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OKREŚLANIE WIELKOŚCI BUFORÓW PRODUKCYJNYCH NA PRZYKŁADZIE WYBRANEGO PRZEDSIĘBIORSTWA

Streszczenie: Obecne zmiany w firmach produkcyjnych skłaniają do ciągłego poszukiwania marnotrawstwa tam gdzie wcześniej mogliśmy je przeoczyliśmy. Artykuł koncentruje się na opisie teoretycznych podstaw określania wielkości buforów produkcyjnych dla linii obróbki wykańczającej i montażu w wybranej firmie. W podsumowaniu artykułu można znaleźć ocenę ekonomicznych efektów wprowadzenia w analizowanej linii obliczonej optymalnej wielkości buforów.

Słowa kluczowe: Bufor, wymiarowanie, linia produkcyjna

MANUFACTURING BUFFERS CAPACITY DIMENSIONING IN A COMPANY

Summary: The article focuses on the description of theoretical background to the dimensioning of the production buffers for the grinding-assembly line in the selected company. In the conclusion of the article, we can find the economic impact of using calculated optimal capacity on the solving line.

Keywords: Buffer, dimensioning, manufacturing line

1. Introduction

The manufacturing buffers are important parts of manufacturing system. Their use in practice is subject of space, product, production volume and other factors. In present time are buffers used without capacity limitation whereas capacity is limited only by

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maximum volume of the buffer or by weight limitation. Workpieces contained in buffers, however, cause often-negative economic impact.
When an optimal buffers capacity is set the cost can be reduced while maintaining present performance.

1.1. Downtime

Downtime can be defined as an interruption of the work by unexpected event that may be caused by the break of some parts in production system. We can meet with different downtimes in companies, caused by:
- Overhaul and setup of machines.
- Insufficient welding material.
- Replacement tools such as grinding and lapping stones, turning tools etc.
- Electrical failure.
- Mechanical failure.
- Problems caused by conveyor etc.

Downtime caused by human activity can be negligence, when worker do not trace the surrounding or failing supply. [3,4]

1.2 Manufacturing buffers

Every interoperation buffer (Fig.1) can be characterized by its capacity, i.e. the maximum number of workpiece that the buffer can store. Depending on the failures, it occurs in a system consisting of automats with interoperation buffer to the mutual influence of single automat´s operation. This is caused by inadequate supply or removal of workpiece. It is due to the interoperation buffers (Fig.1) where η downtime is compensated, and influence of failure of adjacent automats is not reflected into downtime. [2] The primary purpose of the interoperation buffers is to create the stocks, before each automat, that are gradually released when failure occurs on a precedent automat. In this way, it is possible to prevent the entire line downtime when a single automat is in failure. [6,7]

