A proposed integrated manufacturing system of a workshop producing brass accessories in the context of industry 4.0

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Abstract

Industry 4.0 is the basis for the transformation of manufacturing companies into digital enterprises. It promises more flexibility in manufacturing, as well as mass customization, better quality and enhanced productivity. As a result, it empowers companies to meet the challenges of smart manufacturing of increasingly individualized products with shorter time-to-market and improved quality. Smart manufacturing has an important part in Industry 4.0. In fulfillment of a need for empirical exploitation, this contribution aims to characterize and analyze a smart manufacturing process of a company specialized in the production of brass accessories, namely the spherical bushels. Basically, we set up a simulation tool to develop a numerical production platform for Industry 4.0 which efficiently operates and manages the production, procurement: through the Material Requirement Planning (MRP, Master Production Program) method, the logistics warehouse and the Cyber-Physical Production System (CPPS). The findings have been optimized by a new redesigned approach of MRP 2: it is the load-capacity adjustment for the manufacturing planning of a smart workshop and Industry 4.0. Indeed, it is a process of setting up an integrated manufacturing system, which has allowed us to reduce the assembly time of the spherical bushels and to control the production and the assembling process. It allows us to increase the equipment utilization rate by comparing it with the company's equipment before the switch to smart manufacturing. In addition, the optimized results show that the proposed model can significantly increase the production efficiency and practical application in Industry 4.0. To the best of our knowledge, this is a first work addressing the implementation of a simulation platform controlled by a dedicated Cyber-Physical Production System (CPPS) and a Master Production Program. A case study for a company manufacturing brass accessories is presented in this paper. The developed simulation platform present a basis for a future digital twin of the company.

Introduction

Industry 4.0 and the associated digital transformation, referring to the advent of new digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Cloud computing, Cyber-Physical Production Systems (CPPS), Big Data and Analytics. These technologies imply a profound change in processes and activities, skills and business models (Gimléc, 2014). The emergence of these technologies generates a multiplicity of challenges and opportunities for manufacturers and notably disrupts the organizational ecosystem through the development of automation and the arrival of smart factories (Hecklau et al., 2016). Modern businesses have never experienced such speed in terms of technological change. The scope, impact and speed of transformation are emerging as the original drivers of the "Industrial Revolution 4.0". Although, functional and emerging technological innovations are often referred to as disruptive. It seems important to highlight the contextual and chronological elements in order to characterize the constitutive foundations of Industry 4.0 in Fig.1.

In addition, smart manufacturing allows companies to achieve customized products while sustaining low costs and reducing their time-to-market if they want to remain competitive in a globalized world (Schuh et al., 2017; Carvajal Soto et al., 2019). Indeed, A. Kusiak (1990) affirm that Smart Manufacturing is a wide concept of manufacturing with the goal of optimizing production and product transactions by maximizing the use of advanced information and manufacturing technologies. It is seen as a new manufacturing model based on smart science and advanced technologies that significantly enhance the design, production, management, and integration of the entire life cycle of a typical product (A. Kusiak, 1990). The entire product lifecycle can be made easier with the help of various smart sensors, adaptive decision-making models, advanced materials, smart machines and data analytics (B. Li et al., 2017). This will allow manufacturing companies to improve their production efficiency, product quality and service levels (J. Davis et al., 2012). In fact, the competitiveness of a manufacturing company can be strengthened by its ability to deal with the dynamics and fluctuations of the global market. This situation poses tremendous challenges for manufacturers as they seek to implement new technologies to achieve their goals while expecting a return on investment (J. Cadavid et al., 2020). In fact, the Intelligent Manufacturing System (IMS); allows to meet the challenges of manufacturers; which is considered as a new generation manufacturing system obtained by adopting new models, new forms and new methods to turn the traditional manufacturing system into an intelligent one. In 4.0 era, an IMS uses a Service-Oriented Architecture (SOA) via the Internet to deliver collaborative, customized, flexible and reconfigurable services to end users, enabling a highly integrated Man-Machine Manufacturing System (A.B. Feeney et al., 2015). This high level of human-machine cooperation aims at setting up an eco-system of the different manufacturing elements involved in the Intelligent Manufacturing System (IMS), in a way that the organizational, managerial and technical echelons can be seamlessly combined.

