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A Modeling & Simulation based approach to support collaboration between SMEs operating in the furniture sector

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Abstract

The research study supports two SMEs, nearby located and operating in the furniture sector, whose goal is to start a collaboration with the intent of finding synergies in terms of costs reduction and development efforts related to the launch of new products into the market. The authors have been asked to support both companies in the design process of two bookcases by identifying their main technical features as well as defining common design guidelines of a new common bookcases production line. To this end, an approach based on the combination of Modeling & Simulation (M&S) tools, multiple design parameters and multiple performance measures is proposed. In particular, a simulation model has been used to assess the effect of different design parameters on several performance measure. The quantitative evaluation of the effects of the multiple design parameters on the multiple performance measures is achieved by using the Design of Experiments (DOE) being validated by means of the analysis of variance (ANOVA).

Keywords: Small and medium sized enterprises; Modeling & Simulation, product design, production process design, design of experiments

1. Introduction

Small and medium-sized enterprises (SMEs) today represent 90% of all businesses in the world and, in particular in high income Organization for Economic Cooperation and Development (OECD) countries, SMEs account for the vast majority of companies (99% of all firms), about 70% of employment and more than half of value added. SMEs in emerging markets (EMs) represent a little less than half of total employment and about one-third of gross domestic product (GDP) (Tannenbaum et al., 2020).

Although SMEs play a significant role in the world economy, they face many problems, including lack of finance, difficulties in exploiting technology, limited managerial skills, low productivity, regulatory constraints, aggravated in the last period from globalization, the fast evolution of technology innovation and COVID-19 pandemic, whose main impacts are as follows described.

The globalization of the economy poses a challenge to the SMEs in terms of resources and capabilities needed to monitor and take advantage of the multiple global opportunities down-stream (exports) as well as up-stream (sourcing/out-sourcing) (Sørensen, 2018). From the SMEs point of view, the enlargement of the EU and the creation of the single market can represent a problem of competitive position (Pirtea et al., 2009). Literature highlights many issues facing SMEs in the competition, and the nature of the issues varies according to the type of SMEs (Prasanna et al., 2019). SMEs have to deal with several challenges, such as limited access to capital, raw material, information technology, qualified human resources, marketing the product or services, lacked of guidance from government, exchange rate, high interest rate (Eravia et al., 2015) and even the trend in manufacturing, to increase the productivity, is a huge challenge (Johansen and Rönnbäck, 2014).

In terms of technology evolution, it can be stated that SMEs practicing innovation show growth and sustainable performance compared to others who do not use technology (Rahman et al., 2016). Even if the advantages in technological innovation are innumerable, the efforts and difficulties to be faced in this process have not to be underestimated. With the rapid changing world of internet and its impact to the SME, the fight to sustain business is more crucial than business growth and profitability (Rahman et al., 2016).

Another significant factor that has recently put a strain on SMEs is the COVID-19 pandemic crisis. In fact, this has changed almost all countries from the socio-economic point of view, causing shocks and financial tensions all over the world and in particular in some weaker and less structured SMEs companies. This impactful event has in some cases been defined as ''black swan'' (Thorgren and Williams, 2020, Tannenbaum et al., 2020), precisely because of the consequences and aspects it represented. The current crisis caused by the COVID-19 pandemic is different from others, as economic activities have been interrupted in different ways, in different geographical areas with unforeseen implications (Rapaccini et al., 2020). In general, SMEs during this period experienced significant impacts on three factors such as: money flow, supply chains and market demand. These are the main problems that in general afflict SMEs in any crisis situation (Lu et al., 2020, Hossain et al., 2022).

In this challenging context, the aim of this paper is to supports two single-product SMEs, nearby located and operating in the furniture sector, whose goal is to start a collaboration in order to enter the market competitively. The authors have been asked to support both companies in the design process of the bookcases by identifying their main technical features as well as defining common design guidelines of a new common bookcases production line. To this end, an approach based on the combination of M&S tools, multiple design parameters, DOE and multiple performance measures is proposed. The paper is organized as follows. Section 2 presents the design and technical characteristics of the bookcases. Section 3 and section 4 respectively describe the production process and the development of the simulation model. Section 5 presents the design parameters and the performance measure definition as well as the main results of the DOE. The last section reports the conclusions that summarizes the scientific and academic value of the work.

