Innovative Way of Optimizing the Manufacturing Processes on Parallel Production Lines in SME

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ABSTRACT
The goal of the paper is to present a new way for scheduling the processes within and not limited to manufacturing companies. The aim of the paper is to offer the management of SMEs a revolutionary way for increasing the company's productivity using a better planning and usage of the available resources. Author's sequencing rules are presented together with their implementation methodologies and then are put to work into a Romanian middle size manufacturing company. Obtained data is statistically worked and conclusions are drawn. The paper is part of the authors' yet not published work and represents partial results of their research in the field of Operational and Supply Chain Management.

KEYWORDS: *analysis, optimization, resource, SME, quality.*

JEL CLASSIFICATION: *L23, M11, O14, O32, L15.*

INTRODUCTION

The impetuous for our research comes from a real problem manufacturers are facing as a result of this economic and financial crisis, which is far from over in several European countries like Czech Republic and Romania, in our case. In the manufacturing industry, due to today's market conditions, when the production begins, it begins also the loss of working time and increase in costs, which is an important barrier for an increase of the degree of productivity, as it showed us concurrent manufacturing companies in countries like Germany, South Korea, USA or Japan.

Small and medium-sized manufacturing companies are the ones which have the highest impact on the world's economy and a good management of this industry (especially the manufacturing one) can influence in a greater way the world's GDP that the big size companies. According to the European Union's annual report on small and medium-sized enterprises in the EU from 2012, "it is estimated that SMEs accounted for 67 per cent of total employment and 58 per cent of gross value added (GVA)". The same report (European Union, 2012) states that with more than 87 million person employed by the EUs SMEs, continue to be the backbone of the EU economy. Based on this report, we've developed a survey with which we've tested the market for their biggest problems. One of the outputs of this initial step of our research was the need of a managerial tool which can be used for quality control as well as for scheduling different production processes on parallel lines.

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In other words the quality of the operational management of time usage in order for the products to be manufactured Just in Time, according to the technical standards imposed by their construction constraints. There are several well-known specialists in their field who consider ways for improving the quality (Feibenbaum, 1951; Juran et al., 1998 or Teruo Mori, 2012), but none of them considers time consumption together with the quality assurance within the same methodology.

Gruia (2012) considered the quality in SMEs, in terms of the product's lifecycle, however the time together with quality has never been considered together until now. This is also the research gap which Gruia (2014) considered as part of his doctoral research and published it accordingly. In another article Gruia and Kavan (2013) managed to schedule processes in a greedy manner on parallel production lines in order to reduce total input costs. Also Gruia and Gruia (2013) consider the scenarios development and how they are influenced by different aspects of the society. We can therefore see that decisions based on scenarios are the foundation of our daily activities and can affect our productivity and our decisions in managing a company. We have applied this concept of scenarios in the scheduling of operations within a manufacturing company of jobs on parallel lines and based on our research, we can state that three main factors influence the success or failure of scheduling of jobs within the manufacturing industry, i.e.:

- Quality of time usage within the scheduling process
- Setting up and dividing the workload on the production line.
- Allocating of the resources within the organization and their utilization.

We will further focus on the latter factor of optimizing the processes and using the method Design of Experiments (DOE), an experiment will be developed and partially implemented in a Romanian medium size manufacturing company. Data is statistically worked and results are interpreted accordingly.

1. PROBLEM DEFINITION

We want to find a way of sequencing and scheduling the available resources on each operation of the production line so that for each operation in part the available resources to be at maximum utilized. Considering the fact than the operations which can have the same processing time on two parallel lines, but not the same utilization of the other resources (people, equipment, tools, finances), we will further analyse the means of resource utilization on the available parallel lines, which ought to be maximum and the same applies for all the parallel lines within the same particular manufacturing company. However the means can differ from company to company according to their particular technology and business model used.

1.1. Design of Experiments on the target company

We have tested and analysed the noise effect of resource utilization on parallel manufacturing lines where jobs with more than one operation were done, using the Randomized Complete Block Design.

Within our research we have identified and selected a so-called "target company", which was further used in our research as the significant representative type of manufacturing company. However due to intellectual property rights the data had to be altered, but the authors tried to maintain the same ratios as in reality.

The target company was a middle size Romanian manufacturing company where by using the ANOVA tool, results were interpreted and the production line was redesigned in order to increase the utilization of the available resources.

