An innovative way of improving just in time delivery by using the Quality Scheduling Index

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Abstract. The article is focused on presenting a new Quality Scheduling Index which can help managers in producing and delivering goods to the customers according to their quality requirements and time deliverables. The index is combining the required level of quality of the products and the Just-In-Time production schedule, which a company should maintain in order to deliver the requested products by the market. The authors present a new managerial tool which can be used to assess, control and improve the manufacturing process by reducing manufacturing time and increasing the quality of the products. This offers a new perspective on the consumer’s safety and their requested level of qualitative products and forces the management to consider customers and their satisfaction level, starting with the manufacturing process of the goods. The Quality Scheduling Index is then partially implemented in a Romanian middle size manufacturing company and results are analyzed. An increase in average of 27% in time better consumption of the available time is obtained corroborated with a 6% increase in the production of qualitative products with zero defects. The article presents partial results of the authors’ yet not published work in their research of operational management.

Keywords: quality, scheduling, index, consumer, time.

JEL Codes: L23, O21, M11, L15

1. Introduction

In these difficult economic times, where the whole world is affected by the financial crisis from 2009, the manufacturers should increase their sales and awareness of their products, by innovating and improving their business models. The consumers are harder to acquire and to maintain, because their needs are changing with a faster pace now more than before the crisis. Also a new attention is given to the quality level of the purchased products and their costs.

That is why companies should try to find new and better ways how to improve the quality of their workforce labour, how to decrease the time schedule of the production process so that their products to be delivered to the customers according to the Just-In-Time philosophy and last but not least, how to minimize accordingly the manufacturing costs.

Also as a result of the e-commerce and the increase in internet utilization of the possible customers, the products should be at a qualitative level imposed by the market, in order to answer its requirements. Our

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In other words, manufacturers should be producing according to the PULL principle of the market and not PUSH, and the customers’ requirements should be met before the final product exits the production hall. And questions like: At what level of the desired quality should we produce our goods? and At what moment of time shall we finish producing the goods and shipping them to the customers? are in our opinion critical and decisive for the future of each and every company, and thus we will focus on answering these questions in our article.

We believe that a solution to these questions should come from the management of the companies through their active involvement in the production process, i.e., by continuously improving the quality of their products and the time consumption within their companies. In this way the managers are increasing the work productivity and the consumer’s satisfaction is maintained and increased by products which answer their quality and time delivery requirements. We have developed a new Quality Scheduling Index (QSI), which connects the quality, time and costs related to the time consumption and we will further present partial results of its implementation in a Romanian middle size manufacturing company.

The paper is organized as follows: first it is presented the literature review, where the most important books and articles are presented and the research gap is identified; secondly the Quality Scheduling Index is presented and its main implementation steps; thirdly new sequencing rules are developed as part of the implementation methodology of the QSI; and finally results are interpreted and conclusions are drawn in the studied area.

2. A new way of improving Just in Time delivery of products

2.1. Literature review

In the scientific literature there exist different methods for improving the quality of the products like: Total Quality Management, Lean Management, Six Sigma, as well as for scheduling different jobs on different production lines and/or working tables. However, there isn’t a single tool which connects these two problems and which can be used by managers in order to control and improve the manufacturing process.

The article is focused on the outputs of one of the author’s Ph.D. thesis and we will try to further present it in a short form. The author developed a new managerial tool entitled Quality Scheduling Index (QSI) which is based on the manufacturing process on parallel machines with application of the bee algorithm and connects the quality of work and the manufacturing schedule of the products. The author had to mathematically describe the process, which was then implemented in a computer program used for different simulations in order to find the optimum result of the index.

Bees, like ants and other insects are social insects and have an instinct ability known as swarm intelligence, which enables them to solve complex problems of the group, beyond capability of individual members, by functioning collectively and interacting with each other amongst members of the group (Nakrani and Tovey 2004, Teodorovic and Dell’orco, 2005). For the honey bees this intelligence is crucial due to the complexity of finding flowers and collecting nectar and pollen, in a relatively short period of time, related to the life of a honey bee.

