The International Journal of
TRANSPORT & *LOGISTICS*
Medzinárodný časopis
DOPRAVA A LOGISTIKA

ISSN 1451-107X

BALANCING OF PRODUCTION PROCESSES - QUICKLY, EASILY AND EFFECTIVELY

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Abstract: *The paper contains a brief definition of process, operation and system. It describes some of essential points that have to be solved during designing of production processes. It also mentions some systems, concepts and philosophies that can reduce Muda and improve efficiency of processes. The core of paper explains the principle of production processes balancing based on basic formulas, graphs and especially practical experiences from the balancing. Moreover paper emphasizes an importance of standardization and its relationship to the improvement activities. In the conclusion paper summarizes some practical examples of savings, improvements and benefits from application of described balancing system and its possible utilization.*

Key words: *balancing, bottleneck, cycle time, efficiency, process optimization, tact time*

1 INTRODUCTION

Processes are everywhere. They are basic "building blocks" of each system. Their designing and balancing significantly affect the performance of the whole system. Therefore an optimization of processes (does not matter if it is manufacturing sector or sector of services) is one of the key factors to the elimination/reduction of waste, reduction of cost and increasing of efficiency, productivity and flexibility. That ultimately means also improvement of competitive position of the system and lead company to the success.

Therefore, this paper looks at balancing of production processes as one of improvement systems, which can help to achieve all above mentioned benefits.

The main objective of the paper is to point out important points and support systems within designing of production processes and to deeper analyze the balancing of production processes (based mainly on practical experiences from optimization of production processes), what as a whole can serve as a guide for production processes balancing. About success of this improvement system speak practical benefits at the end of the paper.

2 DEFINITION OF PROCESS, OPERATION AND SYSTEM

Process (figure 1) is a set of activities, which requires one or more types of inputs and creates output with value for the customer. It is a chain of activities, in which is material transformed to product or order to service for customer [1].

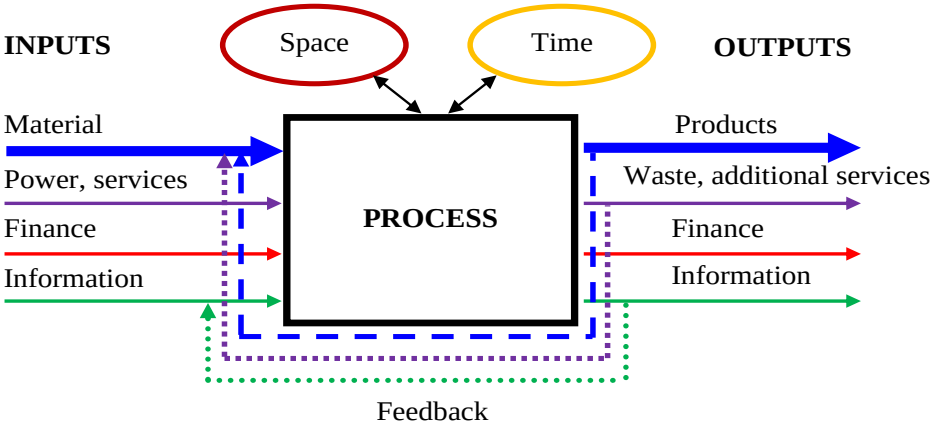

Fig. 1 *Definition of process. Source: [1]*

Process can be defined also as an input – transformation – output system, that uses transforming resources (people, technologies, equipments, buildings, etc.) to work on transformed resources (materials, information, customers, etc.) in order to produce products and services [2].

Operation is an activity (part of process), in which employee or machine processes assigned item(s) [1].

System can be defined as a set of basic subsystems (processes) and their interactions.

Wrong setting of single process can have a negative impact to the other processes and thus to the whole system.

3 DESIGNING OF PRODUCTION PROCESSES

Designing of production processes consists of general formation of a production disposition (layout) according to a character of production followed by addition of supporting elements and „tuning" of all details for their most efficient running. For character of production are especially important a volume and a variability of production. Based on differences in these two parameters will be the type of production, layout, technologies, work and flows defined differently.

