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A New Managerial Tool For Scenarios In Scheduling

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Abstract: - The purpose of this paper is to introduce a newly developed managerial tool, Quality Scheduling Index (QSI), which can be used at the improvement of quality and time consumption within not only manufacturing companies. The authors present this tool as a result of the actual market conditions of finding a way for managing and controlling the usage of time, quality of work and the costs associated with these two factors. The paper is focused on the area of Management of Production and Operations with the main goal of developing the area of scheduling research and main purpose of increasing the productivity of a manufacturing enterprise by using at maximum the available resources, without any additional costs or investments. A survey is realized regarding the market requirements and partial empirical results of the authors' researches are presented, with conclusions being drawn for future studies. A scenario mainframe is also developed and a relation between QSI and scenarios is presented. The paper represents partial results of the grant projects GAČR P403/12/1950 and SGS13/191/OHK2/3T/12.

Key-Words: - quality, scenarios, scheduling, index, process

1. Introduction

Scenarios can be used in management in order for the company to learn and be prepared to answer the possible questions regarding the development of the business environment and the corresponding strategies. Managers should come together and decide about the next step in the company's future on the market. Scenarios are part of the selecting process of the right strategy for the required segment of the market and in nowadays market time usage and quality improvement can be considered strategic for the survival of the company.

Innovation is part of the company's business model and each company should decide which innovation portfolio to adopt according to the competitive environment. As Davila (2012) considers in his book, we too consider that the right amount of innovation at the right time, can differentiate winners from losers of the market and of the customers. He considers that there are two types of strategies (Play To Win Strategy and Play Not To Lose Strategy), which companies must consider on a long term to achieve their goals. In the same sense Gruia (2014a), considers that the innovation and development of the public sector are also important in the good development of the state, and thus the area of applicability of our research can be broaden in the private as well as in the public sector. We consider that the productivity of work can be increased by combining the quality of work, time consumption and appropriate sequencing rules.

Gruia & Kavan (2013a) show that the Just-In-Time delivering of the jobs from one working area to another, within a manufacturing company are in direct relation with the resources' utilization, but also with the Greedy approach of designing the production lines in order to minimize the total cost of the work load, according to the costs of the possible locations of the workplaces (Gruia & Kavan, 2013b).

The present paper aims to present a way for solving two main problems, i.e. quality control and time management within the companies, with only one managerial tool and to show how this new developed tool, can affect the decisions and strategies taken by the top management within the public, as well as private sector. The research for our paper is focused on the field of quality management and operational management (specifically the scheduling of manufacturing operations on the production lines).

In order to find the latest studies regarding Scheduling operations in a manufacturing company, a research was made with the help of online scientific databases. Based on the initial research of scientific papers, books as well as by developing a new questionnaire, the market was tested and it was discovered that one of the main problems which affects the productivity of work in manufacturing processes, is the quality of time consumption in scheduling manufacturing process. The survey was taken by scheduling professionals, online with the help of the website SurveyMonkey and Linkedin, where the link to the survey was posted online on scheduling groups, which are visited and read every day by professionals and quality and scheduler practitioners. The questions were designed in such a way so that it was obtained as much information as possible from apparently simple questions (the bias of the questions were minimized). Based on this survey, it was discovered that there is a need in the market of a way of managing the time usage and quality of workforce together, as well as the important role the customers' perception plays in the establishment of the management of the utility value and accordingly of the quality of the products.

By analyzing the results of this survey, we have found that a number of more than 88% of the managers are willing to manage the quality of the work and the time used on the production line, with the help of only one tool, which we have developed as part of one authors' doctorate thesis and which we will further present.

Thus the present paper presents a new solution, i.e. Quality Scheduling Index, to the market requirements regarding quality and scheduling management and ways of improvement which can be further used in the scenarios done by the managers and implemented in their long-term strategies.

2. Quality Scheduling Index and its role in scenarios development

Managers in manufacturing companies are facing every day with questions like:

"How can we deliver the goods requested by the market at the desired level of quality?" AND "How can we deliver our products at the right moment (Just-In-Time)?"

These questions are part of our Research Questions and are the basis for the newly developed Quality Scheduling Index, which can be implemented in different scenarios to help them decide which strategy to adopt on the desired market.

Based on one of the author's research as part of his Ph.D. thesis, we can consider different scenarios based on different values of the QSI. The main goal of the index is, based on the input data, to find the best value for obtaining maximum value for the requested quality level by the customers, with minimum production costs and time usage.