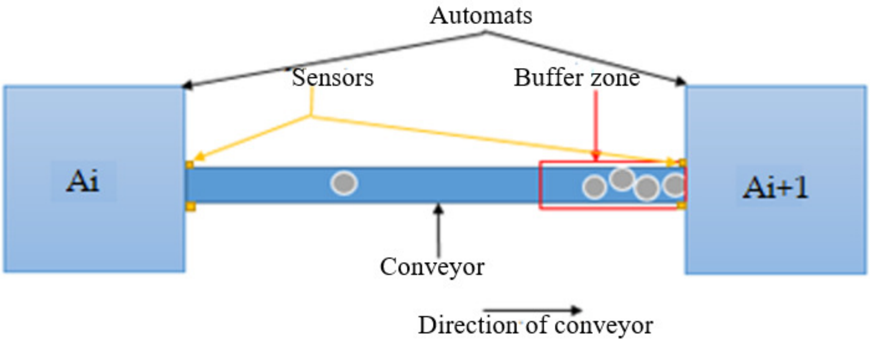


Figure 1. Interoperation Buffer

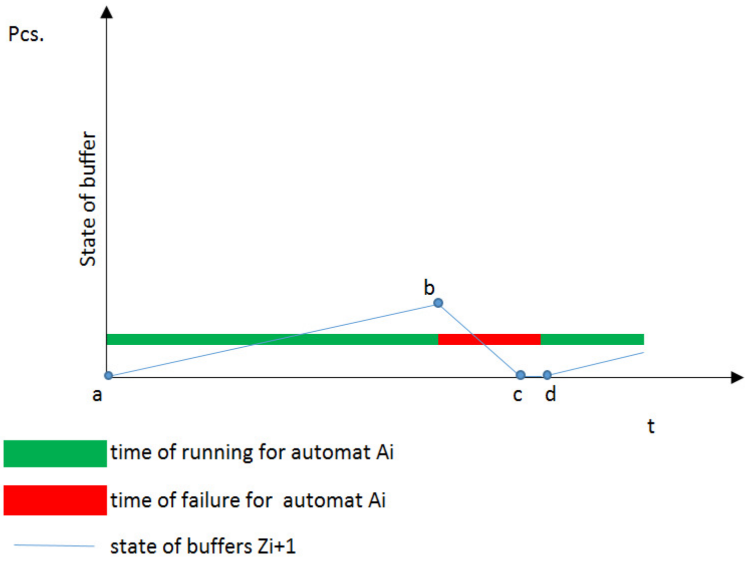


Figure 2. Graphical Expression of a Buffer State

Fig. 2 shows the progress of the buffer state. The automat Ai starts to produce in point *a*. The automat Ai produces in a faster tact than the $A_i + 1$ automat witch also starts to produce. The failure occurs on the automat Ai in point *b*. and the automat $A_i + 1$ starts gradually to withdraw from the $Z_i + 1$ buffer. The buffer is empty in point *c*. and, if it is the last automat, the downtime starts on the manufacturing line. The automat Ai is repaired in point *d*. and starts again to produce goods for the automat $A_i + 1$ and buffer $Z_i + 1$.

2. Dimensioning of manufacturing buffers capacities

At the present day the buffer capacity dimensioning is very much unknown in companies. The principle of dimensioning of buffer capacity is suitable for manufacturing lines, which are already utilized, in the manufacturing process and it is possible to specify downtime on individual devices. If downtime of a given devices is known, the tact times for single products are known, added value of the products and the costs relative to the buffer are known, the optimum capacity of the production buffer for each product can be determined. By keeping the optimal capacity of buffers the benefits like reduction of lead time, the decline of tied capital and better through flow can be obtained.

2.1. System for dimensioning of buffer capacities

The designed system consists of modules, which are bounded together (Fig.3). Each module contains a process diagram with activities. The basis for entry are appropriate data from operations, information about machines, manufacturing line layout and product data. Those data enter to the input module (A) where all data, required for further calculations, are collected. The purpose of the decomposition module (B) is the division of manufacturing line into the parts that can be solved as a task on three machines and two buffers. In next module (C) various model capacity simulations were conducted through developed simulation model using different input information about machines, layout etc. By the realization of series of experiments with the simulation model by one factorial optimization, we get a matrix of downtimes. The obtained matrix is the result of changing of buffer capacity. The module also includes calculation of the objective function for the selected buffer capacity. Following the maximum value is selected. The next module (D) of capacity assessment of the buffer according to the production limits compares if it is possible to create calculated stock in a given buffer. If the system is not able to maintain selected stock, such objective function is chosen which given constraints fulfils and achieves the highest value. The following module of reconfigurability (E) evaluates if there is a potential for the introduction of such solutions, which referred as reconfigurable systems. This requirement fulfill those buffers which have tact $A_i > A_i + 1$. This condition says if it is possible to select a faster tact on automat A_i than on automat $A_i + 1$ than it is possible to create a certain stock before automat $A_i + 1$. This stock is dimensioned according to a certain type of failure that occurs on the automat $A_i + 1$ and the occurrence of such failure is predictable.