Layout can be defined as a physical arrangement of devices and equipments in space. Its main purpose is to minimize, simplify, streamline and provide better overview of all movements. Four basic layouts types are: fixed, functional (technological), cell and product [2]. Most of practical layouts are derived from these four basic types. Here can be mentioned as an example a production line that is typical and very often used representative of product layout. They are known its three basic arrangements (figure 2) which can be modified, combined and formed to the specific lines according to concrete requirements (for example line in shape „S", line with one main and more side streams or line as a circle). On the other

hand are manual assembly workstations. They can also have different arrangements (for example in shape „X“, „T“, „Z“, in shape square blocks or square, hexagonal, starry or rotary tables).

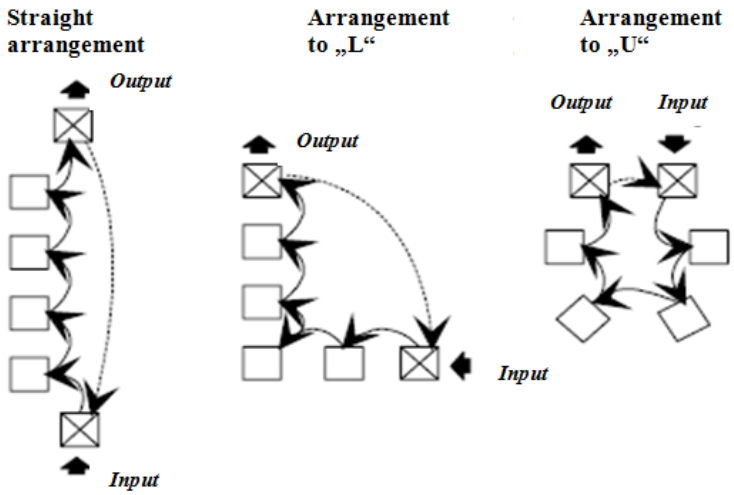

Fig. 2 *The basic arrangements of production line. Source: [3]*

The layout is closely linked with technique and technology which are used in process/system. Important is a careful consideration of automation level which depends on every company and its needs. Within a technology improvement can be also mentioned an implementation of Jidoka concept. It is about transfer of responsibility and opportunity of simple decision making in certain situations from a worker directly to a machine/device. It should in time detect anomaly and then for example by using Andon (light, sound or other signalling device) inform about real situation. An example would be emptying the container, ending of activity, failure of machine, etc. One of advantages of this system is elimination of work for a worker. Then, when he will have more “free time”, he can perform another activity, for example a parallel operating of more machines/devices. Extension of Jidoka concept is a “Line Stop” philosophy, which talks about possibility of an immediate stop of line in case of any problem. Each worker can stop the line. A team of specialists comes at that moment to the line. They attempt to identify the root cause(s) and immediately make corrective actions, so the problem does not occur again and no Muda (waste) is created in process.

In designing is also important a work and thus a man himself – worker located in process. Here, within reduction of errors and mistakes and improvement of working performance can be highlighted Poka-Yoke system. Its purpose is just a prevention before error, so the machines, lines and systems are modified and to them are installed „idiot-proof” devices like backstops, stoppers, guides, fixtures, counters, orientation points, sensors, etc.

Also in connection between a worker and a workplace is safety and ergonomics very important. It means an improvement of work conditions without health risk, in a comfortable environment and with increasing of work efficiency [8]. Pleasant working environment results from elimination of dust, noise, vibration, chemical pollutants and by ensuring of proper lighting, temperature and humidity. In arrangement of workplace is necessary to establish suitable working position with optimal working height, so worker will feel comfortably and does not have to work in unnatural position. It is necessary to ensure for worker to have in his “working field” all necessary tools for job, sufficient working and handling space and eliminated waste as much as possible. Also it is important to ensure that material will come to

workplace in correct position without additional manipulation. Worker has to manipulate with burdens at the lowest possible level. The better will be the workplace adapted for expected work of man - the higher will be the work culture and performance of the worker. In this manner we could continue with other ideas like designing of one piece flow, etc. but let´s move further.

