Industrial processes efficiency and lower energy consumption initiatives through advanced retrofittings in the wood industry

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Abstract. In a modern manufacturing system for furniture production, raw material and material, energy and information flows are directly interconnected to obtain competitive products while increasing the productivity, profitability and environmental performance of the enterprise. In the wood industry manufacturing system, raw wood undergoes physical and biological transformation processes (drying and transformation of the biological properties of wood) as well as disruptive actions that are compensated by the order quantities. Energy as a resource has an important role to play in this production process, and it involves consuming a certain amount of energy. It is one of the biggest and costliest resources involved in the manufacturing process. The required energy is generally transmitted from the outside in the form of electric or thermal energy. From the energy input, only a part becomes useful energy, the rest representing energy losses. By reducing energy consumption, reversing energy losses and integrating materials and material losses into energy recovered through retrofitting, revenue and profit can increase, leading to an increase in employee satisfaction. The easier it is to maximize profits and lower the operating costs, the quicker is the recovery of the investments, and that will change in the operating mode in: "WORKING SMARTER NOT HARDER".

1. Introduction

The purpose of any company and, implicitly, those in the wood industry is to obtain the maximum profit. For this, special attention is paid to any efficient management, to find the methods of streamlining the consumption of raw materials, energy, materials, production times etc. and to optimize the production flow in order to increase the quality and finishing degree of the finished products. These methods need to be as cheap and easy to implement as possible, and at the same time to deliver the fastest results from implementation both in quantitative and qualitative terms [12].

These aspects have been analyzed in practice at a national company to improve their production. This company has a long history and tradition in this domain. It was founded in 1948 from a carpenter's shop and later developed into a furniture factory with an annual capacity of over 10 million euro. That is why the applied methods can be studied very well and the results can be seen very quickly. At present, this factory is one of the most important furniture manufacturing companies in Eastern Europe, producing furniture but also other items (such as solid wood laminated panels) which are mainly intended for foreign and domestic markets, keeping a specific character given by the well-selected raw material.[1]
The method used was Six Sigma. This is a management technique that aims to improve business processes to create and deliver almost perfect products and services. This measures how many flaws exist in a process and then determines in a systematic way how to improve this business activity [2].

This method quantifies the value of a variable (or more) that shows the distribution of an output characteristic from a process. A higher value for the Sigma index indicates a more stable process (less risk for wastes, lower costs). As mentioned earlier, the symbol for this indicator is σ, the Greek letter used in statistics to represent the standard deviation [11].

The easier it is to maximize profits, the easier it is also to lower the operating costs and to achieve asignificant recovery of investments, which will result in a change in the operating mode: "working smarter not harder".

In the analyzed case, a trend was observed for the Nordic customers towards massive wood furniture and towards processing and finishing steps that are as natural as possible, without paints, varnishes or mordant. They were offered massive furniture made from oak, finished with oiled lacquer (Trendsetter model furniture).

In this case, despite the fact that the production of this assortment requires fewer processing operations but with a more detailed visible finish and which involves a decrease in energy consumption and materials, the price remains high, being set according to demand and supply. It is kept at the same level as the rest of the solid wood furniture, and the difference between the cost of production and the retail price being higher, it will lead to greater profitability and higher profit [10].

2. Research methodology
For the application of this method, or rather, before applying this method, in order to have a maximum quantifiable result and at the same time to implement this method, well designed steps should be prepared and completed according to the 6 Sigma methodology.[4] The projects and tools used have to follow a series of well-established steps that ensure the correct prioritization of the projects, a very detailed analysis based on statistical methods of the processes, determination of the profound implications and causes for correct taking of the decisions regarding the activities to be carried out based on a clear and verifiable data, with the purpose of achieving advanced retrofitting[4].

Principally retrofitting describes the measures taken in the manufacturing industry (wood industry too) to allow new or updated parts to be fitted to old or outdated assemblies Modifying existing equipment or structures with additional or new components or units. That’s why retrofitting can improve a machine or system’s overall functionality by using advanced and updated equipment and technology—such as integrating Human Machine Interfaces into older factories (define retrofitting).

These steps are defined under the acronym name of DMAIC (both in Romanian and English), which means: Definition, Measurement, Analysis, Improvement and Control [3].

2.1. Define
By reducing consumption and defects, improving the quality and lifecycle of the finished products and increasing the customer satisfaction, there can be achieved an increase of the profit that also leads to an increase in employee satisfaction. That is why in this analysis a problem is to define the energy consumption and high costs during the manufacturing process.

2.2. The measurement
The measurement process aims to determine current performances / present capabilities and to quantify the problem that is presented in this article, through the Six Sigma study, in order to identify at various stages the essential factors of internal processes that can influence the CTQ policy. These must be measured in order to determine their impact on defects resulting from those processes. In the analysis, the following factors were taken into account: - Energy Consumption
Only from the use of the drying chambers (Sececa 4chambers/4motors/5,5kwh per motor, Gann1chambers/6motors/3kwh per motor, HB 1chambers/6motors/3kwh per motor, Muhlbock 11chambers/3motors/3kwh per motor) it result a consumption of 223kwh.