Thus, several countries have developed projects that aim to help manufacturers adapt their industries to new production technologies. In 2011, the German government proposes an Industry 4.0 strategy, which integrated new digital technologies to build a digital Industry 4.0 system (HF Binner VDI and REFA 2014). Several researchers and famous companies like SIEMENS have formed development teams, trying to create a sophisticated and perpetual industrial system (C. Zhiwen, 2014). Among the 4.0 industrial projects, we mention the project of Professor D. Zuehlke who has set up a business strategy for a smart and automated plant. It took as its stakeholders: production of intelligent products, remote control, wireless delivery, radio frequency identification, Bluetooth connection, tablets and other technologies; mentioning that this is the first transformation model in the 4.0 era (D. Zuehlke, 2014). In another way, the doctor Ruth; !manager of industrial activities in SIEMENS maintains that the first thing of industry 4.0 is the incorporation of the network of production inter-firms. In second place, virtual reality (the models of simulation / to take back real behavior numerically) and in third place is cyber-physics. Also in 2015, China offered a plan called: the made in China of 2025 intended to stimulate energy and innovation. It is about a Chinese version of industry 4.0 (W. MIAO, 2015; Wang et al. 2018). This has conducted to significant financial support for manufacturing research; for example, in the European Union, about 7 billion euros will be invested by 2020 in factories of the future (A. Kusiak, 2017).

Moreover, Lee and his colleagues (2015) analyzed the innovation of service of industry 4.0 and huge databases. In fact, they explained relation between the creativity of service and industry 4.0 from the flux of information of the lines of production of the predictions of the state of equipment, industrial model and other aspects (J. Lee et al., 2015). Luthra (2018) established a questionnaire of 96 questions to discover challenges and opportunities of India in industry 4.0 (S. Luthra and K. Mangla, 2018). ZHANG (2014) mentions two significations of the industry 4.0 namely: intelligentization and greenization; other one is the incorporation of network and CPS in the productive lines. It provided examples of Chinese firms facing challenges of industry 4.0 (S. ZHANG, 2014).

In the era of Industry 4.0, the advanced platforms for communication, computing, and control systems are integrated into cyber-physical systems (CPS) that incorporate a network of multiple production systems. CPS provides us with a new paradigm of smart factory, known as cyber manufacturing. Additionally, conventional smart manufacturing has relied on traditional data-driven decision-making methods in order to perform better in the manufacturing process, such as statistical process control of individual manufacturing systems. In fact, the smart manufacturing also called cyber manufacturing, which is handled by a CPS that constitutes a physical entity. The cyber-physical systems are also known as a digital twin (Kendrik et al., 2020).

Otherwise, Cyber physic systems (CPS) can be further developed for managing Big Data and maintaining the interconnectivity of machines to reach the goal of intelligent, resilient and self-adaptable machines (Krogh. BH, 2015). Furthermore, by integrating a cyber-physic system with production, logistics and services in the current industrial practices, it would transform today's factories into an Industry 4.0 factory with significant economic potential (Lee. J et al., 2013). For that, Kang and his colleagues set up challenges of modeling and analysis in cyber-physical production; which is a review from a machine learning and computation perspective (S. Kang et al., 2021).

Modern companies are implementing cyber-physical production systems to meet fluctuating production demands. Indeed, we talk about an intelligent manufacturing system that is developed during the past decades and nowadays gaining further momentum thanks to the potential brought by the Industry 4.0 vision. Therefore, we cite the study of A. Barari (2021) who makes an editorial of a short historical and future perspective on Intelligent and Smart Manufacturing Systems, underlining its main characteristics (A. Barari et al., 2021).

Practically, G. Li-xiong a simulated model of motorcycle coating product line based on FlexSim (G. Li-xiong et al., 2014). Moreover, he has proposed a simulation platform for automobile mixed assembly line in the context of industry 4.0 based on FlexSim software, which is controlled by a cyber-physical production system (G. Li-xiong et al., 2019). In our paper, we proposed a simulation platform for a brass accessories production workshop controlled by a cyber-physical production system and based on FlexSim.

Nowadays, modern manufacturing industries have to incorporate an integrated manufacturing environment. To achieve truly this, the integration of Material Requirements Planning (MRP) is essential to fulfil the demand of industry 4.0. To develop a window-based application that helps the manufacturing industry to reach the best procurement practices and support the operation of the optimal total cost procurement activity in the right conditions. Due to the customized production, shorter product life cycle and frequent process reengineering gives a rapid response to changing requirements, reduction in both time and cost of the product realization process (G. Polssl, 1995). Materials Requirements Planning (MRP) philosophy is still employed by the majority of manufacturing enterprises for production planning (J. Orlicky, 1975). MRP has been an effective way to consider the relationships between end items and the various components and subassemblies. MRP systems determine the quantity of each material that will be used in the production of a mandated volume of finished goods. In fact, when each of these materials must be purchased or manufactured to meet the prescribed due dates for the finished goods. MRP systems are highly detailed and an excellent means for determining and tracking materials requirements through a master production program. As a means for production scheduling, MRP systems leave a good deal to be desired. In fact, MRP is generally considered as the main part of the production planning system. It defines the batch size and start time of all intermediate products or even supply to guarantee the execution of the master production schedule.