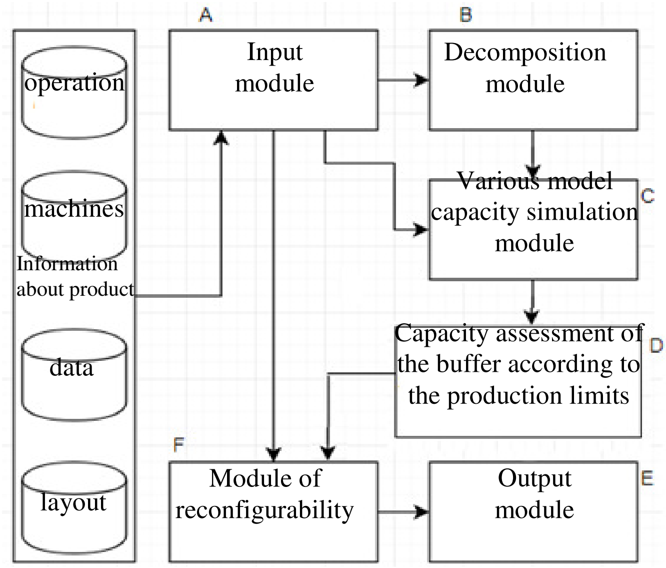


Figure 3. System for Buffers Dimensioniong

If automat Ai starts to produce in a faster tact, it is possible to create such a stock before the automat $A_i + 1$ which will fully cover existing failure and manufacturing line will not stop. The output module (F) contains a technical and economical assessment of the benefits of the implementation system for maintaining the optimal capacity of the buffers.

It is characteristic for the manufacturing line that the tact in assigned to each automat according which the automat works. From the point of view of tact and its connection on the line, it is possible to describe the state in which the automat is situated against the next automat. The automat can be found in two states, the first is $A_i \le A_i + 1$ and the second is $A_i > A_i + 1$. The state in which tact $A_i \le A_i + 1$ says that the automat A_i has slower tact than $A_i + 1$. In this case, it is advisable to maintain optimal supply in the buffer behind A_i. The state $A_i > A_i + 1$ says that the automat A_i can operate more quickly than the automat $A_i + 1$. The capacity of the production buffer is changed according to the length of the closest predicted failure on automat A_i. This condition is suitable for introducing reconfigurability in buffers. For example, if on automat $A_i + 1$ is using abrasive disc and we can determine the point at which the failure occurs and its length, we can storage that stock in input zone automat $A_i + 1$, which in ideal case will cover this failure.

2.2. Computing of objective function

There don´t exists any formula for calculation of the optimal capacity of the production buffers. The objective function defined by [1] is used for the determination of optimal capacities:

$$G = \left(D.v - \sum_{i=1}^{N-1} Z_i.b_i \right).s.w - \sum_{i=1}^{N-1} \left(a_i.c_i \right) \cdot Z_i^r \tag{1}$$

where:
G - objective function (unit €)
v - profit from one product (unit €)
D - increase of performance on the line from the current production or fixed bound line (unit Pcs./2 shift)
Z_i - capacity of i-th buffer (unit Pcs.)
b_i - operating and maintenance costs i-th buffer referenced on one piece and two shifts (unit €/Pcs.2 shift)
s - number of working days in year
w - number of years how long will be product made on a line
a_i - production cost per piece of capacity of i-th buffer (unit € /Pcs.)
c_i - Cost of medium and general repair referenced per piece (unit € /Pcs.)
r - coefficient of growth providing costs and repair costs ($r \ge 1$)

After calculating the objective function for each buffer, its capacity is chosen with the highest value. This value represents the optimal capacity of two buffers. This value has to be assessed by production restrictions, which means whether it is possible to maintain the determined value in the system. In case that we are not able to maintain the given state of buffer, the highest value of objective function is chosen, which fulfil the constraints and fit the required buffer capacities.

2.3. Process for decomposition of line

The principle of line decomposition runs on such a way in which the line is divided into parts so that only 3 automats and 2 buffers are solved in the framework of series of experiments. After each series of experiments, the optimal capacity of production buffers is chosen. This value remains constant for a further series of experiments. The process of decomposition of the line is shown on (Fig.4) and (Fig.5) where A are automats and Z are buffers.