Effective Waste Utilization (recycling). During the manufacturing process from the log to the finished furniture it result a lot of wood waste that can be quantified as losses of the production processes. In the wood industry the most losses are registered in transforming tree logs into timbers and further more into wood panels. That’s why, through the utilization of the 6 Sigma, we try to identify the processes with the highest waste results, quantify the losses and find solutions for transforming this losses (waste) into benefits and winnings. The table below present data of the total waste amount produced in the production processes and the reusing of this losses into packaging processes, reusing in other parts of the furniture production but most of it in the use for producing thermic energy in the boiler room.

**Table 1.** Efficient reutilization of wood waste in drying equipment’s

| Drying capacity per shift | 650 mc (function of the wood’s thickness, humidity, essence) |
|--------------------------|----------------------------------------------------------|
| Yearly amount of wood dried | 5000 mc |
| Losses | oak | 70% | 5000 mc | 10 mc | 3 mc wood |
| | beech | 66% | 5000 mc | 10 mc | 4.4 mc wood |
| of | 70% losses | 8% | packaging |
| | | 58% | boiler heating |
| | | 4% | processing defects |
Table 2. Wood waste

| Current number | Month | Furniture 1 | Furniture 2 | Furniture 3 | Total |
|----------------|-------|-------------|-------------|-------------|-------|
| 1.             | January | 0.615       | 60.950      | 0.510       | 62.075|
| 2.             | February| 0.494       | 58.156      | 0.579       | 59.229|
| 3.             | March  | 0.571       | 72.927      | 0.433       | 73.931|
| 4.             | April  | 0.539       | 63.725      | 0.352       | 64.616|
| 5.             | May    | 0.436       | 67.324      | 0.401       | 68.161|
| 6.             | June   | 0.415       | 47.755      | 0.265       | 48.435|
| 7.             | July   | 0.000       | 0.000       | 0.000       | 0.000 |
| 8.             | August | 0.439       | 66.691      | 0.260       | 67.390|
| 9.             | September | 0.669 | 64.103      | 0.213       | 64.985|
| 10.            | October| 0.568       | 76.792      | 0.232       | 77.592|
| 11.            | November| 0.583     | 69.119      | 0.259       | 69.961|
| 12.            | December| 0.395      | 43.881      | 0.185       | 44.461|
|                 | Total   | 5.724       | 691.423     | 3.689       | 700.836|

The deliverable from this step in this analysis was the cost of energy produced from the wood waste trough boiler room.

2.3. Analysis

This step included an analysis of the energy consumption (because every king of energy, even if it is electric power or thermal energy or gas consumption it is energy and can be quantified as such Kwh or kW) used in the production unit. Through the 6Sigma method we searched for the arguments as well as the economic resources (profitability) for the investment decision to change the reusing method in order to decrease those consumptions and costs through retrofitting.

Table 3. Typos of drying equipment with different consumption and capacities

| Curr. no | Drying equipment | Consumption kCal/h | No. of hours of functioning | No. of days/year | Gcal | MW |
|----------|------------------|--------------------|-----------------------------|------------------|------|----|
| 1        | SECCEA           | 1120000            | 24                          | 300              | 80640000 | 9378432 |
| 2        | GANN             | 200000             | 24                          | 300              | 14400000 | 1674720 |
| 3        | HB               | 300000             | 24                          | 300              | 21600000 | 2512080 |
| 4        | MUHLBACH         | 900000             | 24                          | 300              | 64800000 | 7536240 |
| TOTAL    |                  | 2520000            |                             |                  | 18144000000 | 21101472 |

Starting from the worst case scenario that the consumption will be the same in the next year (even if it is foresight that it will increase or the amount of quantity or the price) we have:
- an electric consumption of 4128228 KWh and a cost of 1353050 Ron (result a cost of 0.33 Ron/KWh);
- an gas consumption of 886531.91 KWh and a cost of 182520.97 Ron (result a cost of 0.21 Ron/KWh);
- an energy consumption result from reusing the wood waste of 4128228 KWh and a cost of 1353050 Ron (result a cost of 0.33 Ron/KWh);
- and a resulting price of 0.18 Ron/KWh for energy self-produced from wood waste.

Table 4. Waste Consumption

| Source          | Quantity (t) | Price (Ron/t) | Cost (Ron) | Cost for Energy (Ron/KWh) |
|-----------------|--------------|---------------|------------|--------------------------|
| self production | 701          | 400           | 280.400    |                          |
| acquisition     | 42           | 700           | 29.400     |                          |
| TOTAL           | 743          | 309.800       |            | 0.18                     |

From the analysis of the data and the calculation of energy consumption vs prices on the different energy sources facing the most consumed energy in the production process of the wood industry its more efficient to produce electric energy instead of thermal energy (because it’s the most used energy),
but this depends on different factors: installed equipment’s, capacities, consumptions, waste amount, prices for raw materials, energy and gas.