MRP only provides the means to make broad scheduling decisions: it does not encompass short term scheduling decisions like machine loading and operations sequencing. Once the MRP has set due dates for each period, it is the responsibility of the shop floor scheduling system to fulfill these deadlines. This is a critical activity because the workstation load's changes over time. There may be unexpected events such as machine breakdowns, shortage of raw materials, scrap and rework, which result in the actual lead-time differing from the planned lead time. The research on MRP is one of the current points in the industrial field or even in the production and supply operations. Bogataj and Bogataj (2019) offered a review of 50 years of research achievements on MRP theory and discussed some possible directions in Industry 4.0. It has been used extensively in companies to get the right components to the right customers at the right time (C. Oztürk and A.M. Ornek, 2010).

However, the method of Material Requirement Planning (MRP) is not an optimization technique.

In the aim of this paper, our simulation platform is controlled by a cyber-physical production system and by a master production program; a kind of MRP. The results of this platform are optimized using the load-capacity method of MRP2. Indeed, it is a first contribution that couples a cyber-physical production system with a production scheduling method in the context of industry 4.0.

The rest of this article is organized as follows. In Section 2, we propose the conceptual context; which we aim at introducing an approach of modeling and optimization of a workshop of brass' accessories production. In Section 3, we propose the frame and characteristics of the lines of production and mixed assembly in Industry 4.0. Then, we introduce the detailed design flowchart of our proposed method in Section 4. In Section 5, the simulation platform for the production and mixed assembly workshop for smart factory is presented.. In section 6, we present an adjustment load-capacity method for platform optimization. Moreover, we present our findings and discussions in section 7. Finally, conclusions and future works are given in Section 8.

Production's Workshop: Lines And Mixed Assembly Line Of Products

Conceptual context

Across this paper, we aim to introduce a modeling and optimization approach of a brass accessories production workshop for a manufacturing company, moving to a digital transformation by adopting new digital technologies. For that, it appears critical to insert one prism of analysis; who allows us to identify levels of transformation; or even the characteristics of technologies 4.0 establishing in such manufacturing company.

Framework and characteristics of mixed production and assembly lines in Industry 4.0

With Industry 4.0, it has become possible to implement intelligent products that perfectly meet customer requirements. For this, it was necessary to have an efficient Manufacturing Execution System (MES) that meets the requirements of Industry 4.0. Such a mixed product production and assembly line system; also known as the mixed assembly line; which is quite flexible. The mode of operation and function is almost the same in the mixed assembly line when different products (manufactured on site or purchased) assembled continuously. This mode is widely applied for several types of products. The obvious difference between such a mixed assembly line in Industry 4.0 and another traditional line; is that the first is a highly automated system through MES and under control of the CPS computer.

For our case study, the CPS's mission is to control such an assembly process: it is about transmitting and processing information. Among the fundamental characteristics of a CPS are automation and interconnection of equipment, machine configuration and intelligent process. Fig.2 illustrates the framework.

Our objective in this paper is to set up a simulation platform controlled by a Cyber-Physical Production System and a Master Production Program (Algorithm 1) for a brass accessories production and assembly workshop. The developed simulation platform provides a basis for a future digital twin of the company.

The results of the simulation platform, and especially those of the Master Production Schedule, have been optimized by a new redesigned approach to MRP 2 (Algorithm 2). Fig. 3 presents a global view of our contribution. Algorithms 1 and 2 present respectively the production planning/Material Requirement Planning (MRP) and the Master Production Program optimization through the load-capacity adjustment method.

Proposed method

This study concerns a real case of a mechanical company producing brass accessories. This company has started a digital transformation project to be hyper-connected and digital. For this reason, our study consists of creating a simulation platform; in the context of Industry 4.0; of their production and assembly workshop for spherical bushels (type A: BS ¾ "FF and type B: BS ½ " MM) which is controlled by a CPS computer and a manufacturing execution system (MES). This company has a work rate of 8 hours per day, which there are 12 operators per team.

In this paper, our work will take place in two parts as follows:

- Modeling and simulation of the production and assembly workshop of spherical bushels: building of a workshop simulation platform for which the production and supply are handled by a master production program (MRP) and managed by a CPS
- Optimization of the platform through a restyled approach to production planning for smart workshop and industry 4.0: the load-capacity adjustment method (MRP2)

Fig.4 below illustrates the flowchart of the proposed method in this paper.