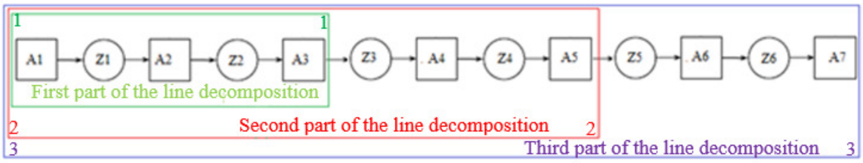
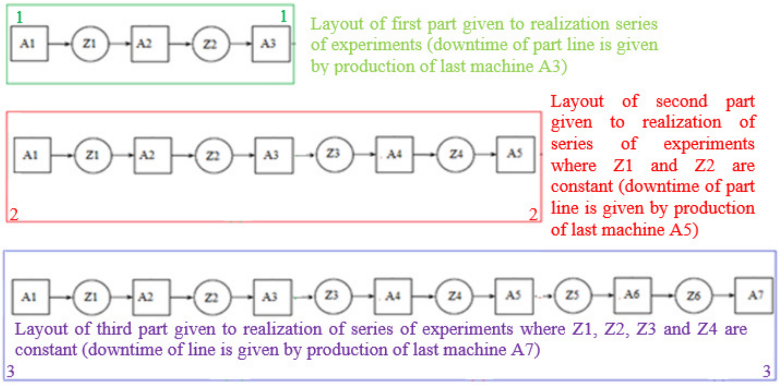


Figure 4. Schema of the Line with Individual Parts of Line



Layout of first part given to realization series of experiments (downtime of part line is given by production of last machine A3)

Layout of second part given to realization of series of experiments where Z1 and Z2 are constant (downtime of part line is given by production of last machine A5)

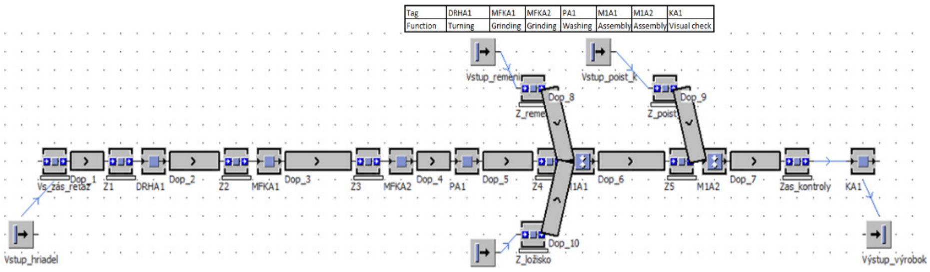
Layout of third part given to realization of series of experiments where Z1, Z2, Z3 and Z4 are constant (downtime of line is given by production of last machine A7)

Figure 5. Layout of Individual Parts of Line Given for Realization of Experiments with Capacities

Such decomposition is possible because the throughput of part of the system is given by the throughput of the last automat. The breakdowns of the last automat, waiting for the supply and removal of the material, influence its performance.

2.4. Dimensioning of buffer capacities for grinding-assembly line in company Schaeffer

The grinding-assembly line in company Schaeffer was chosen for the dimensioning of optimal buffer capacities. The operations of turning, grinding, assembly and manual visual check can be found on the selected line, see (Fig.6).



Tag	DRHA1	MFKA1	MFKA2	PA1	M1A1	M1A2	KA1
Function	Turning	Grinding	Grinding	Washing	Assembly	Assembly	Visual check

Figure 6. Layout of Manufacturing Line

Based on the layout and information about parameters, simulation models were created, so that the results were obtained for only 2 buffers.

After the creation of the first simulation model (Fig.7), where (Z) is buffer, the experiments were conducted.

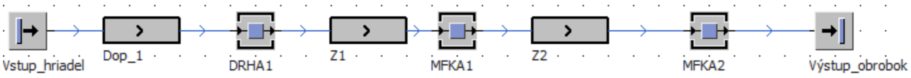


Figure 7. Simulation Model for First Part of the Production Line

Every experiment is one factorial optimisation where the capacity of buffers was changed, and the downtime information was written into the matrix of downtimes. Graphic expression of matrix of downtimes is shown in (Fig.8).