If the "general" design of process/system is solved (for example by using also above mentioned systems and ideas), it is time to look to the process in more details, analyze it and improve. For that is used a balancing of process with aim to reduce waste, downtimes and idle times of workstations/operations on the lines, optimization of working positions, save space, smooth flows, reduce lead times, etc. So let´s have a look at this system in more detail.

4 BALANCING OF PRODUCTION PROCESSSES

Almost in every literature concerning production and operations management can be found various balancing methods and approaches (for example in [4], [5], [6], or [7]). Nevertheless in this part of paper will not be discussed any of concrete methods from literatures and will not be described how they theoretically work (such information is in literature sufficient). Here will be analyzed in detail possible way of production processes balancing from practical point of view without any complicated algorithms, formulas, etc., but based on utilization of common sense, some basic rules and simple formulas.

If a company wants to design, plan, manage, calculate or improve something - as the first, the company has to know how to measure it [1].

The most important input for balancing of production processes is a tact time. It can be defined as a time period in which customer requires one completed product. Tact time gives a "rhythm" of production and it can be calculated according to the following formula (1).

$$\text{Tact time} = \frac{\text{Available working time during defined period}}{\text{Customer demand during defined period}} \quad (1)$$

If the tact time is known, it is necessary to look at the dividing of processes, their operations and find out their time durations. For analysis and measurement of work can be used more methods such as the methods of pre-defined times from which the most preferred are Method Time Measurement (MTM) and Maynard Operation Sequence Technique (MOST). Interestingly, both of these methods do not use "standard" time units like seconds or minutes but use so called Time Measurement Units (TMU), where one TMU is equal to 0,036 second. Method Time Measurement - Universal Analysing System (MTM-UAS) I have used personally in practice and I can say that it is quite laborious. But on the other hand, this type of methods is excellent for a determination of time duration still planned or built processes based on their technological procedures. It is a huge benefit to measure and optimize the process already in pre-production phase, because it ultimately may bring a big cost saving comparing with balancing of running processes. Anyway, from practical point of view, for running process the easiest, the fastest and the most effective way how to get a cycle time, is to go to the production, make multiple measurements of duration of each operation (good is for each position rotate more workers) and calculate average cycle time of the operation. During finding of overall cycle time is necessary to know the details of operation. The reason is, because in some cases (according to setting the operation) is necessary to add to repeated cycle time of producing also other activities carried out by worker. It can be for example inspection of every x-th piece, set up the machine after every y-th produced piece, etc. But

I emphasize the need of carefull consideration which activities (based on their time flow and continuity to other activities) have to be counted to the overall cycle time. The formula for calculating of the overall cycle time can then looks like this (2):

$$\begin{aligned}\text{Overall cycle time} &= \text{Cycle time of machine for 1 piece} \\ &+ \text{Cycle time of loading and unloading for 1 piece} \\ &+ \frac{\text{Cycle time of inspection for 1 piece}}{\text{Number of produced pieces between inspections}} \\ &+ \frac{\text{Cycle time of setup}}{\text{Number of produced pieces between setups}}\end{aligned} \quad (2)$$

From measured/calculated cycle times is for better imagination and overview good to draw a chart of all operations with their time durations. Into this chart draw also the tact time duration of line (figure 3). If the process is very complicated, it is also good to draw precedential chart (it is a chart that displays all processes, their sequences and durations). This chart became a starting point for methods of network analyse like Critical Path Method (CPM) or Program Evaluation and Review Technique (PERT).

