigning it to the proper place in the list it will automatically create a link to the worksheet that has all the information about this subassembly.

Value-added and non-value-added calculations are also present, but in this case they calculated in two different ways:

1. Paid time that considers the number of operators and indicates the time that the company covers with the salary. Its purpose to indicate what economic effect will be created by the increase of operator's number.
2. The time portion spent out of total runtime that considers only the lead time of the production. The purpose is to indicate how efficient the production is.

4.1.8. Subassembly A

Subassembly process allows preparing some parts of the product outside of the main flow of assembly line. It is important to realize that the subassembly work has to be well coordinated with main assembly in order to neither create bottlenecks nor overproduce.

The purpose of worksheet is to list all the operations and issued parameters of the subassembly. The reason to separate these operations from the main assembly is to properly track the runtime, since these operations would be most likely performed parallel to the main assembly process.

The layout of the worksheet is same as previous except it does not require the subassembly column. Some kind of call names has to be used for each subassembly to recognize it and attach to the certain point of main assembly.

4.1.9. Subassembly B

In this case subassembly B is created in order to demonstrate the additional worksheets with same functionality can be created for other parallel processes (this can be done by copying the code to the new worksheets). In practice the amount of subassemblies is limited only by computer processing power. In some cases subassemblies can be built in the separate workbook(s).

4.1.10. Station development

Purpose of this worksheet (Appendix 3.) is to divide manufacturing process on the separate groups of operations that can be performed by different operators simultaneously on different station of the assembly line.

The only operation button is *Add Operations*. As soon as the button is pressed the program askes what are the operations that are to be assigned for the station/ operator (start order number and order number of the last operation in the *Main Assembly* list) and automatically add them to the station.

Notice:

- In order to add only one operation input same start number and the end number
- The way to add or remove the operations to the station is to press the *Add Operations* button again and choose new operation order numbers. The program

will automatically remove the previous list

Program actions:

- Copies the operations from the main assembly list to the station list
- Calculates the total time it will require on the station to complete these operations
- Copies what materials are necessary on this station to go through this list of operations once
- Sums up the required space to fit all the operations on one station
- Copies subassemblies that will meet the main process in this specific station

Worksheet also indicates the necessary takt time, which is a specific time limit that each separate step of the production has, so that every takt will be provided with a ready product. The way takt time can be set on the Final Assessment worksheet will be described in more detailed in the next section. Knowing the takt time makes it possible to set planed cycle time and a good clue to adjust the number of operations on the stations to balance the line.

Bottleneck indicator is another clue that gives a notice about system imbalance. It will tell if there are a lot of work in process accumulating between the stations or if the station has to wait for the preceding operation. Two balanced stations will indicate "Flow".

4.1.11. Working with Main Assembly and Station Development worksheets

The way of time tracing mentioned above is present to insure that the runtime will be calculated properly even if the operations were executed simultaneously by several operators on one station. This feature might not be useful right away since when the operations are listed for the first time it is better not to create parallel operations that are outside of the subassemblies. In this case it is better to analyse the time values without parallel work and to test the *Station Development* first with one operator per each station and to evaluate operator workload.

During the station development process first way to balance the line is to separate operations so that there is no bottleneck between the stations. The bottleneck indicator can be a great assistance in this case. But it might be so that to balance the line by this method cannot be possible. For example, one specific operation takes too much time

and breaking it down to smaller operations has no logical sense or if it is irrational to separate some operations to different stations, for example, from transportation point of view. In this case, another way to avoid the bottlenecks could be to increase the number of operators on the station that causes the interruption of the flow.

New way of time tracking gives flexibility to assign additional operators where they are really needed. More operators can be needed to either increase the capacity or to balance the bottleneck stations. Functionality of *Main Assembly* worksheet allows balancing the system in two different ways:

- Divide the group of operations consigned to the bottleneck station among operators so that they can together perform work on one part/component etc.
- Increase the amount of parts the bottleneck station produces by assigning additional operators to perform same task.