The level of quality is settled according to the utility level, different customers consider for the desired products. In collaboration with the marketing and CRM/CI departments, companies should find the needs and the problems of the customers and develop strategies based on different scenarios, which in turn are based on the computational values of the Quality Scheduling Index, for different levels of quality desired by different customer segments from different markets.

Van der Heijden (2005), states that the language of the scenarios is about the future of the company, but it should differentiate how a company should act in the present. And with the help of the Quality Scheduling Index, different scenarios can be stated and some strategic decisions can be taken accordingly. The usage of the index is for the area in time when the level of uncertainty is bigger and the level of predictability is lower than in the area of planning based on forecasting, i.e. the area of planning based on scenarios for the development of new business strategies. This can be better seen from the figure below.

Companies should use time and quality of time consumption in planning and deciding next steps for maintaining the same or better level on the market. With the help of the Quality Scheduling Index, one can improve the productivity of work within company and thus can produce better and faster outputs with the same inputs (resources, financial and non-financial).

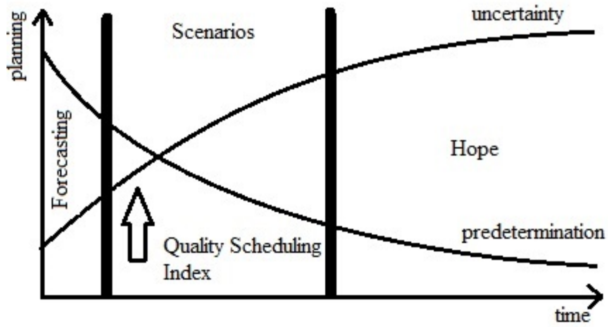

Fig. 1 – Position of QSI in planning using scenarios

Source: Own contribution, based on figure "Balance between uncertainty and predetermination" adapted from Van der Heijden (2005)

We all know that productivity is the ratio between output and input,

$$productivity = \frac{output}{input} \quad (1)$$

and if we know that the input is according to the standards (for e.g. the raw material is delivered in time, at the required quality standard imposed by us, the company, the people are trained and chosen by the HR department to work within our company according to our needs and financial resources and our equipment is advanced enough to perform well our manufacturing operations), the only way to improve the productivity of the company and our work is to increase our output to the market. By output, we understand either a bigger number of products (but which must comply with quality standards) or the same amount of products, but with better quality. In the second case, the quality of the products is improved, thus the company reduces its time (and accordingly its costs) dealing with service, rework or maintenance of our products, when they broke. Also customers will recommend our qualitative products to their acquaintances and relatives and our market share will raise, qualitative products being one of our competitive advantages and thus part of the company's strategy.

If we consider either two cases, we can increase the output of the company by organizing the resources on the production line to produce faster and better products, without any additional costs. That is why here we present the newly developed Quality Scheduling Index which can improve the output of the company and in this way the management can use it as managerial tool to improve the productivity within the company and plan on larger time interval, than the one, where forecasting is used, in order to expand on other markets, destroy the actual competition and faster innovate the products in a radical way, rather than semi-radical one.

A manufacturing company can thus better implement a radical innovation in either the technology or in the business model, or in both actually, by reducing the risk involved with this kind of innovation, because, now, after implementing the QSI on the production line, the time usage of the workers is without any "dead" time, the company doesn't lose money from this, nor uses additional resources than the ones which are absolutely needed for the production process and can relocate these resources in the R&D department for the next generation of products.

However, without strong leadership and vision from the top management, the innovation is not likely to be achieved and implemented in the company's culture. The difference between the two possible types of strategy is given by internal as well as external factors of the company. Between the internal factors, we can recall:

- Technical possibilities
- Organizational abilities
- Success of the actual business model
- Finances
- Vision of the company

And we can add to the internal factors, which drive innovation through the company, also:

- Innovation culture and willingness to improve the process without any financial drive incentives--- and this factor can be easily solved with the help of the QSI.

Every manager wants to develop its products with the minimum production costs, at the highest quality and in the fastest way possible, so that he can take the lead in the market with the innovation of the product. That is why we have developed the following mathematical index:

$$QSI = \frac{\sum_{i=1}^{h}\sum_{k=1}^{f}(ew_{ki}E_{ki}y_{ik} + tw_{ki}T_{ki}z_{ik} + w_{ki}C_i)}{\sum_{i=1}^{h}\sum_{k=1}^{f}\frac{q_i}{tc_i * (E_{ki} + T_{ki} + C_i)}} = min \quad (2)$$

which can be useful for minimum values.