2. Bookcases design and main technical features

This section presents the design process and technical features of the two bookcases. The products differ each other for characteristics and customers' target. The first one, named later on *Bookcase A*, is a living room bookcase, while the second one, named later on *Bookcase B*, is a children's room bookcase. Let us describe first the *Bookcase A*. Following the company inputs and requirements, the authors propose an open and dynamic bookcase structure with optimized weight. The bookcase consists of five oak shelves, four feet and eleven aluminum tubes. Figure 1 depicts on the right side the CAD model and on the left side its main components.

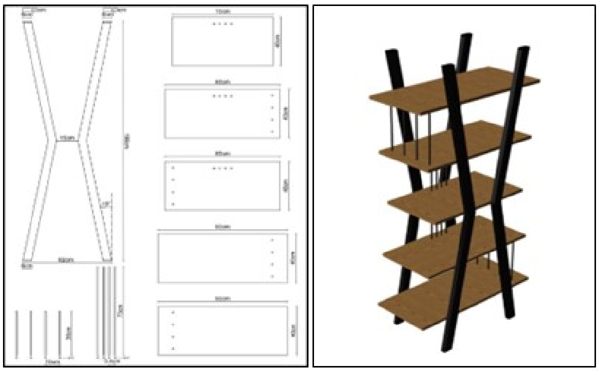

Figure 1. Bookcase A cad model and main components dimensions

Shelves design is based on different shapes and dimensions in order to ensure overall weight optimization and higher dynamism of the structure. The shelves are placed 350 mm distant each other, each of them has a thickness of 20 mm. The aluminium tubes require rubber caps at the extremity as protection material and 5 brackets for each foot are used to fix each shelf to the structure through the use of standard wood screws.

Let us now present *Bookcase B*. First of all, it was decided to have a children's bookcase whose panels are made out mainly of silver fir, so that in the future both companies can take advantages from scale economies in the selection of raw material suppliers. Indeed, oak panel, in the case of *Bookcase A*, and silver fir panel, in the case of *Bookcase B*, can definitely be supplied by the same supplier. Moreover, Bookcase B, based on company requirements, needs to be modern, light and usable both horizontally and vertically. Figure 2 shows the children's bookcase CAD model. It consists of 6 single cubic structures assembled each other to reach an overall height of 1300 mm, a length of 900 mm and a depth of 350 mm. Figure 2 shows the cubic structures position within the *Bookcase B*.

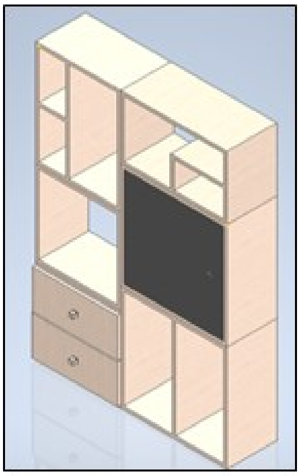

Figure 2. Bookcase B cad model

3. Production process

This section briefly describes the production process of each bookcase. Let us present first the production process of *Bookcase A*. The following macro-operations have been identified.

- *Macro-operation 1A* (*oak panel manufacture*) consists of the following production steps:
  1. *Step 1A.1*: shelves cut based on the designed dimensions starting from a raw material oak panel.
  2. *Step 1A.2*: shelves planning to reach the design thickness of 20 mm.
  3. *Step 1A.3*: shelves sanding to prepare them for the next drilling operation.
  4. *Step 1A.4*: shelves drilling in order to make the holes necessary for the future assembly.
  5. *Step 1A.5*: shelves painting and drying by means of a panting/drying cabin.

- *Macro-operation 2A* (*aluminium tubes manufacture and assembly*) consists of the following production steps:

  1. *Step 2A.1*: aluminium tubes cut based on the designed dimensions.
  2. *Step 2A.2*: aluminium tubes bending operation to reach the X shape as shown in figure 1.
  3. *Step 2A.3*: aluminium brackets welding to the tubes.
  4. *Step 2A.4*: aluminium tubes painting and drying by means of a painting/drying cabin.
  5. *Step 2A.5*: assembly of the welded fit in aluminium by inserting two tube caps.