The production department was interested to increase the resource utilization of people, tools, material, semi-finished products, etc., on the three available parallel production lines.

For winning the next auction within the same consortium, the company had to increase the level of quality of their products. In this manner additional financial resources had to be given to the Quality Department, but this meant that another department would not receive their annual budget.

Also the company was not utilizing their available resources at the full potential because during one working day, workers were seen standing across the production line without having anything to do, or waiting in line for the machine to finish the previous operation.

A need of increase in the quality and decrease in the production time of the line was demanded by the management without any additional costs, with a focus on the increase in the resource utilization.

We have noticed from the available old data of the company that there are significant part-to-part variations in the technical and quality production process, because while the material should have been consistent with respect to the requested parameters like hardness, strength, diffusion of light and so on, it probably wasn't due to the manufacturing variation at the supplier, but of the natural variation in the capacity utilization of the available resources.

We have therefore decided to further investigate the effect of five different degree of utilization of the available resources based on the technological constraints, using a Randomized Complete Block Design and considering the production on three parallel lines as blocks. One can see the considered problem from the table below (see Table 1).

Table 1. Randomized Complete Block Design for three parallel production lines

Available resources	**Production lines**			**Total resources' utilization**
	L1	**L2**	**L3**	
workers	60	75	70	205
time	85,5	86,2	88	259,7
materials	90,3	98,2	87,9	276,4
equipment	43	52	62	157
finances	82,5	90,5	78,9	251,9
Sum of resources	361,3	401,9	386,8	1150

Source: own contribution

From the technological process we know that in order for the parts on each of the available lines to be produced, we need resources at different moments in the scheduling process of the production. Using these resources and the information from the pieces lists used in the production process we have developed a Randomized Complete Block Design, based on the initial data, where the order in which the resources are made available on each of the line is completely random.

We wanted to know in this way where the company with the resources' utilization in the manufacturing processes stands. The response variable is the number of resources which are needed to complete the manufacturing operations at the requested level of quality, time and costs.

Taking this problem into consideration the following research question was developed:

In what way should we use the available resources so that they are used at their maximum capacity (without producing any costs from an unused capacity of the available resources)?

The available resources of a company are: workers (people), time, materials, equipment and tools and finances (which include all the variable, direct and indirect costs related to the manufacturing process).

The management found out that they could produce the same amount of products with fewer workers than needed. This would have reduced the costs with their wages and social insurances, but would have increased the costs related with training so that they could switch and perform more operations than before. But before taking any decision we had to test if by reducing the number of employees and increasing the costs with their training was the right answer in the increasing of the resources' utilization and having a smooth usage of it, by testing the null hypothesis:

H_0: The capacity utilization means are equal in the whole company.

To perform the analysis of variance we have computed the following sum of squares and arranged them into a table (see Table 2):

$$SS_{resources}=\frac{1}{3}\sum_{n=1}^{5} e_{n.}^2 - \frac{e^2}{N}=\frac{1}{3}\left(205^2+259.7^2+276.4^2+157^2+251.9^2\right)-\frac{1150^2}{15}==3,156.22 \quad (1)$$

$$SS_{parallel\ lines}=\frac{1}{5}\sum_{m=1}^{3} e_{.m}^2 - \frac{e^2}{N}=\frac{1}{5}\left(361.3^2+401.9^2+386.8^2\right)-\frac{1150^2}{15}=168.441 \quad (2)$$

$$SS_{total}=\sum_{n=1}^{5}\sum_{m=1}^{3} e_{nm}^2 - \frac{e^2}{N}=91,752.14-\frac{1150^2}{15}=3,585.473 \quad (3)$$

$$SS_{error}=SS_{total}-SS_{parallel\ lines}-SS_{resources}=3,585.473-168.441-3,156.22==260.812 \quad (4)$$

From the statistical table "Percentage points of the *F* distribution" we find the value for $F_{\alpha,r-1,(r-1)(p-1)}=F_{0,01,4,8}=7.01$ for a significance level of $\alpha=0.01=1\%$.

Because $F_0=24.203>7.01$ we reject the null hypothesis and conclude that the resource utilization means differ on all of our available parallel lines (see Table 2).

