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INCREASING THE EFFICIENCY OF THE PRODUCTION PROCESS BY PRODUCTION LEVELLING

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Abstract
The main purpose of this article is to present an author's methodology of production levelling and to show the impact of levelling on the time during which the product passes through the process and on staff performance. The article presents the analysis of literature concerning the method of improving the production process, especially taking production levelling into consideration. The authors focussed on the definition and methodologies of production levelling. A diagram of interrelations showing determinants and efficiency measures of production levelling as well as an author's production levelling methodology have been presented. An example of the implementation of production levelling in one of the departments of a company manufacturing surgical instruments has also been shown. Analysis of the current state, stages of implementation and end effects have been presented. Attention was focussed on the time during which the product passes through the process and on staff performance.

Keywords
production levelling, production flow, Lean Manufacturing, production improvement, production levelling implementation methodologies.

Introduction

The financial 'standing' of an enterprise depends to a large degree on the possibility of fast reaction to changing customer requirements. Currently, the standard is the manufacturing of products exactly in time, in the required quantity and with the required quality as well as at the lowest possible costs. All these actions must yield a determined profit for the company [1].

The accomplishment of the enumerated goals is supported by different production management and organization concepts, such as for example: Lean Manufacturing (LM), Theory of Constraints or Six Sigma [2–5]. The Lean Manufacturing Concept was developed on the basis of the TPS (Toyota Production System) – a production system being a modification of classic production management methods in order to increase operational efficiency [6]. To explain the essence of LM, many models presenting the principles of achieving the assumed goals were developed. In one of his books, Womack [7] presents requirements to be met by processes and actions of which they are composed. Each action should be [8, 9]:

- valuable, i.e., create new added value for which the customer is willing to pay,
- capable – performance of tasks always in the same way, at the same time, with the same effect that is satisfactory to the customer,
- available – possible for execution at the time of demand,
- adequate to the volume of the demand, enabling the continuity of the process flow and satisfaction of customer needs,
- flexible – enabling immediate passing from the production of one assortment to another.

Individual actions should be connected in such a way that the process flow can be characterized by the following principles [10]:

- constant flow without interruptions, preferably in the form of individual items,
- pull – in conformity with the current needs of the direct recipient,
- level – even distribution of production in the shortest possible periods of time (days, shifts and even hours).

Appropriate methods and tools of Lean Manufacturing are applied to achieve separate assumptions. The article focusses on production improvement by its levelling.

Production levelling

The concept of levelled production (*Heijunka* in Japanese) was developed by Toyota for the automotive industry in the sixties of the previous century [10–13]. Currently, levelled production is applied in the automotive, food and processing industries [14, 15].

Production levelling is a method of sequencing different products in a mixed production model, mostly in order to balance production, increase efficiency and flexibility by eliminating waste and minimising differences in load on working positions [16, 17]. Balancing of production is understood as avoiding sudden jumps in values of manufactured products in the schedule [18].

In other words, production levelling is a manner of planning, consisting in determining the sequence and the extent of the inflow of products from the production process in such a way that the current demand is satisfied from the warehouse (while maintaining minimum stock of finished goods) and does not result in an unexpected change in the production plan [19–22].

According to different authors, the main goals of levelled production are:

- elimination of jumps in production [23];
- stock reduction [24];
- avoidance of excessive workload [25];
- increase of production capacity [26];
- maximisation of efficiency [27];
- increase of competitiveness [28].

The common denominator of the presented goals is the exclusive focus on the production process.

Production levelling methodologies

Different approaches to introducing production levelling in enterprises can be found in literature [29–32].

In a work by Araujo [29], an example of implementing production levelling in a manufacturing plant located in Brazil is described, in which serial production according to the 'make-to-stock' (MTO) policy was applied. The implementation consists of two stages: product prioritization and creation of a levelled production plan. In consequence of the steps taken, the monthly production was increased by 10%.

The procedure of implementing production levelling was described by Bohnen in his works [30, 31]. The implementation concerned an enterprise with a broad product variety. Bohnen divides the implementation of levelled production into four stages:

- preparation and analysis of the value stream map,
- division of products into groups,
- development of a levelling pattern,
- launch of a previously developed levelled production model and its constant improvement.

Liker and Meier [32] also proposed a procedure of production levelling for enterprises with a broad variety of products. These authors describe their method as 'cut and chop'; it consists of such stages as: division of products into groups of products characterised by common features and production steps, determination of schedule, launch of production.

The presented studies are laconic or very difficult to implement in real production conditions.

Determinants and measures of efficiency of production levelling

The literature does not indicate or analyse the factors to be taken into account when introducing levelled production (they may be called 'conditionings') or measures that can be used to measure the effectiveness and efficiency of production levelling. Figure 1 presents the proposed diagram of interrelations.