Simulation platform for production and mixed assembly workshop in Industry 4.0

The simulation platform is dedicated for a workshop for the production of accessories and their assembly; which is undergoing to transformation 4.0. In fact, spherical bushels are composed of accessories manufactured and those purchased. Moreover, spherical bushels are divided into several modules to produce and assemble intelligently manufactured and purchased accessories. It should be mentioned that the products produced in the workshop are personalized and controlled by CPS; from the raw material to the assembly unit. While the master production program (MRP) supervises the supply of other products, it is integrated into the simulation platform via code.

Thus, the CPS and the master production program allows us to manage intelligently the production. Fig.5 below shows the model of the mixed production and assembly shop for spherical bushels in Industry 4.0.

Production process and operating range of spherical bushels

In the production workshop, the Cyber-Physical Production System (CPPS) controls the manufacturing process of the accessories and the assembly of the bushels. The latter is the heart of intelligent production, which integrates MRP, ERP, MES and other functions, being responsible for the entire life cycle of the production process.

For our case study, the workshop made the production of two types of spherical bushels respectively type A (BS ¾” FF) and type B (BS ½ " MM). Following, Tables 1 and 2 respectively illustrate the nomenclature of both the products, as well as the operating ranges of the accessories manufactured in the workshop.

Table 1 Products' nomenclature

Product	Component	Designation	Type	Quantity
BS ¾ “ FF (type A)	Body	A1	**manufactured**	1
	Cuff	A2	**manufactured**	1
	Axis	A3	purchased	1
	Sphere	A4	purchased	1
	Butterfly	A5	purchased	1
	seal	A6	purchased	2
BS ½ “ MM (type B)	Body	B1	**manufactured**	1
	Cuff	A2	**manufactured**	1
	Axis	A3	purchased	1
	Sphere	A4	purchased	1
	Lever	B2	purchased	1
	Stand	B3	purchased	2

Table 2 Operating ranges of the accessories manufactured in the workshop

Component	Task	Work station	Observations
Body A1	Bucking	TRO1	Raw material: brass D23 mass portion of 150g
	Stamping	PRS1	
	Deburring	EBV1	After stamping, cooling time = 2 hours
	Machining	TRF1	
Cuff A2	Injection	INJ1	1 shot = 4 items 500g of brass per shot
	Deburring	EBV2	After injection, cooling time = 2 hours
	Blasting	GRN1	
	Machining	TRF3	
Body B1	Bucking	TRO2	Raw material: brass D20 mass portion of 100g
	Stamping	PRS2	
	Deburring	EBV1	After stamping, cooling time = 2 hours
	Machining	TRF2	
Assembly A	Assembly	PMO1	
Assembly B	Assembly	PMO2	

Modeling of the production workshop of spherical bushels for the FlexSim software in Industry 4.0

The entire life cycle of products in the 4.0 era is integrated into the production system. In fact, the CPS controls and personalizes any production process. The process of producing accessories and assembling bushels is a complex system; an assembly station formed by two units can complete the multiprocessing. Referring to Table 2, spherical bushels are products made up of products manufactured in the same shop and others that are purchased. For this, the simulation platform is made up of three production lines respectively for the body A1, body B1 and cuff A2 and two assembly units for the bushels (type A and B). Moreover, if we take all the processes as an object; the simulation model will be extremely complex. Therefore, the main processes are modeled in this paper.

We note that our case study supports a company that has started a digital transformation project. For this, we model the production of accessories A1, B1 and A2 by a Master Production Program (MPP) of the MRP approach. In the context of 4.0, production planning requires a certain amount of data for its implementation. These are essential to establish such a master production program (MPP), from which the component requirements planning derives.

FlexSim is a three-dimensional simulation software and an object-oriented for discrete systems supports C++ language. It is widely applied for manufacturing (G. Li-Xiong et al., 2014).

The FlexSim software according to the process recently; we build the model of the bushels production workshop. The simulation model consisted of more than 150 elements, 300 connections and more than 1500 code lines. Now, we define the main entities of the simulation model as shown in Table 3.

Table 3 Main model's entities

Entity	Number
Source	3
Buffer	3
Processor	13
Operator	12
Transport	4
Conveyor	9
Storage	2

Moreover, Fig. 6 shows the inputs and outputs of the simulation platform.

Hence, Fig.5 below shows the simulation model of the FlexSim software of the spherical bushel production workshop.

According to Table 2, manufactured accessories respectively Body A1, Body B1 and Cuff A2 are sent to the respective stocks A1, B1 and A2 (pre-assembly stocks). Upon arrival of the purchased accessories A3, A4, A5, A6, B2 and B3; all the accessories will be sent to the mixed assembly units according to the nomenclature mentioned (quantities); previously in Table 1. Finally, the two types of products will be checked by sampling before being sent to storage respectively PFA (storage for bushels type A) and PFB (storage for bushels type B).