Honey bee algorithm has been used in other scheduling problems like Job Shop Scheduling (Chong, 2006), but it wasn’t used for parallel machine scheduling with the quality approach.

Also Rebai (2012) introduced a function for total costs but nothing is mentioned about the quality of the work. Other authors like Swink (2006), work under the assumption that the time–cost trade-offs for project
activities are linear and the same assumption we will further consider. An analogy is made between the working bees of a hive, which have to get out of the hive and search for new flowers and parallel machine scheduling.

Feibenbaum (1951), considered the quality control as the input into all phases of production from the specifications of the customer and sales, through the outer appearance, engineering, installation and shipment. According to Juran (1998) in a company that puts quality on the first place, it must also pay the following:

1) The active participation of the management, which sets out responsible and credible professionals to the specific quality objectives.
2) It uses a new approach in the planning, control and quality improvement.
3) Redesign of the existing processes, by identifying gaps in quality, distinguishes between systematic and random effects.
4) Systematic effects are solved by teams.
5) The main factor of payment/rewards is based on the results.
6) Building a masterpiece of planning quality leads to the creation of systematic problems.

Also Teruo Mori (2012) focuses on statistical methods that were developed by Taguchi, the so called Quality Engineering and the mapping of quality from the customer's perspective and designed quality (engineered quality) that minimizes the cost and is designed into the product to improve product performance efficiency.

There are no articles or books which consider both quality and time consumption, thus the research gap was identified and we will further present it. We consider that the QSI can be a managerial tool which can be successfully used in both private as well as public sector. As Gruia (2014) considers in his book, the problem of increasing the productivity can and must be solved in the public sector in the XXI century, and we can add that the QSI can be the solution to this problem, which is still affecting the companies after the financial crisis.

2.2. Quality Scheduling Index

The QSI was developed based on the market need of a tool which can manage both the quality and time consumption in a company. The research was initially based on an online survey sent to manufacturing companies from different European countries, including Czech Republic and Romania, and based on the received answers, structured interviews were scheduled with managers from selective companies to get more accurate data and thus improve the return rate of the questionnaire. The index was then partially implemented in different small and middle size manufacturing companies and we will further present such a case regarding a middle size manufacturing Romanian company. The QSI can be applied for jobs with one operation and jobs with more than one operation. We will further focus on the problem of scheduling a sequence of jobs with more operations per job, which can be seen as a series of operations which after being completed are added to the next one and so on until the jobs on the first until the last line of the parallel machines arrangement are fulfilled and then assembled together to form the final product.

This sequence of operations, when completed should fulfil the requirements of the manufacturing job regarding: time, quality and costs. Costs are in direct relation with the required level of quality and quality and time are in relation of indirect proportionality.
That is why we will further consider the quality as our main function which has to be optimized, if we take in consideration that between the operations of one job there is a relationship of interdependency, as demonstrated by Gruia and Kavan (2013).

As Gruia (2013) presented, the model is a system of equations where we should increase quality of the work, decrease costs and decrease total makespan of the colony and this can be translated as a minimizing criterion of a ratio, which we will denote as a Quality Scheduling Index:

$$QSI = \frac{\sum_{i=1}^{h} \sum_{k=1}^{f} (ew_k E_{ik} y_{ik} + tw_k T_{ik} z_{ik} + w_k C_i)}{\sum_{i=1}^{h} \sum_{k=1}^{f} q_i (E_{ik} + T_{ik} + C_i)} = min$$

Where we have the following symbols:

- $tc$: total costs
- $C_i$: completion time
- $ew_k$: early weight
- $tw_k$: tardy weight
- $w_k$: weight within optimistic and pessimistic due date
- $E_k$: earliness of the job
- $T_k$: tardiness of the job
- $t_p$: prepare time for new job
- $f$: flying time
- $q_i$: quality of the work of the worker

And two binary variables $y_{ik}$ and $z_{ik}$:

$$y_{ik} = \begin{cases} 1, & \text{for } E_k > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$z_{ik} = \begin{cases} 1, & T_k > 0 \\ 0, & \text{otherwise} \end{cases}$$

### 2.3. Practical part – partial implementation of QSI in a manufacturing company

The implementation of the QSI can be done for jobs with one operation as well as for jobs with more than one operation and its methodology is in three main steps:

- Divide the workload within the company according to the greedy perspective;
- Increase the capacity of the utilization of the available resources;
- Apply the QSI and find the optimum values and improve the process.