Additional operators can be manually added to the table opposite to desired operations. Clicking the *Add Operators* button will result in the change of the total calculations. The runtime will decrease as the time will be saved and the paid time will increase as the number of the workers grows. It is possible to return to the initial calculations (without consideration of operators' number) by clicking the *Renew Calculation* button.

Knowing a goal time for the station (takt time/ planned cycle time) makes it easier to decide how many operators should be added. Notice that the takt time will increase respectively as the lead time of the manufacturing will decrease.

The choice here depends on the situation, but what is important that system allows evaluating the outcome of both options.

4.1.12. Final Assessments

Final assessment is made in order to compare the core values and evaluate the benefits of the new system. Table below (table 1) demonstrates the improvement of the lead time as well as possible improvement of processes that especially results in the decreasing of the non-value added time. The time values are given in all three time units and also number of shifts that will be spent on one ready product is calculated. Values used in this section do not represent the actual test case, but give an idea of how assessment works.

There is no pure non-value-added time calculation on the main assembly, because this type of waste has to be eliminated and not translated on the assembly line.

Table 2. Total time calculations

	Production Cell				Main assembly Line			
	sec	min	hours	shifts	shifts	hours	min	sec
Value-added time	12960	69,50	1,16	0,05	0,25	6,03	361,67	21700
Required non-value-added time	12096	201,60	3,36	0,14	0,11	2,58	155,00	9300
Pure non-value-added time	18144	302,40	5,04	0,21				
Total lead time	43200	720,00	12,00	1,60	1,15	8,61	516,67	31000

Next valuable piece of information is the takt time of the production, in other words how many seconds/hours the factory has per product unit according to the real demand on their products. In order to get a result the user needs to enter the forecasted demand on product for the month and production working time information. The rest of the calculation is done automatically. According to the table below (table 2) in order to fulfil customer demand factory has to produce finished product every 2700 seconds (0, 75 hours).

Table 3. Takt time

DEMAND EVALUATION		
Demand per month	200	Input
Working Days/month	20	Input
Working Hours/day	7,50	Input
Working time (Sec/day)	27000	
Everyday demand(units/day)	10	
TAKT TIME		
Sec/unit, sec/station	2700	
Hour/unit, hours/station	0,75	

Next table (table 3) gives total number of process steps in both situations. These values indicate the importance to reduce the number of steps and make the processes more standard in order to achieve a smooth and well balanced flow. Big amount of production steps indicates the necessity in product or process design change.

Knowing the takt time and lead time it is possible to calculate how many operators are necessary to comply with demand. In this case (table 3) the lead time on assembly line is shorter, which means that in order to produce required amount of units per day it needs less operators. Each operator has to spend 2700 (two thousand seven hundred) seconds per unit and pass it to the next operator (station). For the assembly line this

value may also be equal to the amount of separate stations. Takt time can be replaced by the planned cycle time to comply actual situation.

In case of local production each operator works in the separate area where he/she performs all the assembly work from the start to end. In order to keep up with the current demand 16 (sixteen) operators has to be working simultaneously. In this calculation each cell takes space of 10 (ten) m^2 which gives us the total 160 (one hundred sixty) m^2 of occupied, which is 16 (sixteen) separate cells. If the demand grows it will require even more space and additional equipment.

Whereas the space required per assembly line is a fixed value that does not fluctuate with demand and most probably after certain demand level will be less than local system require per same work in process.

Table 4. Additional information on the present and future systems

	Production Cell	Assembly Line
# of process steps	26	20
# Operators/ Stations to comply with demand	16,00	11,48
Space requirements to comply with demand	160,00	100,00
Number of Cells	16	

If in previous case the calculation demonstrated the number of necessary cells to produce the exact amount of units that is demanded by the customer, table 4 provides the calculations for the actual capacity of the plant per shift and different perspective on the capacity improvement.

In reality the number of local production cells is limited, so the capacity of the plant that manufactures in this way is more dependent on the number of available work space than on the amount of operators. Table 4 allows seeing that due to shorter lead time of the assembly line the same amount of operators will be more productive.