Table 2. Computed values for our ANOVA

Source of variation	Sum of Squares	Degrees of freedom	Mean square	
Resources		4	789.055	24.203
Parallel lines	168.441	2	84.22	
Error	260.812	8	32.601	
		14		

Source: own contribution

By analysing only the value of F_0, we can say that the variation among group means was not happening by chance. The experiment's conclusion was that the resources are not used in a productive manner on the parallel manufacturing lines and a new approach was needed to *optimize the process from the resources' utilization point of view*.

1.2. New rules for scheduling manufacturing operations

The initial process was not working well and the problem of resource utilization was affecting in a negative way the final product, because the timing of the workers with the necessary equipment, tools and costs was bad for working the same operation on two distinct parallel lines.

New sequencing rules NoBtl and MaxQminT were developed as follows. The ***MaxQminT rule*** is valid for operations which require different tools or setups after the completion of each previous operation, with the following methodology:

1) Prepare the necessary tools and equipment for all the operations which have to be fulfilled in order to complete the job;
2) Organize the workers in two qualified member teams and assign them 2 consecutive operations, where one will work the first operation and second worker the second operation. When one of them will work, the second worker will be responsible with the quality of the work of his colleague. (In this manner the process of quality assurance is very good implemented into each manufacturing process and the probability of producing a product with flaws is considerably reduced).
3) Then schedule the shortest and longest operation to the same team. The second operation should be the one which takes the longest in the manufacturing process; for the first team always assign the input operation, which is responsible for the preparation of the material, tools and other resources needed for the whole job, as one of the two operations and for the last team always assign, as part of the two operations, the output operation, from the production line, for even number of operations and to the first team for odd number of operations.
4) Assign the second and third longest operations to the next team.
5) Repeat step 4 until only two operations remain and assign them to the last team. If only one operation remains at the end, assign it to the first team.
6) If the requested working area is not available assign the second longest operation to the team which is waiting and thus repeat step 3 to 5 until all operations are worked.

Before applying this rule we should know:

- all the processing times for all the operations (including input of materials and output of the finished product from the production line);
- all the necessary tools and equipment;
- the succession of jobs can but must not play a decisive role in implementing this rule.

The ***NoBtl rule*** was designed in order to answer one of the other minor problems the companies have within their processes and it should be applied in corroboration with the MaxQminT rule. Before applying this rule we should know the time and resources' availability conditions for the input and output operations.

The rule states to sequence and schedule the processes on your parallel lines according to the input/output constraints in the following way:

a) Start from the output operations and their assembly / shipment constraints from each of the parallel lines and schedule the operations in a consecutive manner, where the first will be the output operation and the second will be the shortest available operation;
b) Continue with the sequencing of the operations until the last one is the input operation. If the input operation is not the longest operation, then schedule the longest operation before the input operation.
c) Check and correlate the schedule with MaxQminT rule.
d) Repeat the first three steps until only one schedule remains which satisfy NoBtl and MaxQminT rules together.

After implementing the MaxQminT rule with a partial application of the Shortest Processing Time rule and NoBtl rule, the operations were scheduled according to the quality, costs and time requirements, but also there was seen an increase in the capacity utilization of the available resources, because no bottlenecks were formed and no two operations were being done in the same time with the same resources on two or more parallel production line.

Managing the process in agreement with these two sequencing rules the management had an opportunity in enforcing the production spirit and promoting skilled people in key posts on the production lines so that the process to be managed according to their heart and mind, not only because there were told to do so by the management.

Maintaining quality in their everyday work, the employees improved their own work productivity, by increasing the quality of their work and reducing future cost with maintenance of the production equipment, service and rework of the defected products, and thus decreasing the work time which was assigned for maintenance as part of the product's lifecycle.

This was possible because the time spent with the maintenance and service of the products was reduced, due to the high quality requested by the end-users, but also the lifetime of the product was maintained at the customers' requirements, according to their cost/value ratio and wasn't reduced as was before, due to different flaws which may have appeared due to external factors.

We started from the analysis of the technological process to see how we can improve the process with the available resources. Time, materials and equipment were given by the technological constraints, the finances were the costs which could have been reduced by reducing the variable costs, which are the costs directly proportional with the production (which could be reduced by reducing the number of the produced final products, but this could have endangered the profit of the whole company) of by reducing the fixed costs (the costs which are fixed over a period of time, if we produce or not on the production line).

The company obtained the following results after the implementation of MaxQminT, NoBtl, partial SPT rule, after reducing the number of the employees and increased the costs with the new trainings, regarding their impact on the resource utilization capacity.