The simulation modeling attributes of the FlexSim software and the production parameters of the accessories and the assembly of the spherical bushels are defined as follows:

1) The physical parameters of the source (raw material)

During the modeling of our workshop of production; that we want to transform radically so that it can take the digital road, we proposed the MRP method with an aim of controlling the production and having the good management there thanks to such a master program of production. Indeed, the management of production will be automatic and controllable due to the program that we are going to integrate it as a code in our simulation model under FlexSim. Algorithm 1 details how to do requirements planning for the A1, B1, and A2 accessories. Therefore, we introduced it in the source simulation platform. In order to find our components requirements, we introduce the Gross Need (BB) and the Expected Reception (RP) (lines 2-3). Thus, we can find our component requirements: Projected Stock (SP), Net Requirement (BN), Start of Order (DO) and End of Order (FO) (lines 10-21). In this way, we receive valuable information about the production and supply planning.

Algorithm 1 The Production planning and material requirement planning

```
1. function (SP,BN,DO,FO) = MPP (BB,RP)          % Master Production Program
        BB;                                       % Gross Needs (input)
        RP;                                       % Expected Reception (input)
        SP;                                       % Projected Stock (output)
        BN;                                       % Net Requirements (output)
        DO;                                       % Orders' beginning (output)
        FO;                                       % Orders' End (output)
2. for i in [2; length(BB)-1] do
3. SP(i) = SP(i-1) + RP(i) - BB(i)
4.      if  SP(i) < BB(i+1)
        BN(i+1) = BB(i+1) - SP(i) - RP(i)
                if BN(i+1) < 1000
                DO(i+1) = 1000
                else DO(i+1) = BN(i+1)
                end
        FO(i-1) = DO(i+1)
        SP(i+1) = DO(i+1) - BN(i+1)
        else I = i+1
        end
5. return(SP)
6. return(BN)
7. return(DO)
8. return(FO)
```

2) The Queue parameters and the parameters of the processors (machines)

In the workshop, the queue of raw materials is in the form of large boxes located in front of each production line. Component requirements are planned using the Master Production Program (MPP) already introduced by the Source module ticket. Therefore, there will be no more congestion problems.

Referring to Table 2; that of the operating ranges; we have configured the parameters of the different machines (Setup time, process time...). We identify the setup time as a machine settings time per unit of product (configuration, raw material, positioning, etc.) and the process time is production time. Indeed, these times can be achieved with or without human intervention depending on the operating range.

3) Set the model stop time

In order to get the working status accurately and data of the FlexSim software of the spherical bushel assembly system. In fact, the production management in this simulation platform is programmed with a master production program that we have developed over an 8 weeks horizon (Just for an example). Table 4 below shows the production orders for bushels type A and type B.

Table 4 Production order of spherical bushels over an 8 weeks horizon

Week	BS type A	BS type B
1	3000	2500
2	2500	1500
3	1500	1000
4	1000	1000
5	1000	1000
6	1000	1000
7	1000	1000
8	1000	1000

Therefore, the model will be automatically stopped while the assembly of the bushels is finished (respectively for type A and B). The code is as follows.

If ((get output (courant) == 12000)

And (get output (courant) == 11500))

Stop ( )

The parameters of system-simulated model are set and connecting each entity, and spherical bushels mixed assembly system simulated model based on FlexSim software is built up.

Until now, we have reasoned as if the production capacity was infinite (as a hypothesis) in order to calculate the component requirements. Indeed, we have proceeded to the calculation of the batches without worrying about their realization with regard to the capacities of the available production resources. For that before introducing the production program in our simulation model, it was necessary to optimize it.

Platform optimization through the adjustment Load- Capacity method

In this section, the optimization of the Master Production Program (MPP) through the load-capacity adjustment method. In fact, it will only focus on spherical bushels type A (BS ¾ "FF), which is composed of accessories as listed in Table 1 (respectively in a similar way for type B bushels).

Indeed, it is advisable in a first time to calculate the generated loads, which imply the batches to be produced and to estimate their realizations compared to the real capacity of the production resources.

With reference to the production department, there is a major problem of capacity for the accessories manufactured Body A1, Body B1 and Cuff A2, which require a passage on production lines. However, since the components are purchased, they do not generate any load on the machining stations.

To calculate the loads we have, we refer to Table 5 of the manufacturing range file.

We remember that a work center is a virtual production unit, consisting of one or more activity centers, including machines and tools necessary for the execution of tasks. This unit of production is used in particular for the planning of the capacity requirements. Table 6 below displays the workstation file where there is some information have to be defined namely: the theoretical capacity is the maximum number of operating days, in this case per week. Additionally, the minimum coefficient in percent is the percentage of time that stations are not operating.