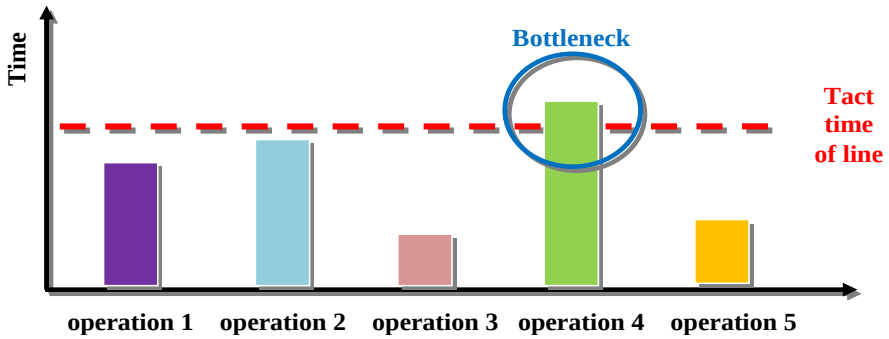

Fig. 3 *Example of unbalanced production line. Source: [Author]*

Figure 3 shows an example of unbalanced production line, from which is at the first sight clear whether operations are undersized, oversized and where is a bottleneck. This situation can be detected directly on the line during measurements. Just watch, in which operations accumulate work-in-process (WIP) and which workers "stand around". Bottleneck (as it is also displayed on previous figure) is the slowest part in the whole process. It means it has the highest cycle time. It is a problematic operation that does not meet customer tact time (request) or tact time achieves very hardly. Bottlenecks operation has to be focused first. Of course, overall objective is to balance the whole line to meet the tact time of customer without any problems or to improve processes so, that the tact time of customer could be even more decreased and remaining "free" time of line can be used for example for other/new customer production. If the process is going to be balanced for actual tact time, it is necessary, as I mentioned, to know and understand operations and divide them to the smallest parts as they can be. Then based on their cycle times and technological procedures has to be decided if there is possibility to do something with that smallest parts of operations. If yes, they have to be optimized, waste has to be removed and (simple) automation, ergonomics, 6S, Kanban, borders of line and other approaches and methods (maybe also mentioned in previous parts of paper) have to be applied. The parts of operations can be relocated only if the technological procedure is not disrupted. And this relocation is done by adding of operations times to the

tact time of line, as it is shown in the following figure 4. In many cases, balancing can reduce also the number of operations.

The second option within balancing of example from figure 3 would be a reduction of tact time, what would mean leaving of five operations (possibly their increase) at the expense of lower tact time of line and possibility to produce more products. Which way is better for company depends on the cost calculation and market opportunities.

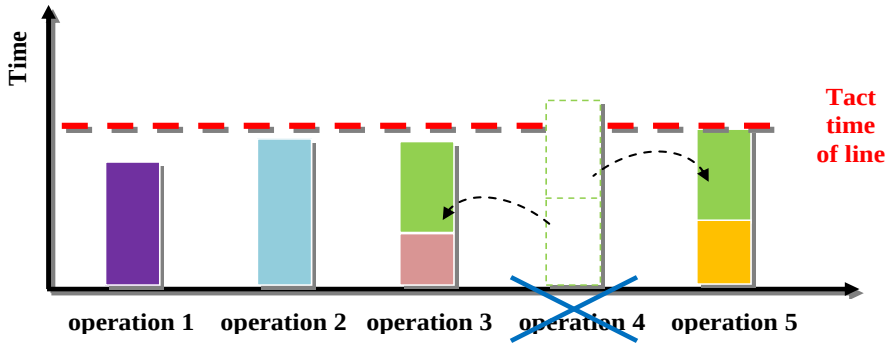

Fig. 4 *Example of balanced production line. Source: [Author]*

In case that technological procedure does not allow to change a sequence/relocation of operations (or their smaller parts) and thus fail addition of operations times to the value of tact time of line, nothing is lost. Balancing still continues. But now, if the efficiency of operation cannot be increased, it is needed to look at a worker. If he does not need to devote to the operation throughout its whole cycle time, it is necessary to find him within his „free time" another work. For example, if there is another similar operation in the process, ensure that worker will operate also second machine (figure 6 B). Here can easily help also a rearrangement of workstations and overall shape of line. Worker then will have chosen operations physically closer to each other.