- *Macro-operation 3A* (*components packaging*) consists of the following production steps:
  1. *Step 3A.1*: preparation of packaging set 1 which includes the 5 oak shelves and the wood screws to fix them to the bookcase aluminium structure and decorative aluminium tubes.
  2. *Step 3A.2*: preparation of packaging set 2 which includes the bookcase feet (4 pieces) and the pivot being used for positioning the decorative aluminium tubes between the shelves as shown in figure 1.

As concerns *Bookcase B* production process, following macro-operations can be defined:

- *Macro-operation 1B* (*silver fir panel manufacture*) consists of the following production steps:
  1. *Step 1B.1*: silver fir panels cut based on the designed dimensions starting from a silver fir panel.
  2. *Step 1B.2*: silver fir panels drilling to make the holes for the assembly of the cubes.
  3. *Step 1B.3*: silver fir panels milling in order to create the carvings which host the drawers' guides.
  4. *Step 1B.4*: silver fir panels sanding in order to eliminate the defects which may come by the execution of step 2B.2 and step 2B.3.
  5. *Step 1B.5*: silver fir panels painting and drying by means of a panting/drying cabin.

- *Macro-operation 2B* (*cubic structures sub-assembly*) consists of the following production steps:
  1. *Step 2B.1*: assembly of the 2 drawers by gluing the pre-worked panels.
  2. *Step 2B.2*: assembly of the cubic structure that hosts the drawers by drilling and inserting the spines.
  3. *Step 2B.3*: assembly of the cubic structure with a silver fir door by means of outsourced hinge;
  4. *Step 2B.4*: assembly of the knobs and sliding guides to the drawers by screwing.
  5. *Step 2B.5*: assembly of the knobs to the doors by screwing.

- *Macro-operation 3B* (*components packaging*) consists of the following production steps:
  1. *Step 3B.1*: preparation of packaging set 1 which *includes* left bottom cubic structure (see figure 2), middle right cubic structure (see figure 2), fir panels, screws, and spines.

4. Simulation model

This section presents the simulation model being developed to recreate, with satisfactory accuracy, the evolution over the time of the two bookcases production process. The simulation model has been developed by means of the discrete event simulation software *Tecnomatix Plant Simulation* (further information on Plant Simulation can be found at https://www.dex.siemens.com/plm/tecnomatix/plant-simulation). Three different simulation frames representing respectively manufacturing, assembly and packaging workplaces have been created. Here below a brief description on the development of each simulation frame is reported:

- *Manufacturing simulation frame*: *STATIONS* and *PARALLELSTATIONS* have been selected from Plant Simulation Toolbox in order to reproduce single machines and parallel machines. As no empirical data were available, *PROCESSINGTIME* has been set for each station by using triangular statistics distribution. The workstations were also equipped with Workplace objects which give the possibility to reproduce the operations carried out by workers. Line 1 uses *PARALLELSTATION* to model the band saw machine, a *SINGLE STATION* to represent the roller bender, *ASSEMBLY STATION* object to reproduce the welding machine and a *COATING STATION* to replicate the coating cabin. Line 2 uses *PARALLELSTATIONS* to model the band saw machine and the sander, and *SINGLE STATION* to reproduce the milling machine and the drilling machine. Finally, Line 3 uses *PARALLELSTATION* to represent the band saw machine and the sander, and *SINGLE STATION* objects to represent the planer and drilling machine. 1 *PARALLELSTATIONS* have been used to reproduce the coating cabin shared by Line 2 and Line 3.
- *Assembly simulation frame*: manual assembly workstations have been modeled by pairing *ASSEMBLYSTATIONS* and *WORKPLACE* objects. Triangular distributions have been used to reproduce the assembly times and a *SOURCE* object has been added to represent the entry of raw materials, being used to properly complete the assembly operations, into the plant.
- *Packaging simulation frame*: *ASSEMBLYSTATION* and *WORKPLACE* objects are paired to model the packaging operations, triangular distribution have been used to represent the packaging process times, and a source object is used to reproduce raw material being used to complete the packaging activities.

An example of a 2D simulation model of the manufacturing workplace is reported in Figure 3.