We mention the real capacity (actual capacity) is the number of days of actual operation in Equation (1).

$$AC = (1 - C) * TC \qquad (1)$$

Where;

- AC: Actual Capacity
- C: Minimum coefficient
- TC: Theoretical Capacity

Table 5 Manufacturing range file

RANGE FILE				
Component	**Station**	**Designation**	**Setup time (min/piece)**	**Process time (min/piece)**
BS ¾ FF (Type A)	Assembly	PMO1	0	0.24
Body A1	Processing	TRF1	0.45	0.656
Cuff A2	Processing	TRF3	0.45	0.39

Table 6 Workstation file

WORKSTATION FILE				
Station	**Designation**	**Theoretical capacity (days/week)**	**Minimum coefficient (%)**	**Actual capacity (days/week)**
Processing	TRF1, TRF3	6	20	4.8
Assembly	PMO1	6	10	5.4

We know that the processing station (TRF1, TRF3) has a real capacity of 4.8 days per week and the unit manufacturing times (Mt) of Body A1 and Cuff A2 are respectively calculate by referring to Table 5 as below:

$$Mt(A1) = 0.45 + 0.656 = 1.106\ min/piece$$
$$= 0.0023\ days/piece$$

$$Mt(A2) = 0.45 + 0.39 = 0.84\ min/piece$$
$$= 0.0017\ days/piece$$

In order to obtain the loads on the various periods, it is enough to multiply the unit manufacturing time (Mt) by the production order (orders beginning) for each period; recently calculated by the master production program; and to make then the sum for total loads.

Master production program: Adjustment by stock

In this subsection, we present an MRP2 approach to optimize our Master Production Program via an inventory adjustment method, in order to take into consideration the capacities of the production lines.

Fig. 8 shows a modeling of the optimization approach of the simulation platform as well as the Master production program through the load-capacity adjustment method by stock.

In order to have an agile and flexible simulation platform, the optimization of the Master production program will take place. It consists in adjusting the production of the products manufactured in the workshop respectively Body (A1) and Cuff (A2). Our objective function is to minimize; which X and Y represent respectively the production's orders of Body A1 and Cuff A2. We presents the function and its constraints as below:

Min H(X, Y)

*H(X, Y) = 4.8 – (0.0023*X + 0.0017*Y)*

Subject to

H(X, Y) > 0

X > 0

Y > 0

In the case where the function is negative, i.e. the costs are higher than the production capacities (4.8 days), we anticipate the production of the product whose production costs more than the other.

This anticipated production implies a storage that we wish to keep as cheap as possible; this leads to the choice of the cheapest item to store. For that, we must evaluate the unit storage cost of accessories: body and cuff. Starting from the hypothesis that admits the cost of storage of such an article is proportional to the value (or its cost price) of this one.

For the development of the method of production adjustment by stock, we adopt the following notations:

- C_i: the cost of the accessory i including the cost of its production as well as the cost of its components. We note Equation (2):

$$C_i = \sum_{j=1}^{n} C_j + C_{production} \qquad (2)$$

- M_k: the operating cost of the station k per week
- $T_{k,i}$: the time required at station k to produce one unit of item i
- P(i): the set of accessories included directly in the composition of the item i
- $L_{j,i}$: the number of units of component j required to produce one unit of an item i

If *P (i) = ∅*; the component is purchased; its cost price is calculated by Equation (3) as below. It is simply its purchase price.

$$C_i = C_{purchase} \qquad (3)$$

If *P (i) ≠ ∅*; the component is manufactured; its cost price is defined by Equation (4) below.

$$C_i = M_k * T_{k,i} + \sum_{j=1}^{n} L_{j,i} * C_j \qquad (4)$$

In the following, we present the tree structure of the spherical bushels type A (BS ¾” FF) as shown in Fig.9.

In order to calculate costs and referring to Table 1, it is advisable to start with the purchased items (A3, A4, A5, A6) and gradually move up the other levels until the finished product (BS ¾ “FF).

On the one hand, the accessory Body A1 needs for its composed of a sphere unit A4, an Axis unit A3 and two Seals units A6. On the other hand, the accessory Cuff A2 uses brass for its manufacture, which is purchased in bar of diameter 23 (according to Table 2 of the operating range).

As a result, we can calculate the production costs of accessories Body A1 and Cuff A2 by using Equation (4) as follows:

$$C_{Body} = M_k * T_{k,Body} + \sum_{j=1}^{3} L_{j,Body} * C_j + C_{LT}$$

$$C_{Cuff} = M_k * T_{k,Cuff} + \sum_{j=1}^{1} L_{j,Cuff} * C_j$$

We found that the cost of the Body A1 is higher than the cost of the Cuff A2.

