DETERMINING OPTIMAL MANUFACTURING ORDER QUANTITZ BY THE METHOD OF MONITORING PRODUCTION CYCLE TIME IN SMALL AND MEDIUM ENTERPRISES

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Abstract

Achieving manufacturing excellence today is critical for the success of manufacturing companies, especially for SMEs. It is even more complicated in developing countries without high-tech industrial base, but with a large number of knowledge and resources constraints. This paper deals with the problem of simultaneous determination of the economic manufacturing quantity and the production cycle time and proposes a simple and low cost approach for manufacturing order quantity determination. Proposed method is checked in automotive components producer company, during 4 years, by applying a modified method of current observations and by monitoring the elements of production cycle time. Mathematical criteria for the trends of all elements of productive tp and non-productive time tnp (idle time), control limits CL and standard deviation SD have confirmed the feasibility of the method application. Optimal order quantity is a horizontal asymptote of productive time trend per piece, and for the year 2011 tp amounts to 20 min while order quantity is 10 pieces, for 2012 tp is 13 min for 12 pieces, for 2013 it is 14 min for 9 pieces, and for 2014 it is 25 min per piece, due to launching a new operation, and 8 pieces per lot. It is possible to describe given dependencies using the dependency tp= a/n+b, where n is the number of pieces per lot and tp is productive time.

Keywords: Optimal manufacturing order quantity, production cycle, small and medium enterprises

Introduction

In today's turbulent environment and competitive marketplace, achieving manufacturing excellence has become critical for the success of manufacturing companies. Production cycle time is the critical factor, since companies that can give a quick response can launch new products earlier, penetrate new markets faster, meet changing market demand and deliver product to their customers on time and at lower price. In developed economies small and medium enterprises (SMEs) in the manufacturing sector make a significant contribution to economic growth (Terziovski, 2010), but the majority of the literature focuses on large firms and there are scant papers on high growth of small and medium organizations (O'Regan et all., 2006).
Small and medium enterprises SMEs are generally characterized by below-average labour productivity because these enterprises are too small-sized to achieve economies of scale or economies of scope. In addition, they are less capital but more labour intensive. In developing countries, such as Serbia, technological profile of Serbia's industrial structure comprises 49.9% of low-tech and 25.6% of medium-low-tech companies (Stanisavljev et all., 2015). Although enterprise resource planning - ERP implementation would be useful for SMEs in developing countries, it is usually restricted by knowledge and resources constraints (Loh et all., 2004). For such companies, the method represents an ability to optimize existing production processes through detecting and eliminating possible errors and disturbances before the real production process is executed at an acceptable cost (Debevec et all., 2014). Low and medium- low-tech SMEs need simple and low cost production management methods. Accordingly, this paper deals with the problem of simultaneous determination of the economic manufacturing quantity and the production cycle time that as a result offers a simple and low cost method of determining manufacturing order quantity. As low and medium- tech SMEs in metalworking industry very often produce in small series, a Serbian company with those characteristics is used as an experimental polygon.
SMEs are defined by the European Commission (ec.europa.eu) as having less than 250 persons employed. They should also have an annual turnover of up to EUR 50 million, or a balance sheet total of no more than EUR 43 million (Commission Recommendation of 6 May 2003). These definitions are important when assessing which enterprises may benefit from EU funding programmes aimed at promoting SMEs, as well as in relation to certain policies such as SME-specific competition rules. European Commission policy in relation to SMEs is mainly concentrated in five priority areas, covering: – the promotion of entrepreneurship and skills; – the improvement of SMEs' access to markets; – cutting red tape; – the improvement of SMEs' growth potential, and; – strengthening dialogue and consultation with SME stakeholders. A special SME envoy has been set up in the European Commission Directorate-General for Enterprise and Industry with the objective of better integrating the SME dimension into EU policies. Annual structural business statistics with a breakdown by size-class are the main source of data for an analysis of SMEs. A limited set of the standard SBS variables (number of enterprises, turnover, persons employed, value added, etc.) is available mostly down to the 3-digit (group) level of the activity classification (NACE), based on criteria that relate to the number of persons employed in each enterprise. The number of size-classes available varies according to the activity under consideration. However, the main classes used for presenting the results are: – micro enterprises: with less than 10 persons employed; – small enterprises: with 10-49 persons employed; – medium-sized enterprises: with 50-249 persons employed; – small and medium sized enterprises (SMEs): with 1-249 persons employed; – large enterprises: with 250 or more persons employed. The technological capability and national innovation systems approach