Table 5. Capacity calculation

CAPACITY			
Lead Time	43200	31000	
Working Days/month	20		
Working Hours/day	7,50		
Working time (Sec/day)	27000		
Available operators	15	15	Input
Available Cells	15	Line	Input
CAPACITY(units/shift)	9,38	13,06	
	Production Cell	Assembly Line	

In the situation where only one operator is needed per cell as it is shown in table 4 it is really hard to increase the capacity of the assembly process.

Even so the capacity in the local production system can be manipulated by changing the number of operators per cell; introduction of additional manpower is complicated. It is possible either to increase the number of operators in some cells to achieve a certain capacity level (option 1) or increase the number of operators in all cells to multiply the capacity by the certain factor (option 2).

Both strategies have serious issues. Operators that are sharing the work load in one cell will have to proceed with their work simultaneously, but in this case they would have to share the work on the same product, which could be not possible due to the product design.

In the case of product that allows parallel operations, the problem with first option (option 1) is that different standard procedures for different number of operators per cell would have to be created. This will lead to a lot of confusion, and related waste.

Second option (option 2) will cause overproduction, since the change in the capacity is not flexible and most probably will not be equal actual demand.

On the assembly line additional operators will linearly increase the capacity. Process of introduction of additional manpower is relatively easy, because tasks are repeatable and simultaneous. There is no need for the operators to share the work, because they can produce same components. On the well balanced assembly line that is set to a certain takt time if the demand doubles, the manpower per takt is also doubles and vice versa.

5. RESULTS

As a result of case study Theoretical Calculation Model was created. Through a series of transformation it became a computer program that gives a new convenient and common sense approach to a production line design and deep analysis of current production operations.

System allows thorough testing with minimal resources involved. The most valuable features of this program are that it gives reliable calculations and direction to think more constructively to get deeper to the issues. It allows going away from the surface solutions and finding real root-cause problems, so that they can be solved and will not be transferred to a new design. It brings even small hidden problems to the surface through different approaches: obtained numbers, visual representation.

Tool allows tracking the effect of every activity. It is possible to break down the actions even to the smallest detail, such as movements of the operator and to analyze the effect of its presents and absents on the overall picture. It gives information to find more unconventional solutions or find room to compensate for the problems that cannot be solved at this point. Also it gives a power to create fast and easy different problem solving approaches to compare different ways of implementation to find the best solutions.

The chosen approach proved itself to be beneficial during the case study in the company. It was beneficial to collect the real data to support the ideas that were already present and to find new possibilities for the further improvement. The problematic areas were defined and the directions for improvement were chosen. It was interesting to realize that solving the root issues is easier and cheaper than to deal with the consequences and this way an effect is more beneficial in the long run. Small positive changes on the very basic stages of the production can bring a bullwhip effect on subsequent processes.

The tool minimizes the necessity of repeatable actions, and reduces human error possibility in the calculations, at the same time it keeps the flexibility to adapt to different situations. It has a system of logical sequence of steps that has to be taken in order to successfully accomplish the goal. Going through all the steps hopefully will lead to proper ideas and correct approach to the problem.

Link to the video presentation: https://www.videosprout.com/video?id=e30801e9-0935-4c73-a11c-9875a93cc6c3

6. CONCLUSION

The idea that production management demands creativity proved itself to be true. Best solutions, just like the problems, are not always obvious and require a more comprehensive approach. I was starting my work from the concept that deep approach and the attention to the details has its great benefits, but it also takes a lot of time and effort to be that precise. When you are working on root-cause problems, in most cases, they are easier and cheaper to be solved.

My purpose was to create a tool that will allow making this deep approach to the production system analysis and designing a simpler one by omitting the routine work, difficulty of processing lots data and eliminating the errors that can be done when you are working with very small numbers. I wanted the tool to be able to adapt the changes easily, so the testing of different options could be possible. It was very nice to see that the final product corresponds to the initial conditions and gives even more useful functionality. The program allows seeing a bullwhip positive or negative effect of even smallest changes, which is not obvious without visual and numerical control.

Big finding for me during this project was to see the effect of non-value-added operations and how much of the total productivity it can consume. At the same time it was surprising to see that most of these operations could be easily reduced or even eliminated, once you see them and understand their nature.