The findings are no longer surprising given that the Body A1 is more elaborate than the Cuff A2. According to the method of adjustment by stock, we will anticipate the production of the cheapest item to stock, such the Cuff accessory. Moreover, we correct the start of the production orders while anticipating the production of the accessory Cuff A2 as follows.

Hence, Algorithm 2 details how to optimise the Master Production Program through the load-capacity adjustment method by production ancipation. Therefore, we introduced it in the source simulation platform.

In order to optimize the Master Production Program, we introduce some inputs such as orders' beginning of manufactured accessories Body A1 and Cuff A2 (lines 2-3). Indeed, we calculate the generated loads by the produced accessories in (lines 9-11). Then, we calculate the sum of the generated loads (line 12) and our function objective H already defined in the above (line 13). Moreover, we look to minimize our objective function and find the updated loads (lines 15-20).

In the next section, we present our findings and its optimization through the load-capacity adjustment method.

Algorithm 2 MPP optimization through the load-capacity adjustment method

```
1. function (CC,CM,S,H,L) = Load-Capacity (OC,OM)   % Master Production Program Optimization
        OC;                                    % Orders' beginning of the "Body A1"
        OM;                                    % Orders' beginning of the "Cuff A2"
        CC;                                    % Generated loads by "Body A1"
        CM;                                    % Generated loads by "Cuff A2"
        S;                                     % Sum of generated loads
        H;                                     % Function objective H(CC, CM)
        L;                                     % Updated loads
2. for i in [1; length(OC)] do
     CC(i) = 0.0023 * OC(i)
     CM(i) = 0.0017 * OM (i)
     S(i) = CC(i) + CM(i)
     H(i) = 4.8 – S(i)
 End
3. for j in [0; length(H) - 1] do
     If H(length(H) - j) < 0
     L(length(H) – j – 1 ) = H(length(H) – j – 1) + H(length(H) - j) and L(length(H) – j) = 0
     Else L(length(H) – j) = H(length(H) – j)
     End
End
4. return(CC)
5. return(CM)
6. return(S)
7. return(H)
8. return(L)
```

Results And Discussions

2) Optimization of the Master Production Program through the load-capacity adjustment method

As stated in the above, according to the stock adjustment method, we will anticipate the production of the cheapest item to stock, such as the Cuff accessory. Therefore, we correct the start of the production orders while anticipating the production of the accessory Cuff A2 as follows.

In order to optimize our MPP, we will need to calculate the loads generated by the manufactured products Body A1, Body A2 and Cuff A2. For this purpose, it is enough to multiply the unit manufacturing time (Mt) by the production order (orders beginning) for each period; recently calculated by the master production program; and to make then the sum for total loads.

Table 11 and Fig. 15 below illustrate loads on the manufacturing station generated by the manufactured accessories Body A1 and Cuff A2.

Table 11 Generated loads by the accessories on the manufacturing station

Component	**Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Body A1 0.0023 day/item	Beginning orders	**1400**	**1000**	**1000**	**1800**	**1500**	**1300**	**800**	**0**
	Load	3.22	2.3	2.3	4.14	3.45	2.99	1.84	0
Cuff A2 0.0017 day/item	Beginning orders	600	1000	1000	900	1000	700	1100	0
	Load	1.02	1.7	1.7	1.53	1.87	1.19	1.87	0
Manufacturing station	Total loads	4.24	4	4	5.67	5.32	4.18	3.71	0
	Surplus/ deficit	0.56	0.8	0.8	**-0.87**	**-0.52**	0.62	0.9	4.8

We note a deficit in capacity in period 4 and 5 of *0.87 + 0.52=1.39 days*, which it is possible to solve it according to the method of adjustment by stock (Fig. 3 and Fig. 8) of the Master Production Program (MPP) that we will present in what follows. For that the algorithm 2 generates us automatically the new beginnings of order of production of the accessory Cuff A2.

By anticipating the production of articles in periods 2 and 3; where there is an excess capacity of *0.8 + 0.8=1.6 days*. It is thus advisable to use 0.8 days in period 3 and the complement; which is *1.39 - 0.8=0.59 days* in period 2 (which is possible since the surplus of this period is 0.8 days).

In period 5, the deficit of capacity being of 0.52 days; which presents 0.52/0.0017=306 units to be entrenched from the beginning orders; that is 1000-306=694 units. In fact, this deficit can be filled by using the surplus of capacity of 0.8 days in period three. Therefore, these 306 pieces are more to produce in period 3 than initially planned.