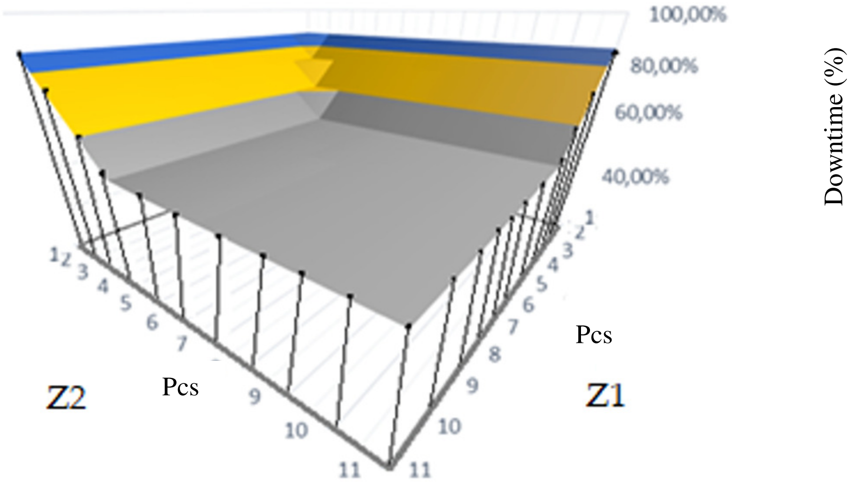


Figure 8. Graphical Expression Matrix of Downtime

This figure shows that the downtime decreases with the increasing capacity of the stacks until the point at which it remains unchanged. Once the downtime is obtained, based on the input data it is possible to calculate the objective function. The course of objective function for the first part of the line is shown on (Fig.9).

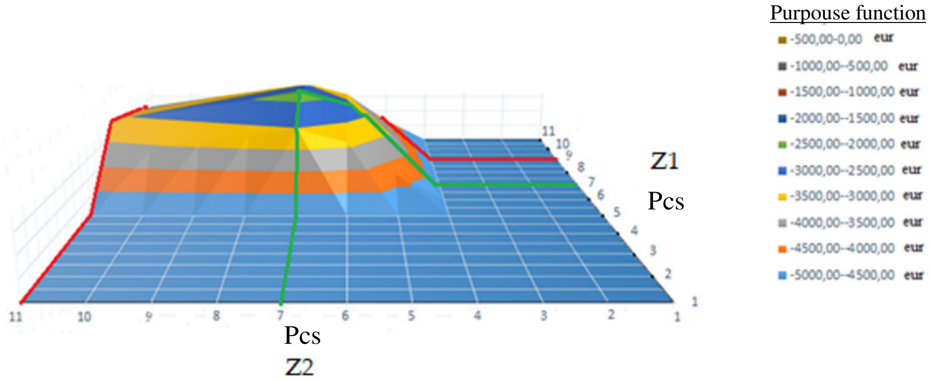


Figure 9. Graphical Expression of Objective Function

In Figure 9, the red line shows the current value of objective function, the green shows the suggested optimal condition where the cost is the lowest.

The second part of the line (Fig.10) was solved with constant values of Z1 (7) and Z2 (7).