We can state that this index has the following important roles in a manufacturing company:

1. Considers especially the processes which have delays and those which are made in advance than their planned schedule, making the management to consider these delays and advances from a financial point of view;
2. Considers quality not only from the ISO norms' point of view, but also from their customer's segment point of view which they want to target with their products, by trying to develop an equation for the level of quality based on the utility values and which processes add this value on specific working places on the production line;
3. It evaluates the time consumption with regard to the quality level and production costs and helps improving the production processes, by increasing the work productivity;
4. Has a positive influence on long term planning within the company based on different scenarios, where can act as a good managerial tool and can answer to questions like:

Are we well prepared and do we manage our actual processes good enough to make the next step and implement a radical innovation in our business model and/or technology?

What will happen if we increase the quality of the products?

How can we increase the quality of products and faster deliver our products on the market?

How will influence our manufacturing costs the increase in quality? and

Where should we act on the production line to increase quality, reduce production time and costs related to time consumption?

5. Can be used as a motivational tool for employees, for managing processes in such a way so that the needed quality level to be obtained, together with the corresponding costs and time, so that together to reach the previously computed Quality Scheduling Index, by the management. In this consideration QSI can be used as a Key Performance Index for the quality of the work of each worker and can have impact on the salary if the worker has reached his previously settled target or not.
6. Can reduce the risk of failure, of the company which can rise from the possible scheduling scenarios related to the semi-radical innovations in business model or technology. By analyzing the processes where the quality can be increased and by taking necessary steps in increasing it, the risk of failure at the operational level is reduced, because as part of the implementation, the management should redesign the production process according to the greedy algorithm and increase of the resource utilization. The index can considered as an effective tool for evaluation of the effects of scheduled changes to the design and operational procedures, as function of quality, time and total costs.

The index can be also used as part of the top management's vision of innovation the business model, by adding value to the produced final products, by increasing the quality and reducing the time spent with their production. Here by "reducing time", I consider reducing of the unnecessary time spent of the product on the production lines, reducing or even elimination of the waiting / dead time of the products from their technological processes and manipulation.

Whatever part of the innovation process we want to improve (business model or the technology), we should also increase productivity of the processes, by reducing the time spent with them and correspondingly the costs, and increasing the quality of the processes and of the products.

The success of the actual business model, as one of the internal factors which influence the choosing of the right innovation strategy, can be analysed from the productivity point of view. Managers must look at the processes and based on different scenarios, made from the data from the customers and suppliers, i.e. data from CRM and CI, should improve the time spent in the factory with the production of their goods, but without reconsidering the quality level required by the standards on one hand (ISO 9001, 14 000, 18 000, etc.) and also by the customers, on the other hand.

We consider that a manufacturing small or middle size company can develop its innovation strategy based on scheduling the internal processes in a productive way.

In other words the following main *scenario mainframe* should be maintained when dealing with a new scenario, as part of the future strategy:

1. Arrange the working areas with the corresponding tools in a “greedy” manner so that each worker can be accounted responsible for his work, if any fault will appear.
2. Prioritize the work according to the available resources and the main skills of the workers so that the time and quality can be maintained within standards.
3. Consider and arrange the machines in a parallel way in order to increase productivity and schedule the manufacturing operations with a focus on quality, time and their corresponding costs.
4. Deliver goods to the market and receive feedback from both the customers and workers in order to improve the process.
5. Adjust the short term and long term strategy of the company, based on the feedback and obtain approval from the stakeholders, with regard to the fulfilment of their needs.

If we look at the first three points of the above mentioned mainframe, we see that we should analyse three different problems in terms of improving the productivity of the company. However in order to create a scenario, all these different views are needed. One view cannot be good enough to create a scenario as part of a long term strategy. That is why scenarios are very difficult to create and implement in a company, i.e. because when we talk about scenarios we should consider different points of view of the same problem in order for managers to come to a single generally accepted idea.

The scenario should take in consideration the companies outside environment as well as the internal one, which is responsible for production and shipment of the goods.

This tool, QSI, can be used for adjusting scenarios made after the external environment has been known. We focus on improving the strategy, by managing the internal processes of the company in a productive time manner.

With the help of Design Of Experiments, based on the input data from the company and feedback from the customers, according to the quality level of the products, we can simulate different scenarios with outputs, which can be used to answer the market conditions and which can be further implemented in the long term strategy of the company. Thus using data from the manufacturing process, in connection with the customers' utility value for our products, we can run different experiments, from which we can draw different conclusions, take specific actions and learn how and where to improve the production processes, in order for the production to be in the Just-In-Time manner.