We will further consider the first step of the methodology and apply it for jobs with more than one operation. In order to be able to schedule more than one operation within a complex job from the quality, time and costs’ points of view, we should first separate the jobs with one operation from jobs with more operations, on the existing parallel manufacturing lines and develop a methodology for solving these two cases.

There are already sequencing rules like:

- a) Shortest Processing Time, where the work is scheduled according to the shortest processing time of the product, which comes as the first operation;
- b) Due Date, where the work which the shortest due date should be done first;
c) First Come, First Served, which says that the work is done according to the sequence how they come at the working area;

d) Critical Ratio, where the work is scheduled according to the increasing ratio between the Due Date and Shortest Processing Time;

e) Johnson’s rule, which minimizes the time for working different operations on two working areas.

But we are interested also in maintaining the requested quality level together with the minimization of time, and all from a greedy perspective. So we have developed the following rule MaxQminT, which 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 had 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.

We have developed the following implementation methodology of the first step of QSI:

1. Divide the jobs in two categories to be scheduled on the available parallel machines:
   a. Jobs with one operation;
   b. Complex jobs with more than one operation, where each operation can be considered as a separate job on different machine from the production lines;

2. Schedule the manufacturing operations according to the rule MaxQminT, which is valid for arranging the jobs in a greedy manner so that the first operation to be responsible with the most amount of work, with the requested quality level in the shortest processing time;

3. Sequence the final operations of each job from the parallel manufacturing line according to rule NoBtl so that the assemble process to proceed in a smooth and lean manner without the formation of bottlenecks.

We have implemented the above mentioned rule into a middle size Romanian manufacturing company, from the aviation industry. From the reasons of intellectual property the numbers had to be modified and the name of the company or the product cannot be displayed in any public work. However we can state that it was a complex product which is part of the engine of a well-known type of airplane. The product, further denoted with P, was composed of 3 parts which had to be worked on different parallel machines. The workers had the opportunity to move along the production lines and pass from one parallel production line to the other in order to fulfil the manufacturing processes. As part of the implementation methodology of QSI, the working areas had to be divided and arranged according to Hasse diagram and thus this condition had to be maintained. A specific representation of the working tables, one can see from the figure below.

The parallel production lines are formed of the following working operations:

a) Line 1 – 1111 (input), 1101, 1100, 1001, 0101, 0100, 1000 and 0000 (output),

b) Line 2 – 1111 (input), 1011, 1010, 1001, 0011, 1000, 0010 and 0000 (output)

c) Line 3 – 1111 (input), 0111, 0110, 0101, 0011, 0100, 0010 and 0000 (output).

The completion time of the parts has to be scheduled in such a way so that each part to come at the assembly, final operation (0000), from the three parallel lines and without producing any delays or without any advances in time. The production process should be smooth, Just-In-Time.

Fig. 1: Modified pseudo-projection of the 4-dimensional hypercube
According to the cumulative processing time on each manufacturing parallel line the following coefficients were computed:

\[
\text{Average working time} = \frac{\text{sum of the cumulative time}}{\text{number of operations}}
\]

\[
\text{Average no. of working minutes} = \frac{\text{sum of the cumulative time}}{\text{sum of total number of operations}}
\]

We also know as part of the rule that the input for the material on each of the lines is:

<table>
<thead>
<tr>
<th>Operation 1111(input)</th>
<th>Processing time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>2</td>
</tr>
<tr>
<td>Line 2</td>
<td>1</td>
</tr>
<tr>
<td>Line 3</td>
<td>3</td>
</tr>
</tbody>
</table>

and the output (assembly of the three parts) should be in the following order:

<table>
<thead>
<tr>
<th>Operation 0000(output)</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>2\text{nd}</td>
</tr>
<tr>
<td>Line 2</td>
<td>2\text{nd}</td>
</tr>
<tr>
<td>Line 3</td>
<td>1\text{st}</td>
</tr>
</tbody>
</table>

Tab. 1: Processing time and order for the input and output operations

The parts from the 1st and 2nd line should be finished in the same time due to the technological conditions, while the part from the 3rd line should be finished first because of the condition of being further prepared to be inserted in the final product. The company is working 8 working hours per day. The processing times include manipulation time and preparation time of the machine (working area).

We approached the company through a questionnaire and further through a structured interview with the production manager and costing manager and referred them to the Quality Scheduling Index, developed in one of the author’s Ph.D. thesis and part of the implementation methodology was to rearrange the working areas on parallel lines from a greedy perspective, i.e. where the longest operation to be made first and the others to follow. The company had jobs with more than one operation and it was a good way for implementing the new sequencing rule MaxQminT (see figure no.2). According to the new rule we had to divide the workers in two member teams and schedule the operations accordingly. Each line had a total number of 8 operations; this meant that we needed 4 teams which we denoted as \(T_i^j\), where \(i = \{1,2,3,4\}\) denotes the number of the team and \(j = \{1,2,3\}\) states the number of the line on which the appropriate team works.

Fig. 2: Sequence of the operations on three parallel lines (L1 – L3) with the throughout and idle time after the implementation of MaxQminT rule
After additional evaluation of the process we have partially applied (together with the previously developed MaxQminT rule) in the second step of the arrangement the Shortest Processing Time rule.

The methodology for the greedy approach in this case of jobs with more operations can be considered and implemented in the following steps:

a) First arrange and sequence the operation within the parallel jobs according to the MaxQminT rule;

b) Evaluate the process from the capacity point of view and if there are some difference in the resources and their availability on different operations in the same production time, partially apply the Shortest Processing Time rule so that to schedule the second largest operation on the line considering the available resources.

c) Check the compliance with the input/output constraint so that no bottlenecks to appear in the production and shipment process and if the schedule doesn’t check out, apply the NoBtl rule.

After applying the MaxQminT and NoBtl sequencing rules, we have obtained the following results (see figure no. 3) with idle time which had to be lost in order for the operations to be scheduled on the available working areas at the given time intervals.

Fig. 3: Sequence of the operations on three parallel lines (L1 – L3) with the throughout and idle time after the implementation of MaxQminT, NoBtl rules and partial application of the Shortest Processing Time rule

Even though in both of the charts, the idle time is the same (14 time units, in our case minutes) the process is smoother after the implementation of NoBtl, MaxQminT and SPT rules (figure no. 3). If the conditions of input and output had not been maintained, that is the first operation on the line is the input and the last is the output, we could have obtained better results. The condition for the output of each part is also maintained by using this rule, thus no bottlenecks are created on the production lines.

When we evaluate the time spent on each line we can see that the value remains the same and the process (on each line) doesn’t have any idle time in between operations. The company decided to further focus on the quality by motivating the workers with financial incentive and with individual and team trainings, where they were taught how to use the idle 3, 5 respectively 6 minutes to prepare the link and clean the working area for the next product which had to be processed.