We've computed the following sum of squares:

$$SS_{resources}=\frac{1}{3}\sum_{n=1}^{5} e_{n.}^{2} - \frac{e^{2}}{N} = \frac{1}{3}\left(191^2+259.7^2+276.4^2+157^2+256.1^2\right)-\frac{1140{,}2^2}{15}=3{,}515.684 \quad (5)$$

$$SS_{\text{parallel lines}}=\frac{1}{5}\sum_{m=1}^{3} e_{.m}^2-\frac{e^2}{N}=\frac{1}{5}\left(360.8^2+393.4^2+386^2\right)-\frac{1140.2^2}{15}=116.837 \quad (6)$$

$$SS_{\text{total}}=\sum_{n=1}^{5}\sum_{m=1}^{3} e_{nm}^2-\frac{e^2}{N}=91{,}752.14-\frac{1{,}140.2^2}{15}=5{,}081.7373 \quad (7)$$

$$SS_{\text{error}}=SS_{\text{total}}-SS_{\text{parallel lines}}-SS_{\text{resources}}=5{,}081.7373-116.837-3{,}515.684==1{,}449.216 \quad (8)$$

Table 3. Randomized Complete Block Design for three parallel production lines after MaxQminT, NoBtl and partial application of SPT rule

New available resources	Production lines			Total resources' utilization
	L1	L2	L3	
workers	58	65	68	191
time	85.5	86.2	88	259.7
materials	90.3	98.2	87.9	276.4
equipment	43	52	62	157
finances	84	92	80.1	256.1
Sum of resources	360.8	393.4	386	1,140.2

Source: own contribution

From the statistical table "Percentage points of the *F* distribution" we find the value for $F_{\alpha,r-1,(r-1)(p-1)}=F_{0,01,4,8}=7.01$ for a significance level of $\alpha=0.01=1\%$.

Because $F_0=4.851<7.01$ we accept the null hypothesis for the significance level of $\alpha=0.01=1\%$ and conclude that the resource utilization means are equal on all of our available parallel lines (see Table 4).

Table 4. Computed of the new values for our ANOVA

Source of variation	Sum of Squares	Degrees of freedom	Mean square	F_0
Resources	3,515.684	4	878.921	4.8518427
Parallel lines	116.83733	2	58.41867	
Error	1,449.216	8	181.152	
	5,081.7373	14		

Source: own contribution

As demonstrated above the process runs smooth without bottlenecks, each operation being processed at the right time, and no operations are done in the same time by utilizing the same set of resources.

1.3. Model adequacy check

We have presumed that the random errors $re_{nm}(0, \sigma^2)$ are normally and independently distributed with mean zero and variance σ^2, but these assumptions are not always valid for all small and middle size manufacturing companies. We want thus to check if the assumed conditions are valid and if our sequencing rules are adequate for the actual conditions of the market.

We examine the residuals between the actual values of the process and the estimated ones (see Table 5) and define the following residual of the effect k in the resource utilization n as:

$$\text{residual}_{nk}=e_{nk}-\widehat{e_{nk}} \tag{9}$$

where $\widehat{e_{nk}}$ is the theoretical value of the corresponding effect e_{nk}, obtained as:

$\widehat{e_{nk}}=\hat{\mu}+\overline{\square}_n=\bar{e}_{..}+\left(\overline{e_{n.}}-\bar{e}_{..}\right)=\overline{e_{n.}}$ and can be interpreted that the theoretical value of the effect of the n^{th} resource utilization is the average of the effects of the resources' utilization.

Table 5. Theoretical and actual effect of the resources with their residuals

New available resources	Production lines and residuals						Theoretical data
	L1	**R1**	**L2**	**R2**	**L3**	**R3**	$\widehat{e_{nk}}=\overline{e_{n.}}$
workers	58	-1.40	65	-0.88	68	4.53	64
time	85.5	3.53	86.2	-6.37	88	-2.70	86.5
materials	90.3	6.84	98.2	3.32	87.9	1.95	92.1
equipment	43	-5.56	52	-1.56	62	6.55	52
finances	84	1.37	92	-6.29	80.1	-3.32	85.4

Source: own contribution

Our goal is to check the model adequacy by analysing the residuals between the actual and theoretical values, which should contain no obvious patterns if our model is the correct to the actual market conditions. We test this by computing and drawing a normal probability plot of the residuals, which can tell us if they come from a normal distribution, which can indicate that also errors from the population are from a normal distribution.