3. Design of Experiments for QSI

We are interested in the effect of different scheduling scenarios, from the implementation of the Quality Scheduling Index, on the utilization of the available resources. In this manner we want to test the robustness of the newly developed index.

As Gruia (2013) has proven, by using a 2^4 factorial design he has showed that the quality function which he considered was viable and applicable in a simple logistical problem as well as into a more complex scheduling problem, as is the case of this research.

We want to see if the model is robust enough to sustain manufacturing of products so that the manufacturing process and its quality will not be affected by the variability transmitted by the components of the system, like priority of the job (A), capacity utilization of the available resources (B), processing time (C) and preparation time for the next operation (D).

Based on the 2^4 factorial design, from the previous studies, we assume that the processing time of the job, denoted by C, is difficult to control in a real situation where jobs are formed of more than one operation and the technological process should be smooth without any delays or works in advance of the schedule, but it can be controlled in the pilot scale experiment, which we have performed. The other factors A, B, D are on the other hand easy to control in a real situation based on the technological requirements.

Thus the noise factor (or the uncontrollable variable which cause variability in the quality of the job formed of more than one operation) is factor C, the processing time, which we denote by p_1, while the controllable variables we denote with $c_1, c_2\ and\ c_3$ for priority of the job (A), utilization of the available resources (B) and respectively preparation time for the next operation (D).

According to Montgomery (2005) a general representation of the regression model of Gruia's 16-factorial experiment can be written as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{34} x_3 x_4 \quad (3)$$

According to table 1, the both the controllable factors and noise factors are in the same 2^4 factorial design and we can apply the combined array design in order to investigate the effect of these factors on the quality of the work from the production process.

The general response model of control and noise variable has the following general form:

$$y(\bar{c}, \bar{n}) = f(c) + g(c, n) + e \quad (4)$$

where function $f(c)$ is function of the controllable variables c and the function $g(c,n)$ considers the interactions of the noise variables n and the interactions between the noise and controllable variables.

If we assume that the noise variables have the mean zero, variances $\sigma_{n_i}^2$ and zero covariance and if the errors e have zero covariance, then the mean model for the response of the factors affecting the product is:

$$E_n[y(c,n)] = f(c) \quad (5)$$

And the variance model for the response will be accordingly:

$$V_n[y(c,n)] = \sum_{i=1}^{j} \left(\frac{\partial y(c,n)}{\partial n_i}\right)^2 \sigma_{n_i}^2 + \sigma^2 \quad (6)$$

Using the results from table 2, the response model will be considered for noise factor processing time of the job (C) and controllable variables $c_2\ and\ c_3$, the utilization of the available resources (B) and respectively preparation time for the next operation (D):

Run Number	Factor				Run label	Quality qi
	A	B	C	D		
1	-	-	-	-	(1)	1,030507545
2	+	-	-	-	a	1,007462277
3	-	+	-	-	b	12,74211248
4	+	+	-	-	ab	2,289437586
5	-	-	+	-	c	1,000001207
6	+	-	+	-	ac	1,000000302
7	-	+	+	-	bc	1,000120665
8	+	+	+	-	abc	1,000030163
9	-	-	-	+	d	1,000003981
10	+	-	-	+	ad	1,000000995
11	-	+	-	+	bd	1,000398264
12	+	+	-	+	abd	1,000099536
13	-	-	+	+	cd	1,000000926
14	+	-	+	+	acd	1,000000231
15	-	+	+	+	bcd	1,000092601
16	+	+	+	+	abcd	1,000023149

Table 1 – The quality of i-th bee experiment
Source: own contribution

$$\widehat{y(c,p_1)} = 1{,}81689 - \left(\frac{0{,}46762}{2}\right)p_1 + \left(\frac{0{,}458428}{2}\right)c_2 - \left(\frac{0{,}46753}{2}\right)c_3 - \left(\frac{0{,}45836}{2}\right)c_2p_1 + \left(\frac{0{,}467525}{2}\right)c_3p_1$$

$$y(c,p_1) = 1{,}81689 - 0{,}23381p_1 + 0{,}229214c_2 - 0{,}233765c_3 - 0{,}22918c_2p_1 + 0{,}23376c_3p_1 \quad (7)$$