reveals a different channel through which firm behavior affects export performance. Focusing on innovation and learning processes in developing countries, proponents emphasize the acquisition of technological capabilities as a major source of export advantage at firm-level (Bell and Pavitt 1993; Lall 1992; Iammarino et al. 2008). The underlying evolutionary theory of technical change emphasizes that difficult firm-specific processes and complex interactions with institutions are needed to absorb imported technologies efficiently (Nelson and Winter 1992) In most theories is the notion that SMEs are at a disadvantage in participation in production networks compared with large firms. SMEs face, to a higher extent than large firms, resource constraints (in terms of finance, information, management capacity, and technological capability) (Levy et all.,1999; and Hallberg 2000.) The probability of SMEs joining production networks (as direct exporters, indirect exporters, or overseas investors) is lower than that of large firms. Furthermore, justification exists for public policies to support the entry of SMEs in production networks. In the main, such support should be geared to an enabling environment that opens access to markets, reduces bureaucratic impediments against SMEs, and provides appropriate SME institutional support services (eg.,technological, marketing, and financial support). The elements of production cycle time in small and medium-sized... Technological machine time ttm, viewing production against machinery, is exclusively linked to machine performance and the quality of technological calculations, and is mainly a deterministic category. However, if the production cycle is viewed from the aspect of a serial sequence of operations, the elements of working time differ, depending on the automation level. If production is automated, then ttm for a series will be simply a sum of individual n equal operations. However, if each part has to be manually or mechanically conveyed for processing from a joint crate or some other room where a certain series of parts is stored, manual placement on the machine is ancillary manual time tpr (in theory, this refers to individual pieces). Such time is not frequently encountered in literature (rear examples are papers (Klarin et all, 2002) dealing with the division of working time elements . In theory, the PC time tpc is divided into production time tp and non-production time tnp and production time is then further divided into technological time tt , with machine ttm and lead time tpf, non-technological time tnt - with time of control tc , transportation ttr and packaging tpk . Nonproduction time is classified according to various causes of stoppages in production, and we have carried out a screening of the most general and common ones caused by the lack of raw materials tmr , organization to , machine breakdown tb and other problems tot. According to Gits (Gits,1992) production is one of the key and primary function of the organization. Huang et al. (Huang et all.,2003) argued this requires the companies to be efficient, work to optimize, and improve the productivity level. Muchiri & Pintelon (Muchiri & Pintelon, 2008) are of the view that production losses lead to decrease in productivity due to an inefficient manufacturing process.

Methods

Since the quantity of identical pieces to be launched as a single lot may vary in serial production, fixed costs are related to lead-time activities and the value of costs does not depend on manufacturing order quantity. Thus they decrease with order quantity increase, because the same amount of costs is distributed to a larger number of pieces. Variable costs refer to current assets – storage, material and salaries invested in unfinished production, finished goods and overall the freezing of the fixed assets, and therefore these costs are growing proportionally to the increase of lot size.

The choice of the lot size in practice is limited by:

- the volume of production anticipated by the production plan;

- the dynamics of the production plan (linked to delivery date);
- assembly space;

- assembly procedure;
- storage and intermediate storage space;
- the volume of unfinished production, and
- other factors linked to material inventories.

Costs per unit of product include the next elements important for determining the optimal lot size:

- material costs per unit of product;
- labour costs per unit of product;
- per cent of waste and subsequent machining;
- total costs per piece, excluding those affected by the lot size.