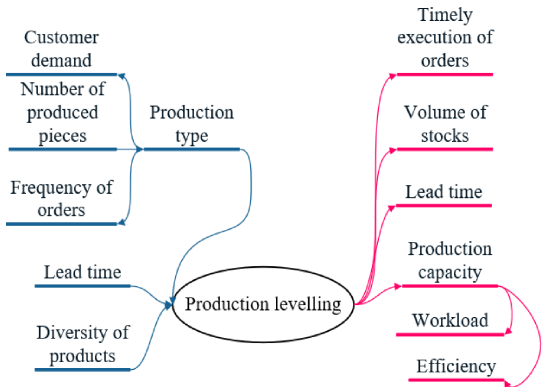

Fig. 1. Determinants and measures of effectiveness of production levelling; source: prepared by the author.

To implement levelled production in a manufacturing plant, in the first place, one needs to familiarise oneself with factors determining the validity of such an implementation. The most important of these are:

- production type, including: the number of manufactured items, customer demand, frequency of orders;
- lead time – this time is understood as the time from the moment the product enters the process until it leaves the process, including the time of refitting, transport, storage and other;
- structural and technological diversity of products.

After implementing levelled production, the enterprise should analyse the measures that will enable determining the condition before and after the implementation. These factors are:

- timely fulfilment of orders placed by the customer;
- volume of the stock of raw materials, work in progress and, primarily, finished goods;
- lead time;
- production capacity, including: utilisation, efficiency, workload.

In the study presented below, attention was primarily focussed on the analysis of the time during which the product passes through the process and on staff performance.

Author's production levelling methodology

Based on the analysis of the literature and own experience, a production levelling methodology was proposed. This methodology consists of five stages presented in Fig. 2.

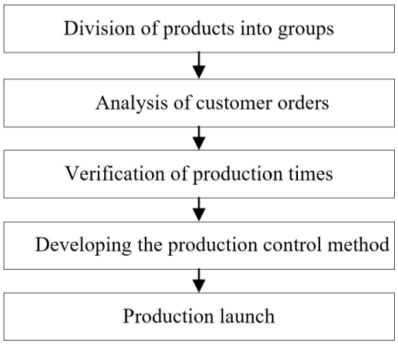

Fig. 2. The methodology of implementing production levelling in the analysed department; source: prepared by the author.

The first stage consists in dividing all manufactured products into groups. To this end, a matrix of product technological similarity is used. Once products have been assigned to specific groups, the analysis of labour intensity of manufacturing and the number of process hours necessary for manufacturing of products is conducted. The results of this analysis permit choosing the group that is manufactured most frequently and in the biggest quantities, and the implementation of production levelling starts with this group.

During the second stage, the analysis of customer orders should be conducted to determine the average demand for products from the priority group. It should also be checked if the enterprise's production capacity is sufficient to manufacture the calculated number of products.

The next stage consists in verifying production times. This verification should include the times of manufacturing of products, the times of waiting between operations as well as machine refitting times. This verification can be conducted using the timing method. The result of the analysis should be a document presenting the flow of the production process. This document enables dividing the process into detailed tasks and determining the total production time of separate products from the priority group. On this stage, the verification of the structure of technological process is also carried out in the information system.

The fourth stage is the development of the production control method. On this stage, the number of items in a production batch, the time necessary for product manufacturing and the frequency of production of individual products should be determined, and also the staff competence matrix should be prepared. The aim is to allocate appropriate operators to the performance of one strictly defined process operation, thus, to a specific working position. On this stage, loads on separate working positions should be calculated, and based on this, the number of operators necessary for the production of one production order should be determined. The final stage of works is the preparation of the production flow map for new production conditions – allocation of operators to the execution of operations, division of operations into tasks, etc. This map should contain the next stages of execution of production orders, taking into account new principles of production control.

The last, fifth stage is the launch of production. This stage consists in the preparation of the production schedule and in adaptation of schedules of auxiliary departments.

This methodology was verifide in one of the departments of an enterprise manufacturing surgical instruments, adapting it to real production conditions. The department is characterized serial production

according to the 'make-to-stock' (MTO) policy with relatively constant customer orders.

Analysis of the current state

Verification of this methodology was conducted using the example of one of the departments of an enterprise manufacturing surgical instruments (Microsurgery Department). This department is responsible for manufacturing over 950 different types of products. Among them are: scissors, clamps, tweezers and hooks. Examples of products manufactured by the analysed department are presented in Fig. 3.

Fig. 3. Products manufactured by the analysed department; source: data provided by the enterprise.

The majority of process operations, i.e., fitting and grinding, are carried out at the department. Most of these works are done by hand. Only certain operations, such as hardening, welding or passivation, are carried out outside the department.

The enterprise divides customers into two groups. Group 1 are customers ordering products from the central warehouse of the company, to which the analysed enterprise belongs. This warehouse has a determined level of stock. An order placed with the department is generated when the level of products falls below the security stock value. Data used to analyse work in progress and production for launching are generated on a daily basis.