Using equations (5) and (6) we can compute the mean and variance of the model as:

$$E_n[y(c,p_1)] = 1{,}81689 + 0{,}229214c_2 - 0{,}233765c_3 \quad (8)$$

$$V_n[y(c,p_1)] = \sigma_{p_1}^2(-0{,}23381 - 0{,}22918c_2 + 0{,}23376c_3)^2 + \sigma^2 \quad (9)$$

We will further assume for the simplification of the computation, that the noise variable, which in our case is the processing time of the job formed of more than one operation (C), has the highest and lowest values deviated with one standard either sides of the average value so that we can use in our computations:

$$\sigma_{p_1}^2 = 1 \quad (10)$$

Model term	Effect estimate	Sum of squares	Percent contribution
A	-0,28061	0,314976	3,726%
B	0,458428	0,840625	9,944%
C	-0,46762	0,87468	10,347%
D	-0,46753	0,874353	10,343%
AB	-0,27506	0,302625	3,580%
AC	0,280573	0,314885	3,725%
AD	0,280521	0,314767	3,723%
BC	-0,45836	0,840383	9,941%
BD	-0,45828	0,840068	9,937%
CD	0,467525	0,87432	10,342%
ABC	0,275017	0,302538	3,579%
ABD	0,274966	0,302424	3,577%
ACD	-0,28052	0,314755	3,723%
BCD	0,458267	0,840036	9,937%
ABCD	-0,27496	0,302413	3,577%

Table 2 – Factor effect estimates and sums of squares for our 2^4 design
Source: own contribution

And the residual mean square obtained from the response model, i.e. the model which incorporates the controllable as well as the noise variables, as seen from the table below, will be:

$$\widehat{\sigma^2} = 0{,}414948675 \quad (11)$$

Source of variation	Sum of Squares	Degrees of freedom	Mean square	F_0	P-value
C	0,87468	1	0,87468	2,10792	0,09438
B	0,840625	1	0,84062	2,02585	0,10005
D	0,874353	1	0,87435	2,10713	0,0944

BC	0,840383	1	0,84038	2,02526	0,10009
CD	0,87432	1	0,8743	2,10705	0,09444
Error	4,149487	10	0,41494		
Total	8,453847	15			

Table 3 – Analysis of Variance for the pilot experiment with factors C, B and D
Source: own contribution

If we analyze the values of the F_0, F-statistic, which is calculated by taking the mean square for the variable divided by the mean square of the error, it represents a ratio of the variability between groups compared to the variability within the groups. If this ratio is large enough, then the p-value is small producing a statistically significant result (i.e. rejection of the null hypothesis). The acceptation of the null hypothesis means that all the group population means are equal versus the alternative, i.e. rejection of the null hypothesis, that at least one is not equal.

The p-value is the probability of being greater than the F-statistic or simply the area to the right of the F-statistic, with the corresponding degrees of freedom for the group (which is equal to 1) and error (total sample size minus the number of group levels, or here 15 – 5 = 10). The F-distribution is skewed to the right (i.e. positively skewed) so there is no symmetrical relationship such as those found with the Z or t distributions. This p-value is used to test the null hypothesis that all the group population means are equal versus the alternative that at least one is not equal. The F-statistic will always be at least 0, meaning the F-statistic is always nonnegative.

In our case for values of "p-value" less than 0,05 it indicates that the model terms are significant. But if we analyze the results there are no significant model terms and values greater than 0.1000 indicate the model terms are not significant.

For example F_0 of 2,10792 implies that the model is not significant relative to the noise and there is a 9,43% probability that a value of F_0 this large could appear due to the noise factor.

Thus Gruia's model (2013) can be successfully applied in jobs with more than one operation and the processing time of the operations will not influence the utility function of the final product.

By substituting equations (10) and (11) in (9), the variance model becomes:

$$V_n[y(c,p_1)] = 0{,}469615 + 0{,}107169c_2 - 0{,}107146c_2c_3 - 0{,}10931c_3 + 0{,}05252c_2^2 + 0{,}05464c_3^2 \quad (12)$$

With the help of Design Expert 8 software, we can draw the contour of the utility function (see figure 4) used in the model of jobs with more than one operation, which is influenced by the noise variable (processing time of the operations) and controllable variables (the utilization of the available resources and respectively preparation time for the next operation). Also with the help of the same software we can draw a surface response model (see figure 5), where one can see the variance in the utility function given by the capacity and processing time of the operations.

The variation is smooth in 3D and we can conclude that the model of the Quality Scheduling Index, which was developed for jobs with one operation can be successfully applied for jobs with more than one operation, because the processing time of each operation in part will not affect the sequence and schedule of the others, nor the available capacity utilization of the available resources.