However, precise determination of mentioned costs is a complex task. Thus, the first, very simple formula of deterministic character for determining the optimal order quantity was reported by Harris (Harris, 1915) a hundred years ago. It is grounded on an assumption that all lot positions are processed in a relatively short time, enter the storage at the same time and thereafter are evenly consumed. Then, Manne (1958) and Wagner and Whitin (1958) have divided time into discrete periods and assumed that the demand in each period is known in advance. Till now several hundred papers have directly or indirectly improved this deterministic model through its extension or providing efficient algorithms for production problems that arise in it (Bahl et all., 1987). Since deterministic assumption is unrealistic, Guan and Miller (2008) have proposed the stochastic version of the deterministic lot-size problem using a polynomial time algorithm to obtain the optimal solution. Guan (2011) studied a more general setting of the stochastic lot-size problem, assuming that there are varying capacities and backlogging of unsatisfied demand. Recently, Vargas (2009) has investigated the problem of planning dynamic order quantities, using stochastic, time-varying demand with a known density function. All mentioned studies indicate a stochastic character and complexity of the problem of the optimal order quantity determination.

On the other hand, to ensure rational production and respect of delivery dates in production, quality production planning and adequate technical-technological calculations are required to provide machine operating regimes and duration of operations as well as the activities in the manufacturing process. This way, they are normed, normalized and standardized, so that the elements of production cycle time can be determined ahead for the machines, means of mechanization as well as control activities. However, in practice they are not deterministic but stochastic, especially in the SMEs conditions, and as such they have to be monitored. Production cycle is the time period between release to manufacturing of a part or batch of parts and their storage. Theoretically, according to Čala et al. (2011) , the production cycle – tpc is divided into productive time – tp and non-productive time tnp, and productive time is further subdivided into technological time tt, with machine ttm and lead time tpf, non-technological time tnt with time of control tc , transport ttr and packing tpk. Non-productive time is divided according to various causes of stoppages in production: stoppage due to the lack of raw materials tmr, tools ttl, organization to, machine breakdown tb and other troubles tot. The organization of the sequence of operations has the strongest impact on productive time as the most important time of the production cycle in small-serial and serial production.

The problem of experimental determination of optimal order quantity in the metalworking industry applying screening of the work sampling method has not been encountered in the literature to date. Studies are mainly directed to automated or semi-automated systems to monitor the elements of the cycle time in machines and stoppages (ERP systems), which are most often inadequately applicable in respect of costs and human resources in low and medium-tech SMEs in developing countries. A modified method of current observations was also deployed for other purposes in papers by Cala et al. (2011) , Klarin et al. (2010) and Cockalo et al. (2014).

Experimental determination of the optimal order quantity by monitoring mean productive time

In order to experimentally determine the optimal order quantity by monitoring mean productive time in low-tech automotive components producer medium-sized company, screening was conducted in this study during a 4-year period, in October and November 2011, 2012, 2013 and 2014. The organization of operations sequence was consecutive. It is characterized by performing the operation on all pieces at the same place, and likewise the operation is repeated at other workplaces.

Practical application of a modified work sampling method consists of instantaneous observations of time elements, where the object of labour is moving according to the production operations list through operations sequence, as given in detail in Klarin et al. (2000). Screening is conducted according to randomly chosen times for which the element of production cycle time is recorded, and thereafter the numbers of individual elements of work – frequencies – are entered in a screening sheet.

Models based on stochastic functions, or instantaneous observation methods (work sampling). Our research is directed at designing a new original method for monitoring the production cycle and its time elements by using a stochastic work sampling method, whose basis was set up by Tippett. However, this method we innovate and adapt to research the production cycle.
Representative screening time is related to the length of the production cycle time. It is clear that it must not be shorter than the production cycle time and that under identical production conditions it must be repeated a certain number of times in order to make the sample representative. Production and productivity are also related to the production dynamics which are planned at the operational level on a daily, weekly or monthly basis. Hence, the production cycle for the above mentioned periods is also provided for the purposes of monitoring and comparing (Stanisavljev et all., 2015) . The third criterion for determining screening time duration is the adopted margin of error in the stochastic model applied in these investigations, i.e. the number of instantaneous observations and their distribution per working time element.