Table 2: Computed coefficients on the available lines before and after implementing the new rules

<table>
<thead>
<tr>
<th>Line 1</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average working time</td>
<td>11,75</td>
<td>16,125</td>
</tr>
<tr>
<td>Average number of working minutes</td>
<td>3,9</td>
<td>5,4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average working time</td>
<td>9,75</td>
<td>14</td>
</tr>
<tr>
<td>Average number of working minutes</td>
<td>3,5</td>
<td>5,1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line 3</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average working time</td>
<td>11</td>
<td>14,375</td>
</tr>
<tr>
<td>Average number of working minutes</td>
<td>4,2</td>
<td>5,5</td>
</tr>
</tbody>
</table>
The time had to be managed by each team in such a way so that they can manage to fulfill their job of cleaning the working area in the available time, which was used as follows:

- The workers from the 1st and 2nd line clean the equipment, tools and prepare the working area before receiving a new part to work on;
- The workers from the 3rd line clean the equipment, tools and prepare the working area after they finished the work on their part;

When analyzing the two considered coefficients we see an increase in the time spent with each product of about 27% in average. However the total processing time on each line was not increased! For instance the amount of products produced by the three lines together during a working day of 8 hours, decreases from 55 (from which 4 are defective) to a number of 54 (from which none is defective). In addition when the company was using only the SPT rule, due to the necessity of using the same machine for two operations which had to be worked at the same time, bottlenecks appeared and inventories had to be designed between each two consecutive operations and from a theoretical number of 57 products, in reality only 55 were produced. The workers had to remain almost every day an additional 50 minutes overwork to finish the parts which were started in the morning. Nevertheless the rule is implemented from a greedy perspective with the first goal of increasing the amount of work, and indirectly the quality of the products and this can be seen from the graph below. After the implementation of the rule, the company registers an increase in the time consumption from a total average of 10.83 minutes worked per operation to an average of 14.83 minutes worked per operation (however, without the increase of the total available time on each line), i.e. an increase in average of 27% in time consumption of the available time, and an increase in the production of qualitative products too, from 51 to 54, i.e. approximate 6% increase in the quality of the products with zero defects. In the same manner the costs of quality were considerably diminished, with up to 17%.

![Fig. 4: Time consumption and no. of qualitative products before and after MaxQminT with Shortest Processing Time implementation](image)

3. Conclusions

In this paper we have presented the partial implementation of the Quality Scheduling Index and the results of the first step of its implementation, i.e. the division of workload from a greedy perspective. We consider that this newly developed index can solve the actual problems managers are facing regarding quality control and time consumption and in this way the customers can be protected from defective products entering the market. New sequencing rules were developed in order to answer the manufacturing requirements of jobs with more than one operation, where a level of quality was imposed and needed by the
buyers. In this particular case scheduling involved timing of these operations which had to be worked on three parallel lines where different machines and tools were displayed. The coordination of these manufacturing operations involved a partial implementation of the Shortest Processing Time rule which helped the company to achieve the requested level of quality and a reduction of costs related to rework and scrap in time due to the available idle time in which the workers from each line were motivated to perform cleaning and maintenance operations of the used tools and working areas. The optimization problem was here considered from a greedy point of view, where the previous working area had to perform most of the work, or in this particular case, first working area had to perform first the longest operation, with the initial conditions that the input and output from each line to correspond to the first, respectively the final operation on each line.

The process is improved from the point of view of increasing the quality and reducing future manufacturing costs (with rework, with maintenance, with marketing campaign to re-establish the lost image of the company due to flaws which have appeared if the rule was not used, etc.). The management also registered a positive effect of this sequencing rule on the maintenance and service of the tools and working equipment, because the time between two consecutive breaks of one machine had increased, due to periodical cleaning and maintenance done during the each 27th minute cycle of production of one part on each of the parallel production lines. An increase in quality of the products of 6% was achieved by implementing this rule and an increase of 5% of the satisfaction of the customers was achieved after the first month after implementation of the MaxQminT and NoBtl rule. Besides this, the costs related with the additional overtime of the workers spent to finish the parts started in the morning of the same day are eliminated, the defective products are eliminated from the production process and are not shipped to the customers (the company registered a decrease with the maintenance and post-selling services of the products of 17% after the first 6 months of the implementation of the MaxQminT and NoBtl rule) and after implementing the rule for increasing the utilization of the available resources together with the Quality Scheduling Index, the company found financial capital for R&D of a new product, which was produced faster and with higher properties than the previous one.

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