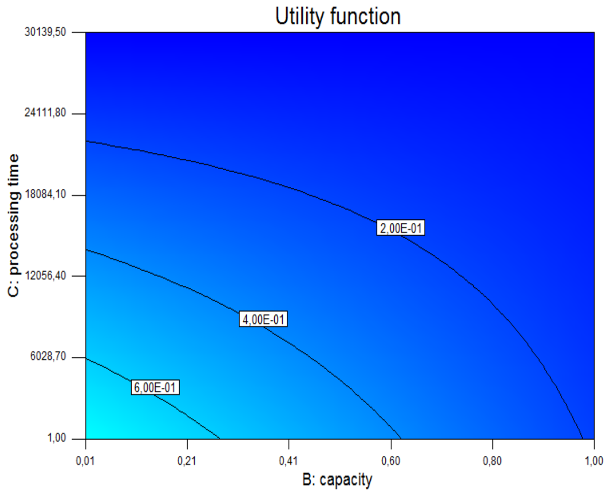

Fig. 4 – Contour plot of the utility function from the Quality Scheduling Index model
Source: own contribution

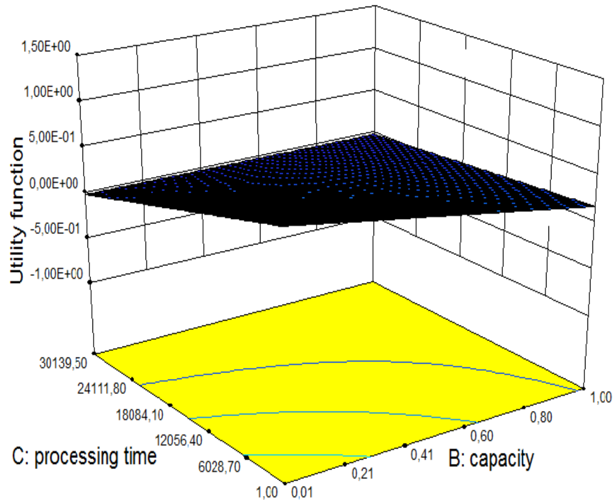

Fig. 5 – Response surface plot of the Quality Scheduling Index model
Source: own contribution

The model is viable and can be successfully applied for jobs with one operation. The case when the jobs are composed of more than one operation can also be considered, but the manufacturing processing times should be known in advance for each operation. The Quality Scheduling Index was developed in such a way, so that it can be applied to both cases of jobs with one as well as with more operations. The only difference is in the implementation methodology which I will further present.

When dealing with jobs with more operations with the same goal of increasing the productivity, specifically to increase the quality of the workforce and decrease the time and costs associated with the manufacturing processes, we should decompose each job according to the resources which are used, time consumption and required level of quality.

By applying this index, the managers can compute the best values according to their specific customers' and standard's limits and the company can take these values and use them to evaluate their our manufacturing process. Doing so, they have a way of improving their processes using their actual data, computed from their customers' utility value. The values of the QSI can then be implemented back into the individual manufacturing operations, according the optimal values of the quality, time and costs which have to be maintained at all considered working areas, so that the process to be Just-In-Time.

4. Conclusion

The paper presented a new managerial tool, i.e. Quality Scheduling Index, which was developed in compliance with the present market conditions. A connection between the index and scenarios was also presented and a scenario mainframe was developed accordingly. The roles and importance of the index for the management are presented. An initial study was done by the authors as part of their research grants and accordingly actions were taken in order to solve the problem of increasing the productivity, which is still a major problem in, but not limited to, manufacturing companies worldwide.

The model was developed with the main goal of increasing the work productivity within the company. The robustness of the model is tested and we find out that a less than 10% probability exists that our model, which is in direct relation with the utility function of the customers and productivity of our company, to be affected by processing time of each operation. Thus the duration of each operation can affect the satisfaction of our customers in a small percent, but on the other hand we have showed that there exists a probability higher than 90% to increase the productivity using our QSI index which is focused on scheduling the operations and quality of the work done by the employees.

This paper presented partial results of the research done by the authors within their research grants. Also it represents part of the Ph.D. thesis of one of the authors (Gruia, 2014b).

To sum up, the index QSI can be successfully applied for jobs with one and more than one operation in order to measure, control and improve the time consumption on the production lines and quality of work, which affect the productivity of the company in a direct way.

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