Results and discussion

Within the production cycle time the highest per cent, viewed by years, refers to the technological machine time, amounting to 24.6% for 2011; 25.9% – 2012; 23.76% - 2013 and 22.4 % - 2014, then to lead time 10.9% - 2011; 16.82% - 2012; 16.15% - 2013 and 19% - 2014, thus making up overall technological time tt. Average productive time was significantly decreased in the period 2011 - 2013 from 249 min (76.4%) to 193 (79.77%) min. On account of organizational level improvement and production running-in as well as launching of a new 30-min operation in the manufacturing

process, cycle time was again increased in the next year, 2014, to 263 min. In the productive time, the lowest oscillations by years are shown by the technological machine time: 24.5% - 2011; 25.29% - 2012; 23.73% - 2013 and 22.4 % - 2014. Lead time tpt was permanently increasing from 10.7% to as high as 19% in 2014 due to launching a new operation, however its decrease could cause production cycle time decrease.
The trends of all elements of the production cycle time are seen in fig. 1 and limits were calculated using the formula KG = tp± 3SD·tp. Consequently, mean productive time is CC =   =78% (263 min table 2), the lower control limit BC = 64.28% and the upper limit AC = 91.7 %. Mean productive time ranges according to the normal distribution.
Data on the elements of production cycle time for 2011, 2012, 2013 and 2014 are given in table 1.

Tab.1. Data on the elements of PC working time for 2011, 2012, 2013 and 2014

	Productive time t_p						*Nonproductive time t_{np}*					*Year*	*Cycl. No*	*Min/ $t_{c/N}$*	*$t_{p/kom}$*	*$t_{p/min}$*
Unit of measure	t_{pt}	t_m	$t_{pt}+t_m$	t_c	t_{tr}	t_{pk}	t_{mr}	t_{tl}	t_o	t_b	t_{to}					
%	10.7	24,6	35,3	12,7	15,2	10,6	5	0,3	0.27	1,6	16,5			100		
min	16,32	3762	5394	1939	2413	1709	704	116	376	2,71	2465			326		249
%	16,82	25.29	42.11	15.41	15.7	11.83	1.42	0	0.31	0.15	14,53			100		
min	11,24	1737	2861	10.55	1093	837	104	0	22	10	1022			233		194
%	16,15	23.73	39.88	13.57	12.25	14.1	0,99	0	0.68	0.36	18.33			100		
min	1560,4	2296	3856	1292	1184	1362	96	0	66	34.8	1771			248		193
%	19	22,4	41,4	14,1	14,9	9,55	0,76	0,001	0.002	0.001	16,9			100		
min	2760	3254	6.014	2.040	2.164	1.387	110	15	20	15	2.456			338		
$t_{t/v}$	64,2	75,7	140	47,6	50	32,3	2,3	0,35	0.47	0.35	57			263		263

The trends of mean productive time   per piece in a lot and experimentally determined optimal order quantity representing a horizontal asymptote of the function. The mean productive time function has the form 2011= 297.54/n + 2; 2012 = 239/n – 7.36 ; 2013 = 192/n + 0.65 and 2014 = 438.2/n – 11.3, where n is the number of pieces. It is also evident from fig. 1 that for the year 2011 an approximately determined optimal order quantity is obtained from the horizontal asymptote with time duration of approx. 20 min, which holds for the number of over 10 pieces per lot.
Optimal lot size for 2014, with a change in technological procedure due to launching one operation more of a 30-min permanent duration, amounts to 8 pieces according to

graphical interpretation, but slight increase of time per piece in a lot has reasonably occurred amounting to 25 min.