For a better imagination on figure 5 is shown „a standard way" of work and motions in the workplace that need to be optimized. The first is solved an elimination of unnecessary motions and activities of a worker. For example turning around, bending to pallet and selection of components. At the beginning could help a simply conveyor, around in height of waist, in which material can be transported (next) to the machine (figure 6 A), so the first waste and non-ergonomics can be removed. In this way is needed to continue further, divide and analyse all operations and activities and try to improve them as simplest, cheapest and fastest as possible.

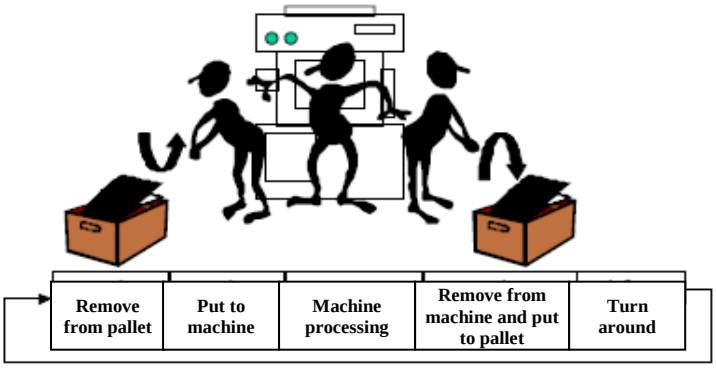

Fig. 5 *The standard sequence of worker´s motions in the workplace. Source: [1]*

Figure 6 (A, B and C) shows three possible ways of workstations optimization. Variant A of that figure refers to the optimization of workstation supply that brings effect of reducing unnecessary movements and worker time. Variant B suggests possibility of multi-machine operation. If this is only about two machines/devices, they could be placed in "V" shape for easier and faster access to the machines and elimination of worker movements between machines, reduction of work-in-process (WIP) and increase of performance and efficiency of worker. If this is about operation on more than two machines/devices, it is important to pay attention to waste – inefficient movements, what illustrates figure 7. Variant C in figure 6 refers to the sequential work of two workers (if one does not have sufficient time to operate on two machines), possibility to omit a buffer between machines and to move material directly from one machine to another. The result is saving of movements and reduced WIP.