Group 2 are individual customers who order products directly from the enterprise. Schedules of production tasks are created by analysing data concerning work in progress and production for launching. Each day, the quantities and types of products that must be manufactured during the working day are determined. Primarily, demand, staff skills and semi-finished products availability are analysed. It was assumed that a full batch of products would be manufactured, and the batch volume differs for respective groups of products. When drafting schedules, it is also taken into account that 2.04 pending orders on average fall on one employee. The average time during which products pass through the process is approximately 20 days. To a large degree, this time depends on the product labour intensity and the time when it remains outside the department, e.g., in the hardening shop or the welding shop.

Justification of the implementation of levelled production

The analysed department mostly faces difficulties connected with anticipating the time of products inflow from production, a large number of pending orders and the long time during which the product passes through the process.

The enterprise took a decision to implement levelled production. The main assumption was to increase the supervision of orders and to systematise inflows of products. The main goals of the implementation of levelled production are:

- time during which the product passes through the process – maximum 13 days,
- time of waiting until the product reaches the next working position – maximum 1 day,
- fixed production schedule,
- increase of staff performance.

Application of an author's production levelling methodology in the analysed enterprise

Division of products into groups

On the first stage, according to the matrix of technological similarity, all products manufactured at the department were divided into groups. The indicator of technological similarity of products was also used. In consequence, six product groups were obtained. The figure below presents examples of products belonging to separate groups (Fig. 4).

Fig. 4. Examples of products from groups 1-6; source: data provided by the enterprise.

Analysis of the labour intensity of manufacturing and the number of process hours necessary to manufacture the products showed that the biggest share in the total production of the department corresponds to the first group, and with this group the

implementation process of production levelling in the department will start (group I – 138 models).

Analysis of customer orders

The next stage was the analysis of customer orders from the last 2 years. This analysis showed that the first group contained the highest number of sold items (Fig. 5).

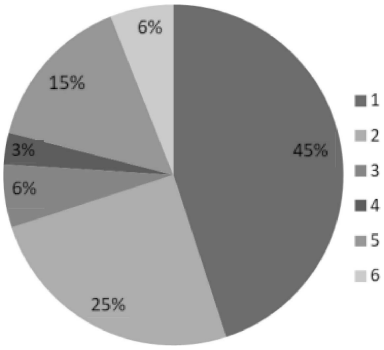

Fig. 5. The percentage share of orders for each product group in the last 2 years; source: data provided by the enterprise.

On this stage, the average weekly demand for products from the priority group was determined, which is 300 items per working week (5 days, one working shift). Thus, the average daily demand is 60 items per working shift. It was also found that the production capacity of the department was sufficient to cover the calculated demand.

Verification of production times

Production times were verified using the timing method. After the verification, a calculation sheet in Excel was created, showing the course of the production process with real times of performance of process operations (Fig. 6).

Then, on the basis of the created document, the structure of technological processes and times was verified in the information system.

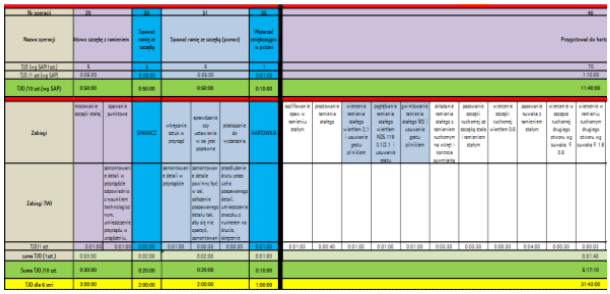

Fig. 6. Fragment of the calculation sheet; source: data provided by the enterprise.

Production control – production levelling

The execution of production orders the labour intensity of which is one day was assumed. Thanks to the calculation sheet prepared on stage three, operations could be accumulated and divided into one-day tasks. Based on previous stages, the number of items per production batch was determined – 10 items. In consequence, the daily production schedule may include 6 production orders. The rule connected with determining execution deadlines of process operations was adopted at other production departments. For operations performed outside the department (e.g., hardening, annealing and other) one production shift was designated, during which operations connected with the daily production inflow (60 product items) are performed. Additionally, a two-day time buffer was introduced before the hardening operation, which enables correlating this operation with schedules of other departments.

Further on this stage, a staff competence matrix was created, and based on it, operators were assigned to the performance of a single process operation. The workload of working positions was calculated, and based on this, the number of operators necessary to produce one production order was determined – 21 persons.

The final stage of works was the preparation of the production flow map (Fig. 7) for the new production conditions.