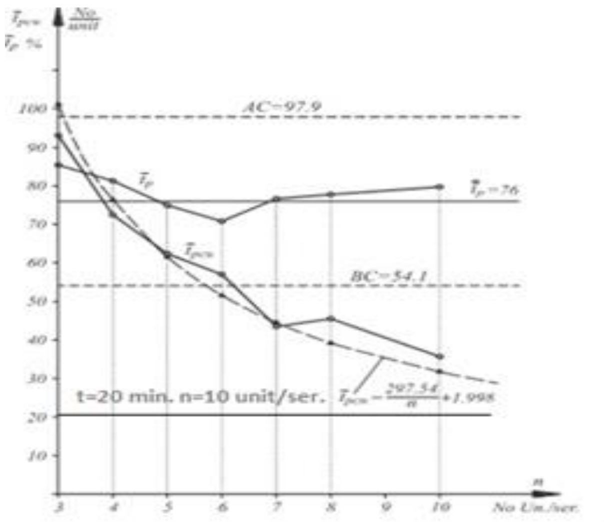

Fig.2.Dependency of productive time on the number of pieces per lot for 2011

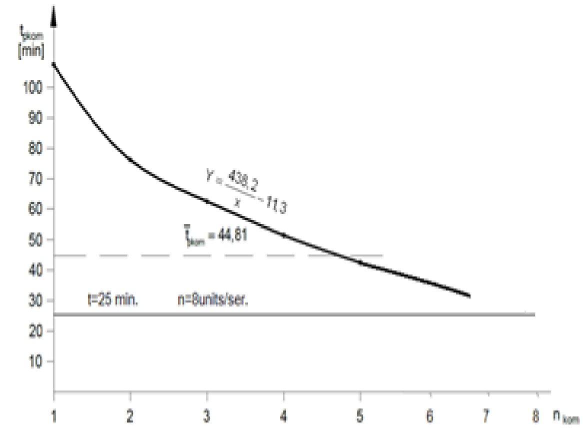

Fig. 5. Dependency of productive time on the number of pieces per lot for 2014

Also, emphasis should be placed on a large number of papers dealing with the problem of production cycle on the assembly lines, of which the most prominent works are by Hu et al. (2011) and Kumar & Dalgobind (2013) who employ the calculations of time for the assembly line, using the binomial and normal distribution, and also the work by Hackstein & Budenbener (1989) that reports the results of monitoring the production

cycle performed by semi-automated means in a flexible manufacturing system in German industry.
Bottleneck control in real time production (Li et all., 2009), prioritizing machine fleet preventive maintenance (Patti & Wattson ,2010) , spare parts inventory for maintenance, optimization of initial buffer adjustment (Schultz, 2004), reduction of machine setup time (Kusar et all., 2010) and predicting order lead times (Berlec et all., 2008), can lead to production effects improvement and manufacturing cycle time reduction (Jovanovic et all., 2014).
Most of this research involves large companies. Today, however, a significant problem for monitoring and influencing the production cycle (time from entering the case of production and to obtain the finished product and its packaging) is far less present in literature, especially the condition of the duration of the production cycle and the participation of elements of time in the production cycle of small and medium-sized enterprises.

Conclusion

Simultaneous determination of the economic manufacturing quantity and the productive cycle time represents a simple and low cost method for determining manufacturing order quantity, as can be seen in this case study of a low-tech automotive components producer medium-sized company. Mean productive time for 2011 amounts to 20 min, for 2012 it is 13 min, for 2013 approx. 14 min and for 2014 approx. 25 min per piece, and that for the lot size of 10, 12, 9 and 8 pieces, respectively.
In that way, it has been shown that even companies that are not ERP users can manage production accurately enough and with quality, without investing in new technologies or employees' training. Without the application of a proposed stochastic method, by further increasing order quantity disregarding the stochastic factors, the company can achieve the opposite effect, because the material will accumulate in some machines thus creating bottlenecks. It is proposed that future investigations involve long-term implementation of the method for its upgrading and elaborating a more detailed analysis of all elements of the production cycle time.

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