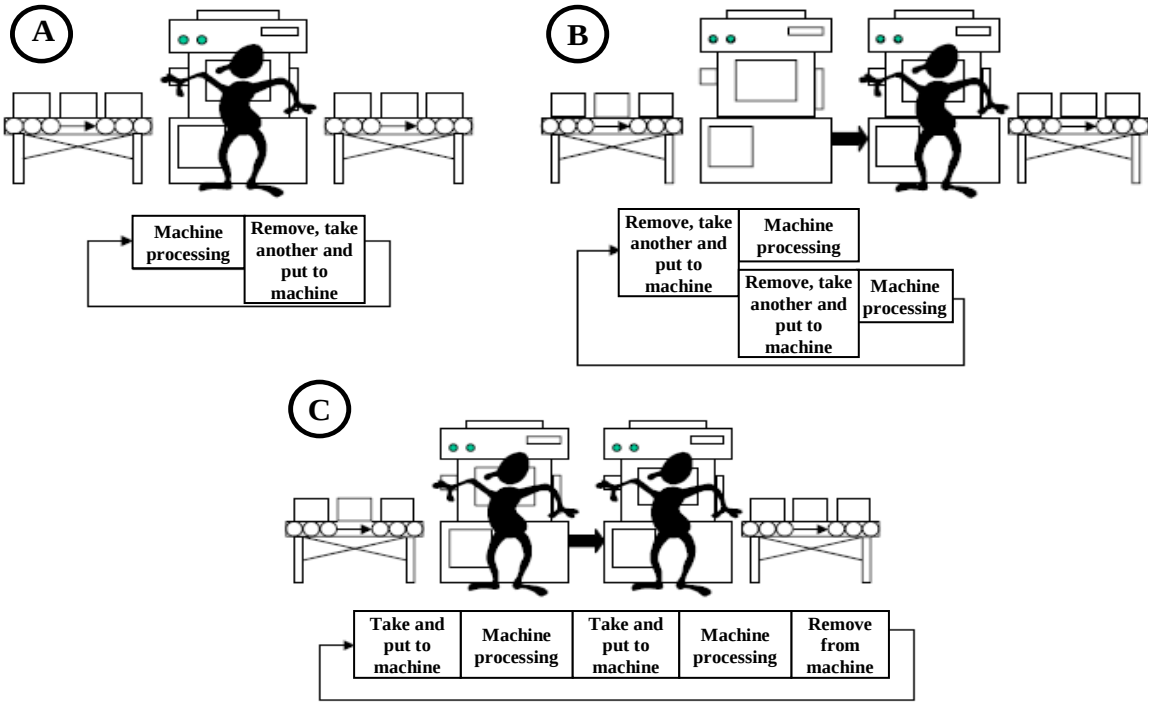

Fig. 6 *The possible optimization ways of workplace. Source: [1]*

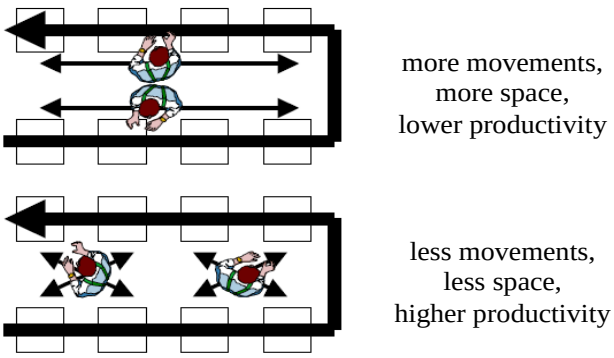

Fig. 7 *The multi-machine operation and minimization of movements on the line. Source: [1]*

In case of building a new line, the tact time could be found out from forecast requirements of customers and the cycle times of processes/operations/activities from technological procedures for example by using methods of pre-defined times, computer

simulations or by using time information from similar lines. But how to obtain the information about number of needed operations for the line? This theoretical minimal number of operations can be calculated by the simple formula (3).

$$\text{Number of operations} = \frac{\text{Overall working time}}{\text{Tact time}} \quad (3)$$

When during overall working time (what means a sum of all cycle times in the process) is needed human resource for 100%, the formula (3) can be used also for the calculation of theoretical required number of workers. Also overall unbalance of line can be measured by the formula (4).

$$\text{Unbalance of line} = 1 - \frac{\text{Overall working time}}{\text{Number of operations} * \text{Tact time}} \quad (4)$$

I would like to put to the attention one more formula (5). It describes a relationship between lead time, work-in-process (WIP) and tact time. This relationship nicely shows the importance of work-in-process amount and its impact to the overall lead time of production.

$$\text{Lead time} = \text{Work-in-process} * \text{Tact time} \quad (5)$$

It is also interesting to look to the formula (5) from the opposite side. If in real production is known the lead time and the tact time, from that can be calculated required amount of WIP (6). Then this "theoretical value" of WIP can be confronted with the real value of stock in the process. The result from that confrontation can be sometimes very interesting.

$$\text{Work-in-process} = \frac{\text{Lead time}}{\text{Tact time}} \quad (6)$$

Of course, there exists a huge amount of various calculations and improvement ways. It is only up to you which one you choose. But it should not be forgotten that balancing of production processes does not finish here. At least one more step follows.