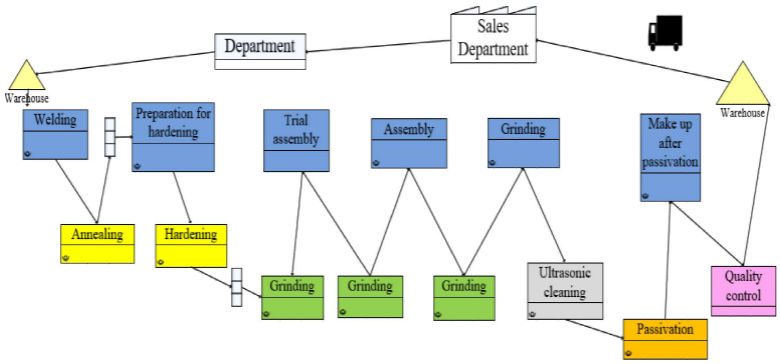

Fig. 7. Production flow map; source: data provided by the enterprise.

Production launch

The last stage was the production launch. A production schedule for the analysed department as well as detailed schedules for auxiliary departments were prepared (Fig. 8).

Day of the week	Changing production	Production department / batch
Monday	1	
	2	
	3	microsurgery, 6 batchs
Tuesday	1	
	2	
	3	microsurgery, 6 batchs
Wednesday	1	
	2	
	3	microsurgery, 6 batchs
Thursday	1	
	2	
	3	microsurgery, 6 batchs
Friday	1	
	2	
	3	microsurgery, 6 batchs

Fig. 8. Schedule of annealing operations, source: data provided by the enterprise..

Additionally, a two-day buffer was assumed, the purpose of which is to eliminate problems with supplies.

On each stage of the production process, tasks were prepared in advance so that production on each working position could commence at the same time. At the moment of the start of production, each working position had a certain number of products already made on a given stage.

Conclusions

Based on literature research and own experience, a production levelling methodology and a diagram of interrelations showing determinants and measures of efficiency of production levelling were developed. This methodology was verified in a production plant.

The improvement of the production process at the analysed department consisted in production levelling. Tasks performed within improvement enabled:

- dividing the manufactured products into 6 groups depending on the technological and structural similarity of these products,
- creating a fixed daily production schedule for the analysed department,
- implementing the rule of launching 6 orders per one working shift,
- allocating operators to specific process operations,
- creating buffers after annealing and before hardening,
- adapting and organising working positions in a better way,
- eliminating unnecessary activities from the process.

The assumed goals have been achieved. In consequence of these works, the time during which the product passes through the process was shortened from 20 to 13 working days. Staff performance has also improved; in the first month, the improvement reached approx. 20%. What is more, thanks to accumulation of operations and elimination of unnecessary transport, the flow of products has also improved. Figure 9 shows a flow diagram for one order before introducing changes and Fig. 10 after introducing changes.

Fig. 9. Flow diagram for one order before changes, source: data provided by the enterprise.

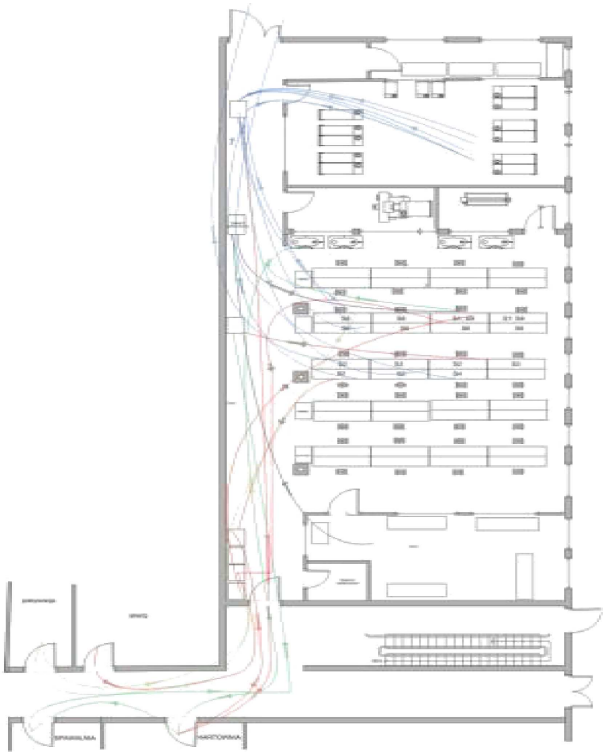

Fig. 10. Flow diagram for one order after changes, source: data provided by the enterprise.

The implementation of production levelling faced certain problems. The biggest one was the hostility of managers of auxiliary departments in adapting to the schedule of the analysed department. Another problem was the hostility of production staff with regard to the new way of controlling production. However, finally after training and the first days of work according to the new rules, they accepted the introduced changes noticing that their work became more effective, efficient and less burdensome.

In summary, production levelling at the analysed department contributed to considerable shortening of the time during which the product passes through the process and to increasing efficiency and satisfaction of production staff.

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