That’s why in this analysis process, there were identified the most important causes for high energy consumption [9]. The analysis tried also to identify the causes of this consumption by identifying the key variables. But due to the limitation of the length of the article they are presented in detail only at the end of the article together with the conclusions.

2.4. Improve

In the next stage of the 6 Sigma method, it was analysed which of the causes for consumption can be eliminated. These key variables need to be quantifiable themselves and also their effects needed to be measured on behalf of CTQ policy.

In the production flow, the maximum acceptable limits of the key variables were identified and they were validated in a system of measuring the variables’ deviations (G). The duty and involvement of the management is crucial because they have to find the best ways to improve the technological flow, because once the limits were determined and they were implemented in the production process changes, they must be kept below the maximum limits [4].

In this phase we analysed:

- The cost of energy efficiency (it is the calculation of the amount of economy if the company is switching from different energy sources into electric energy produced trough reusing the waste resulting from the wood production);

| Table 5. Quantity and cost efficiency for energy consumption by self-produced energy from reutilisation of wood waste |
|---------------------------------------------------------------|
| Retrofit equipment to consume only | Existing equipment that consume different type of energy |
| Waste produce | Power consumption | Gas consumption | Total |
| energy equipment | Power consumption | Gas consumption | Total |
| 21101472 | 0.14 | 2954206 | 21101472 | 0.14 | 2954206 |
| 4128228 | 0.14 | 577952 | vs | 4128228 | 0.33 | 1362315 |
| 883712 | 0.14 | 123720 | vs | 883712 | 0.21 | 185579 |
| 3655877.6 | vs | 4502100.7 | |

- From the calculation above (Table 4) it result an economy of 846223.1 Ron/year;
- The quality of the products obtained;
- The possibility of increasing the production capacity, for the purpose of export and the anticipation of the increase of the turnover resulting from the capitalization of the production;
- Improving the workforce and its cost.

2.5. Control

| Table 6. Efficiency result by advanced retrofitting |
|---------------------------------------------------------------|
| Indicator | Initial value Unit | Quantity | End value 2018 Unit | Quantity | End value 2019 Unit | Quantity | End value 2020 Unit | Quantity |
| Increase of turnover against the balance sheet of the year 2017 (%) | % | 24% increase over | % | increase of 22% (Fiscal value 31.12.2018 was 33193485) | % | increase of 32 % (Fiscal value 31.12.2019 was 36657274) | % | increase of 22% (Fiscal value 31.12.2020 was 33776251) |
| Number of jobs pers. | 550 | pers. | 550 | pers. | 550 | pers. | 552 |
| Export increasing (%) | % | 24% | % | 30,33 | % | 52 | % | 52 |

At the end of the 6 Sigma process, it is imperative that the identified and applied improvements continue to be maintained to not allow a regression to the initially identified problems. That is why tools are installed to ensure that key variables remain within the maximum limit over time.
In some situations, the fifth step mentioned above should be accompanied by "recognizing" the problem before "defining" it and "standardizing" and "integrating" should be the last steps in improving the process, by permanently incorporating the solution.

3. Conclusions
As a consequence of the elements discussed above, this chapter will present in the form of conclusions also the last step of the Six Sigma method, in which it was desired to identify, in agreement with the production engineers the places (machines) of high consumption and the possibility of controlling the investment plan for advanced retrofitting with the purpose to reduce the existing consumption [6]. These are:

- Merging some stages of production to remove from the production flow the classical equipment with high energy, time and raw materials consumption. These, in the current situation, perform simple operations, and by retrofitting and replacing them with CNCs, these operations are simultaneously achieved by increasing the optimization of the previously mentioned consumption [5],[7].

- focusing on the production of high added value products and by retrofitting the production lines with high-tech and specific machines (Veneer Panning Machine, Edge Panning Unit, Panels Cutting Aggregate) increases the quality of finishing of the products, minimizes the scraps and the quantity of waste [9].

- acquiring new machines similar to those already in production to increase processing capacity by maximizing productivity and eliminating tight places (stocks in the production stream) (e.g. spraying rooms).

- maximizing the efficient utilization of the waste resulted from the technological process and reduction of the footprint on the environment by acquiring an exhaust system [8] and a wood regasification plant with a generator for producing electric power in its own direction, because in the furniture production the largest share in the production cost is after the raw materials the energy costs. As it results from the calculations presented above, the price per unit of energy is the highest for the energy produced from gas and which is used predominantly for the drying stage of the wood and for the presses for gluing and the lowest price is the production on own direction by burning waste and turning it into energy and that can be used also for the same machines.

- lowering the working time, auxiliary time and increasing the labor efficiency by purchasing elevators and machines for flipping and handling wood panels.

The new technologies are the result of human creativity, innovation and technical progress and aim both at increasing product flexibility and product quality, reducing consumption and, implicitly all the costs, and increasing the quality of professional life and protecting the environment.

The easier it is to maximize the profit through the implementation of new advanced technologies, the quicker it is to lower the operating costs and the significant recovery of investments, which will result in a change of operating mode: "working smarter not harder".

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