5 STANDARDIZATION OF PROCESSES

In order to balancing of production processes and overall improvement activities make sense, it is necessary to standardize. It is very important element in the improvement (although many people still do not give respective importance to it), which helps to sustain achieved improvements. Figure 8 illustrates, that in improvement process operating in the principle of PDCA circle (Plan-Do-Check-Act), the standardization acts as a "wedge", which in the principle of SDCA circle (Standardize-Do-Check-Act) prevents a process returning to the original (worse) status.

Within the standardization (after balancing of processes) is created a standard, where are described all changes, sequence of cyclically repeated operations and also other necessary activities with their order, etc. To the standard can be attached also a chart of standardized work and a layout of workstations/lines with an arrangement of machines, devices, equipments and material and also with drawn all workers motions with sequence of their

execution. Based on these documents is required to train all workers in the process. It is also good to keep these documents directly in the workstations/lines.

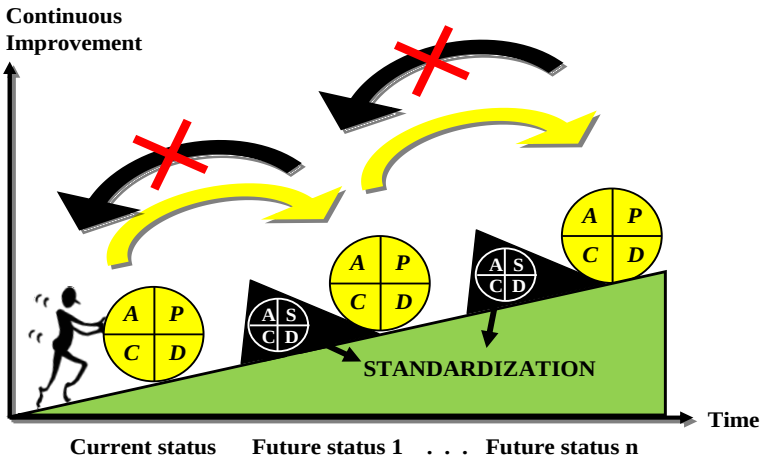

Fig. 8 *The principle of standardization. Source: [Author]*

6 PRACTICAL BENEFITS AND UTILIZATION OF BALANCING

Here you can see some practical benefits reached through the execution of balancing in manufacturing company.

- Reduction of working positions from 10 % to 50 % (or after modification of product, change of machine or working technology can increase to 100 % reduction)
- Reduction of lead time up to 74 %
- Reduction of work-in-process (WIP) from 8 % to 54 %
- Increase of productivity from 10 % to 75 %,
- Increase of machines capacity from 6 % to 62 %
- Saving of space up to 67 % from original space
- Saving of energies up to 75 %

Typical utilization for balancing of production processes is in batch and mass production where are higher volumes and lower variety with cell or product layout, higher automation, etc. In these types of production is application of balancing very easy. And even though Chary [6] points out that satisfactory analytical solution how to get completely optimal solution of the line balancing problem has not been discovered / invented yet. Therefore it is important to balance, improve, modify and experiment with already discovered methods and try to get the most from them. For example I have used information also from this paper and I have started to balance processes in typical project business with fixed layout, interrupted flow, diverse and complex manual work, without any automation, high variety and low volumes, etc. Even though I have not finished with balancing process yet, I can see some changes and improvements even now. The examples are changed fixed layout to functional, saving space, more transparent flows, better overview, tracking and managing of work and employees, etc.

7 CONCLUSIONS

It is really important to know and understand your processes, to take care of them, analyze them and continually work on their improvements. As also in this paper has been described, it can be done very easily. But then, each improvement needs to be standardized to achieve the sustainability for better level of processes and their increased efficiency. The effect of your improvement and optimization work can be seen (almost) immediately.

But do not forget, that as soon as the conditions in the production or the customer requirements are changed, it is necessary to look to the processes, their designing and balancing again.

At the end my personal recommendation is to do not be afraid, break the boundaries of conventionalism and experiment. Many times it can bring not only interesting ideas but also perfect solutions.

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