When you design a new production system for the product it is very important to understand the current processes. Practice showed that deep analysis of the current process can send you far back by showing higher priority challenges that should be met first, since it doesn't make sense to transfer them to a new design. That is why I was trying to pay great attention to the current system analysis and dedicated my internship in the company to this subject.

The theoretical base of this study is dedicated to importance of having the markers or, in other words, the ideal conditions for the processes. The final goal and the clear direction give meaning to the journey and will get you to the result much faster. During the theoretical research I found that for today's manufacturing world it is important to have a philosophy. I made my personal choice toward the Toyota Way and took a lot of ides from Toyota Production System (TPS) from the standpoint of what my calculation model has to become in the end and what functionality it has to include. Also as the theory for this project I included the description and explanation of the tools and ideas that TPS

implies, so that the final user of the calculation model could use it to set his/her ideal process conditions.

Most issues with this study came from the coding process. The time for such project cannot be measured very precisely even in the professional world, so it was very hard for me to predict the time frame also. I found out, that making corrections to the code, or debugging, even more problematic than to find the initial solutions. Some issues with the code were found only on the last stages through the testing or even from reading the theory and realizing that some of my initial ideas were incorrect.

The other difficulty I faced is problem with the scope. The goals were set in the planning phase, but the final result had a wide range of actions and ways of evolution. The list of final functionality wasn't set, so the new ideas what this program should be able to do required new coding, which every time led to the question of creativity, since solutions do not come easily.

The data collection for the test was also challenging since there were higher priority goals from the company perspective that had to be executed, so this particular project wasn't the only task during my internship, it was more of an additional result of the work done. But this was a better approach, because I had a chance to really understand and learn the production process on all its levels and to see the whole perspective of the company procedures. The time of the internship wasn't enough to collect all the necessary information to meet all the objectives that is why space requirements analyses was omitted from the project and the calculations of this aspect were not tested properly in the calculation model.

The project was very challenging since it consisted from three big and important parts: case study, coding and documentation. I found the documentation process quite difficult, since the case study of the real production process and coding process are the tasks of very different nature, nevertheless they were connected by the same purpose within the frame of this project. But I was always told that the greatest findings are hidden in between different scientific disciplines, so I believe that accomplishing such task was a great learning opportunity for me.

As the result of my internship there a lot of accurate data was gathered, that pointed out the areas that need more attention. These areas were included in the yearly production development plan and final report was distributed among the departments of the company. It was great to hear that Managing Director, and concurrently supervisor of my internship in the Client Organization, was surprised by the amount of work that was done in a very short period of time.

My next challenge for this project is to find the way to make the adaptation of the code to the specific case easier, because right now it is still requires basic knowledge of the VBA programming language. Also I am thinking to modify space requirement calculations and implement distance calculations for the operators' movement around the factory.

 As a conclusion I can say that I am very satisfied with the result of my work. The project met most of the goals that were initially stated. But there is still limitless opportunities to improve the system and it is not developed to the point where it can be used for the production yet, but I believe that the calculation model can be used for the educational purpose to teach the students to cover not only tools and workspace in production renovation projects, but also think deeper and understand the importance of the process itself in such projects.

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LOCAL PRODUCTION SYSTEM WORKSHEET DESIGN AND FUNCTIONALITIES

Automatic calculations in three time units: seconds, minutes and hours.

	Total runtime:	Cell Area, m²	Value-added Time	Non-value-added Time
Sec	7260		4170	3090
Min	121,0	fixed value	69,5	51,5
Hours	2,02		1,2	0,9

Present System	Content Description	Save			
Assembly /Production Cell	Create Operation	Delete Operation	Change Operation	Renew Calculations	

2 **4** **5** **6** **7**

Operation Order **1**	Operation Name	Type of Operation (value-added- YES/ non-value-added- NO)	Time,sec	Detail Name, Code	Amounts	Tools	Importance Indicator
1			**3**				
1	Floorstand construction	NO	720	123 Detail 1 456 Detail 2			
2	DHW heat exchanger attachment + pipe part for comtrol valve and DHW hex +after cooling pipe part	YES	510	789 Detail 3 456 Detail 2 789 Detail 3			
3	Connection of Heating HEX & pipe part for	YES	360	123 Detail 1	1		Necessary