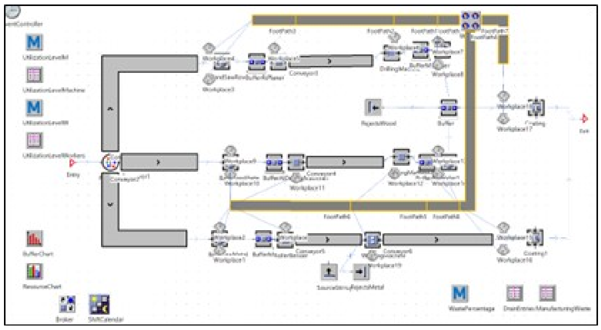

Figure 3. 2D simulation model of Manufacturing workplace

5. Design parameters, performance measures and simulation results

One of the main goals of the paper is to define design guidelines of a two-companies common bookcases production line aiming at costs and initial investment optimization. The guidelines definition is supported by 2D simulation model that recreates the bookcases production processes in a simulation environment. In particular, the simulation model has been used to assess the effect of different design parameters on several performance measure. The quantitative evaluation of the effects of the multiple design parameters on the multiple performance measures is achieved by using the DOE being validated by means of ANOVA. Such evaluation allows to define the production line design guidelines. Section 5.1 presents the design parameters while section 5.2 describes the performance measures as well as simulation results.

5.1. Design parameters definition

A preliminary analysis for detecting the design parameters (named also factors) that could have an impact to the production line design has been carried out. The analysis shows that workers number and efficiency as well as machines number and stock management level could be significant factors in terms of costs and initial investment optimization. 2 levels for each factor have been identified; the factors level combination generates 16 scenarios to be tested by using the simulation model. Three simulation runs for each scenario has been simulated resulting in a total number of 48 trials. Table 1 reports the selected factors and the levels assigned to each of them.

Table 1. Design parameters.

FACTOR	MIN LEVEL	MAX LEVEL
Number of workers	58	74
Worker efficiency	85%	95%
Number of machines:	33	39
Stock management level (units)	15600	24000

5.2. Performance measures definition and simulation results

The definition of design guidelines is based on the assessment of multiple performance measures. The performance measures are 1) the flow time (FLLI), 2) the machines utilization level (MUL) and 3) the worker utilization level (WUL). In particular, the authors use the simulation model in order to assess the impact of the design factors (described in section 5.1) to the aforementioned performance measures. Each scenario, defined as outcome of a well-planned DOE, has been simulated and the simulation results have been assessed by using the Minitab software. As follow the simulation results for each performance measure are reported:

1) *FLLI performance measure*: following analysis can be considered valid for both bookcases. Higher number of workers as well as higher workers efficiency level decrease FLLI value, while FLLI drastically increases in case of a higher number of machines (related to the manufacturing workplace). Even if those results may seem contradictory, those can be easily explained. Higher number of workers definitely bring to a FLLI reduction due to the presence of additional resources which can in parallel perform the assembly and packaging operations. A higher number of machines even if reduces FLLI in the manufacturing workplace, at the same time, leads to a much higher FLLI in the assembly and packaging workplace. In fact, since those workplaces are mainly characterized by manual activities, a higher input in terms of subcomponents to be assembled and packed doesn't not bring to higher output since the process time cannot be reduced by keeping fixed the number of workers. Finally, as concern the inventory level, an increase of this factor brings to a slightly increase of FLLI.
2) *MUL performance measure*: let us describe the simulation results related to the manufacturing workplace since it is the one with the highest number of machines. While an increase of the workers number has no impact to the MUL, higher inventory levels bring to higher values of this performance measure. Indeed, keeping to the minimum the number of machines and setting to the maximum the inventory level determines a reduction of the machine idle times and therefore bring to higher MUL.
3) *WUL performance measure*: let us describe the simulation results related to the packaging workplace since it is the one with the highest presence of manual operations. In this workplace, it can be easily understood that the machines number has no impact to the WUL, since no machines are used to carry out the packaging operations. An increase of the stock level brings to a higher WUL, while an increase of workers efficiency leads to a WUL reduction, since more efficient workers can simply perform better. Finally, an increase of the workers number slight increases the WUL; this result may appear contradictory, however can be easily explained as follows: the additional workers are distributed in the 3 workplaces, the assembly workplace is the one getting more workforce and therefore the number of assembled components per shift increases drastically; the higher number of the assembled components given as input to the packaging workplace causes a higher workload in this latter workplace that, even with an higher number of workers, cannot be fulfilled.