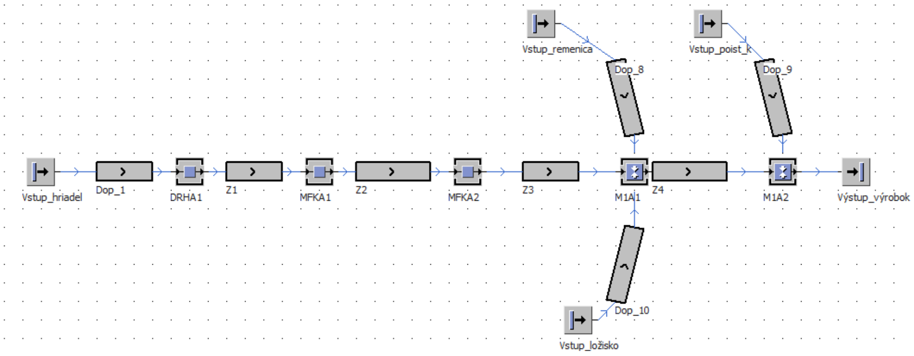


Figure 10. Simulation Model for Second Part of the Production Line

The calculation procedure is the same as it was at first part of the line. It is necessary to detect downtime and the individual capacities of buffers and on their basis to calculate the value of objective function. The resulting solution is evaluated by the production restriction.

3. Financial and non-financial benefits

The Schaeffer Company is in present time not using the systems for maintaining of optimal capacity of buffers on production line. The yield that is below is related to the product, which was produced by 250 days. The unit profit from one product was 0.50 €. The maintenance costs are in the objective function and its height. The table 1 shows ROI of implementation of these systems on the selected line.

Table 1. Return of investment and yearly benefit from implementation

	Maintaining optimal capacity of production buffers	Maintaining optimal capacity of production buffers + reconfigurable buffers	
Costs of implementation	2102	104312	€
Savings obtained by maintaining optimal buffers capacity against the current state	1720,51	35099,36	€/year
Return of investments (ROI) in days	447	1088	days
Return of investments (ROI) in years	1,22	2,97	years

3.1. Non-financial benefits

The non-financial benefits of maintaining the optimal capacity of the buffers included reduction of development of manufacturing, reduction of lead time, faster detection of defective products and improved system throughput.

4. Conclusion

The basic prerequisite for each enterprise's success is that the enterprise will increase its production performance at a constant cost reduction. Every business meets the dilemmas of production control where, on the one hand is active reduction of the intermediate production time, storage costs and delays on the other hand production capacities must be utilised on the maximum with the minimum downtime. Specifying of optimal buffers capacity is nothing more than a solution of the problem where we try to reduce production developing and throughput time with the lowest downtime and maximal utilization of equipment capacities on the other side. With the appropriate choice of buffer capacity, it will not be increased the downtime but work in process inventory will decrease. Reconfigurable buffers can achieve the reduced downtime of production line. Result of the implementation of regulation of work in process inventory in manufacturing is reduction of the tied capital, the better throughput of the system and the reduction of the costs for scrap caused by the low quality of operation before the buffer.

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REFERENCES

1. MAIXNER, L.: Navrhovanie automatických výrobných systémov, SNTL – Nakladatelství technické literatúry, Praha. (1980)

2. GREGOR, M.: Digitálny podnik. Žilina : Slovenské centrum productivity, 2006. 139 s. ISBN 80-969391-5-7. (2006)
3. SKOKAN, R., BUČKOVÁ, M.: Application of logistics FMEA in the selected enterprise in Projekt interdyscyplinarny projektem XXI wieku : monografia. Tom 1. - Bielsko-Biała: Wydawnictwo Akademii Techniczno-Humanistycznej, 2017. S. 497-504. ISBN 978-83-65192-80-7. (2017)
4. RAKYTA, M.: Údržba ako zdroj produktivity, Slovenské centrum produktivity, Moyzesova 20, Žilina, ISBN 80-968324-3-3. (2002)
5. MOZOL, Š.: Určenie kapacít výrobných zásobníkov vo vybranom podniku: diplomová práca. Žilina : Žilinská univerzita v Žiline, 2018. 69 s.
6. HALUŠKA, M.: Rekonfigurovateľné výrobné systémy [Dizertačná práca]. Žilinská univerzita v Žiline. (2015)
7. HODOŇ, R., GRZNÁR, P.: Dynamic model creation algorithm for the value stream mapping in Projekt interdyscyplinarny projektem XXI wieku : monografia. Tom 1. - Bielsko-Biała: Wydawnictwo Akademii Techniczno-Humanistycznej, 2017. S. 411-417. ISBN 978-83-65192-80-7. (2017)