Create an Operation Name ✕

Operation Title? | OK |

| Cancel |

Dialog window one by one asks all the parameters to fill up the table

1. To track the order of the operations (+ for the purpose of VBA coding)

2. To identify what are the operation

3. To evaluate operation from the customer perspective

4. To track time for each operation

5. To track the material flow

6. To assign the tools and equipment to the operation

7. To evaluate operation from the

MAIN ASSEMBLY WORKSHEET DESIGN AND FUNCTIONALITIES

Create Operation	Change Operation	Renew Calculations	Delete Operation	Save

Main Assembly

Operation Order	Operation Name	Type of Operation (value adding- **yes**/non value adding- **no**)	Start Time	Finish Time	Duration	Runtime	Detail Name, Code	Amounts	Tools	Space requirements, m²	Sub Assembly	Travel Distance
3												
1	Floorstand construction	YES	0	720	720	720	456 Detail 2	1	Screw Driver	1		
2	DHW heat exchanger attachment + pipe part for comtrol valve and DHW hex +after cooling pipe part	NO	720	1230	510	1230	789 Detail 3	2	Screw Driver	1	B	

(Time parameter) — (List of Materials)

1. The change in the time input method makes it possible to track parallel operations. Duration and runtime calculated automatically
2. Automatically created hyperlink to the sub assembly worksheet that has all the information about this sub-assembly
3. Demonstrates the total value-added and non-value-added time you pay your operators for. (in the situation when parallel operations are executed by different operators)
4. Value-added and non-value-added time of the total runtime
5. Demonstrates the total time working hours to be paid to the

	Total runtime:	Sum of time spend on value-added operations	Sum of time spend on non-value-added operations	Value-added Time of Runtime	Non-value Adding Time of Runtime	Total Working Time
Sec	1230	720	510	720	510	1230
Min	20,5	12,0	8,5	12,0	8,5	20,5
Hours	0,34	0,20	0,14	0,20	0,14	0,34

STATIONS DEVELOPMENT WORKSHEET DESIGN AND FUNCTIONALITIES

Station Development

Station 1/Operator 1 | Add Operations |

| Operation Order | Operation Name | Time on Station | List of Materials | | | Max Space Required, m² | Sub Assembly |
			Details	Amount	Tools		
1	Floorstand construction		123 Detail 2	1		**3**	
2	DHW heat exchanger attachment + pipe part for comtrol valve and DHW hex +after cooling pipe part	1230 **2**	789 Detail 3	2	Pipe wrench Level	2	B

Bottleneck:
510
Waiting!

Bottleneck:
200
Accumulation of WIP
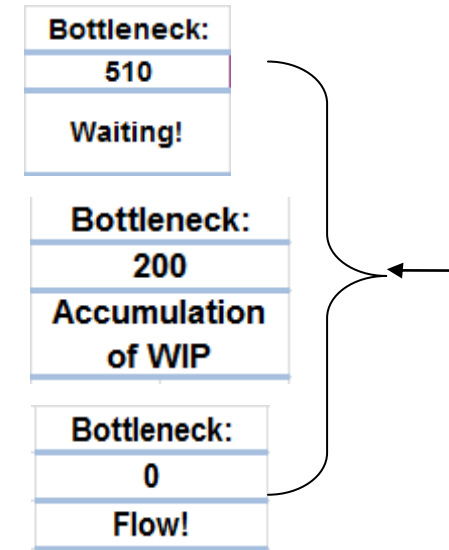
Bottleneck:
0
Flow!

Bottleneck indicator - gives a notice about system imbalance.

Operations Assignment for Station 1 ☒

Add operations

From: [   ]   To: [   ]

1

OK   Cancel

1. Dialog window allows copying the operations *from Main Assembly* worksheet that makes it possible to test different options.

2. The field demonstrates how much time will elapse with this amount of operations on the station or per operator.

3. The field indicates how much space in square meters is required per station to proceed with the chosen operations.