Figure 4 and figure 5 report simulation results for the *Bookcase A* flow time (similar graphs are also available for the other performance measures, including the ones related to *Bookcase B*).

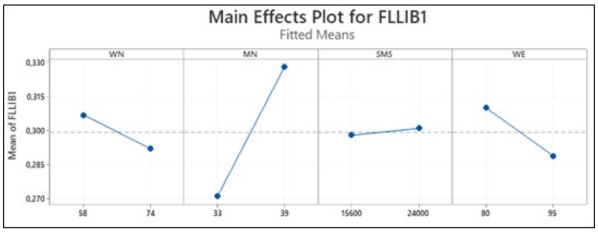

Figure 4. Main effects plot living-room bookcase

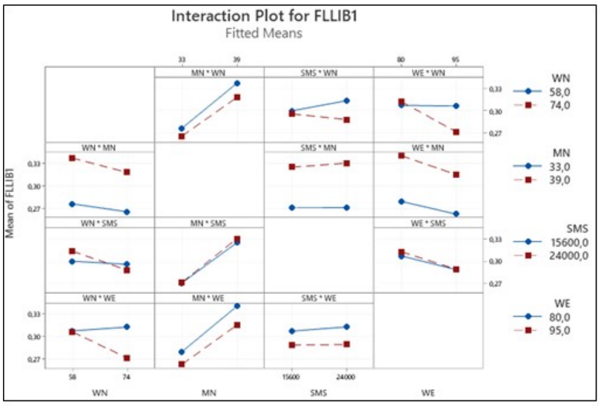

Figure 5. Interaction plot living-room bookcase

The last section of this paragraph reports the outcome of ANOVA, that has been used to validate the simulation results. The analysis of variance has been carried out for all the performance measures and it has confirmed the reliability and validity of the research study. As an example, figure 6 shows the residual plot graphs for the *Bookcase A* FLLI in the packaging workplace.

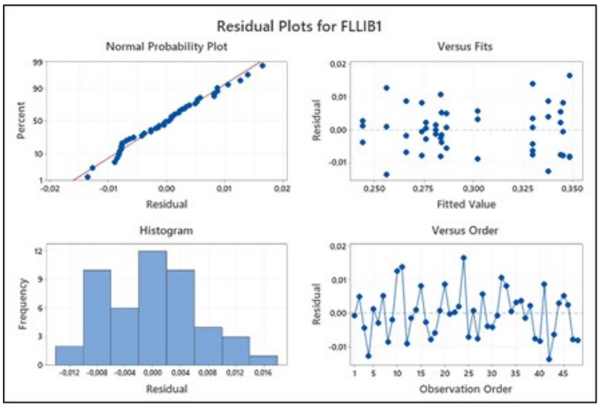

Figure 6. Residual plot for bookcase A flow time

6. Conclusions

The research work aims at supporting two SMEs, operating in the furniture sector, whose main goal is to start a collaboration to enter the market competitively. As first step, a common approach for a common design and definition of companies' products has been adopted with the aim of finding synergies in terms of costs and design efforts. Once the products have been defined, next step was to define the guideline to proper design a common production line aiming at optimizing costs and initial investment. To this end, several design parameters and performance measures have been identified and M&S has been used as support tool for the design guidelines definition. In particular a simulation model has been used to assess the effect of different design parameters on several performance measure. The quantitative evaluation of the effects of the multiple design parameters on the multiple performance measures is achieved by using the DOE being validated by means of the ANOVA. Final simulation results show that an increase of the automation level of the production line doesn't lead to more efficiency and generate only additional initial investment for the companies. Since the production process is mainly characterized by high presence of manual operations, both companies should invest in manpower by increasing the number of operators to be hired and paying attention to properly assign the right workforce to the workplaces. It has been showed that an increase of workers in the assembly workplace higher than the one in the packaging workplace doesn't bring to a flow time reduction and at the same time reduce the workers utilization rate. As concern stock management level, higher values of this performance measure guarantee higher productivity and improved workers utilization rate. Finally, both companies should deeply invest on workers training and development; workers efficiency has strong benefit on overall performance measures due to the high presence of manual operations characterizing the production process. Further research studies are still on going with the aim of finding potential collaborations synergies between companies operating in different sectors.

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