There are designed 15 scheduling scenarios where 14 values out of 15 are kept constant as the theoretical values and the 15th value is left at the choice of the production system, formed of the workers, the available working time during 8 hours of labour, the available material and equipment as well as finances.

By controlling 14 of 15 values and by repeating this experiment 15 times we obtain 15 values which may or may not be different than the average (theoretical) value.

By varying the one of the 15 available input data, a certain residua is obtained each time and this data I work statistically and arrange it according to my standard normal curve value, which will correspond to the values on the x axis. But for being able to compute these values, I must rework the data, because normal curve in theory goes to infinity in both of the directions and the edges of my distribution must coincide to the normal curve. So I use the following formula to compute the proportion of the proportion of the residua in the sample size:

$$proportion_i=\frac{rank-{}^{3}/_{8}}{sample\ size+{}^{1}/_{4}} \tag{10}$$

Based on these computed values, the normal scores are computed as the inverse of the standard normal cumulative distribution, with a probability of the proportion of appearance of the residua.

Values for the y-axis will be in turn the values of the residua. I will use this in computing the residuals and drawing the normal probability plot.

The data is rounded where appropriate (for workers for example), however taking in consideration that I use statistical methods, the residuals cannot be rounded.

As one can see in the figure below, the point fall under a straight line and the more linear they are, the more we are convinced that the residuals came from a normal curve and therefore the normality assumption is valid.

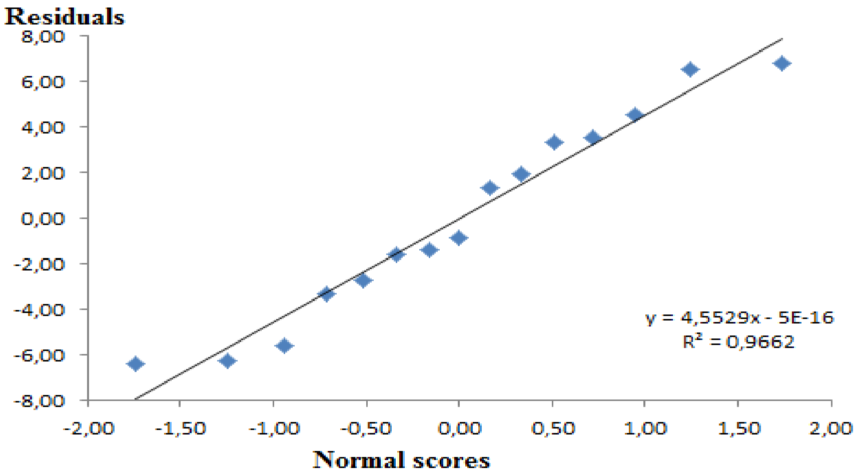

Figure 1. Normal probability plot of residuals after implementation of the MaxQminT, NoBtl and partial SPT rule, regarding the utilization of the resources capacity

Source: own contribution

The points were worked using regression analysis and we can find the value of $R^2 = 0{,}9662$, which states that our model explains about 96,62% of the possible variability of normal scores when computing all possible solutions for the possible residuals which may appear when increasing the population of the sample.

CONCLUSIONS

We have presented a new way of optimizing the manufacturing processes on parallel lines from the capacity point of view, without any additional costs. With the help of the newly developed sequencing rules which were implemented into a middle size representative Romanian company, the utilization of the capacity of the available resources was increased with up to approximate 1%. We have thus showed that there is still place for improvement in terms of resources' utilization and Supply Chain and Operations Management within small and middle size manufacturing European companies.

The statistical work of the data showed that the means of the capacity utilization are the same on all available parallel production lines and the processes run smoothly without bottlenecks, each operation being processed at the right time and with the right amount of the available resources, without any wastage.

The model adequacy checking shows that the points fall under a straight line and the more linear they are the more we are convinced that the residuals came from a normal curve and therefore the normality assumption is valid.

We can conclude that by implementing the MaxQminT rule, together with NoBtl rule and partial application of SPT rule, the operations are scheduled and sequenced in such a way, that the capacity utilization is increased, thus increasing the company's productivity and Just-In-Time delivery of the final products to the customers, which can be a decisive improvement in nowadays market, where the effects of the financial crisis are still felt by the manufacturers and the consumers together.

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