In period 4, the capacity deficit is 0.87; this presents 0.87/0.0017=512 units to be entrenched from the beginning orders; that is 900-512=388 units. However, this deficit can be filled by using the surplus capacity of which is now equal to 0.8-0.52=0.28 days in period 3. Indeed, the 512 units are to be produced as follows: 0.28/0.0017=165 units in period 3 and the 347 units (512-165) remaining in period two. Since, we have in this period a surplus of 0.8 days of which one will be able to produce until the 0.8/0.0017=471 units. Thus, the beginning orders in period three will be 1000+306+165=1471 and in period two will be 1000+347=1347 with an excess capacity of 0.8-0.59=0.21 days.

Table 12 below provides an update of the beginning production orders of the Body A1 and the Cuff A2 in order to optimize the Master Production Program (MPP).

Table 12 Update of the beginning orders according to the adjustment load-Capacity method

Period (week)		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Body *0.0023 day/item*	Beginning orders	1400	1000	1000	1800	1500	1300	800
	Load	3.22	2.3	2.3	4.14	3.45	2.99	1.84
Cuff *0.0017 day/item*	Beginning orders	600	1000	1000	900	1000	700	1100
	Variation		((0.87-0.28) /0.0017)	(0.52/0.0017) + ((0.8-0.52)/0.0017)	(0.87/ 0.0017)	(0.52/ 0.0017)		
	Beginning orders updated	**600**	**1347**	**1471**	**388**	**694**	**700**	**1100**
	Load	1.02	2.29	2.5	0.66	1.18	1.19	1.87
Manufacturing station	Total load	4.24	4.59	4.8	4.8	4.63	4.18	3.71
	Surplus/ deficit	0.56	0.21	0	0	0.17	0.62	1.09

The optimization of the Master Production Program (MPP) through the load-capacity adjustment method allowed us to manage the planning of component requirements for the various commands over an 8-week horizon.

By optimizing the MPP, we noticed that the time required to produce 12k bushels of type A (BS ¾ " FF) increased from 3072 min to 3289 min and respectively we retained for the production of 11.5k bushels of type B (BS ½ " MM) a time increased by 191 min (from 3624 min to 3815 min). In fact, the times found are not surprising, given that the planning and management of the production were well optimized.

Thus, it is stated that the optimization of the master production program and its integration into the simulation platform has been interesting and remarkable. According to the statistical data of the mixed assembly lines, the company will be able to deliver these eight-week commands from the beginning of the second week thanks to such a planning of the component requirements. On the one hand, for the BS ¾ " FF bushels, the 12 000 items are produced in a time of 3289 minutes, which is worth 54.8 hours and then 6.85 days. Given that, the company works 8 hours per day and for 6/7 days. On the other hand, for the BS ½" MM bushels, the 11500 articles are produced in 3815 min, which is worth 63.58 hours and then 7.94 days.

Figures 16 and 17 illustrate performance indicators of assembly units PMO1 and PMO2 flowcharts, after compilation of the model with the update Master Production Program (MPP), as below.

Conclusion

With the emerging technologies, such as big data, Cloud computing and Cyber-Physical Production Systems CPPS together with the simulation and modeling technologies, we believe the smart factory of Industry 4.0 can be implemented. The smart configuration of machines and products communicate and negotiate with each other to reconfigure themselves for flexible production of multiple types of products.

In this paper, we proposed a successful implementation of industry 4.0 in the future would save a lot of cost for a company and bring huge economic benefits. In the aim of this paper, we elaborate a workshop's simulation platform whose production and supply are handled by a master Production Program (MPP) and controlled by a CPS. In this platform, we model and simulate the production and mixed assembly of spherical bushels. In order to achieve an intelligent production and scheduling, we optimize the simulation platform through an approach of MRP2 for production planning of the smart workshop and industry 4.0: we are talking about the load-capacity adjustment method.

In fact, simulation and modeling technologies can be very useful for multiple objectives and complex processes or even for making a road map for such project of digital transformation in the context of Industry 4.0.

The optimized findings show that the platform simulation and method proposed in this paper are good guide and reference for such digital transformation of a company to the 4.0 era. We mention that this method can be generalized for any sector and even for any manufactured factory.

In guise, the smart platform helps us to implement the sustainable production mode to cope with the global challenges. It can lead to novel business modes and even affect our lifestyle.

As a perspective, this simulation platform handled by a CPPS and MPP presents a basis for a future digital twin of the spherical bushels production facility.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and Material

Authors declare the presence of data associated with the manuscript, whether in repositories, available upon request, included in supplementary information, or in the figure source data files.

Code Availability

The authors declare the availability of the application software and the programming codes (custom code).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent for publication

The participants have consented to the submission of the case manuscript to the journal.

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Figures

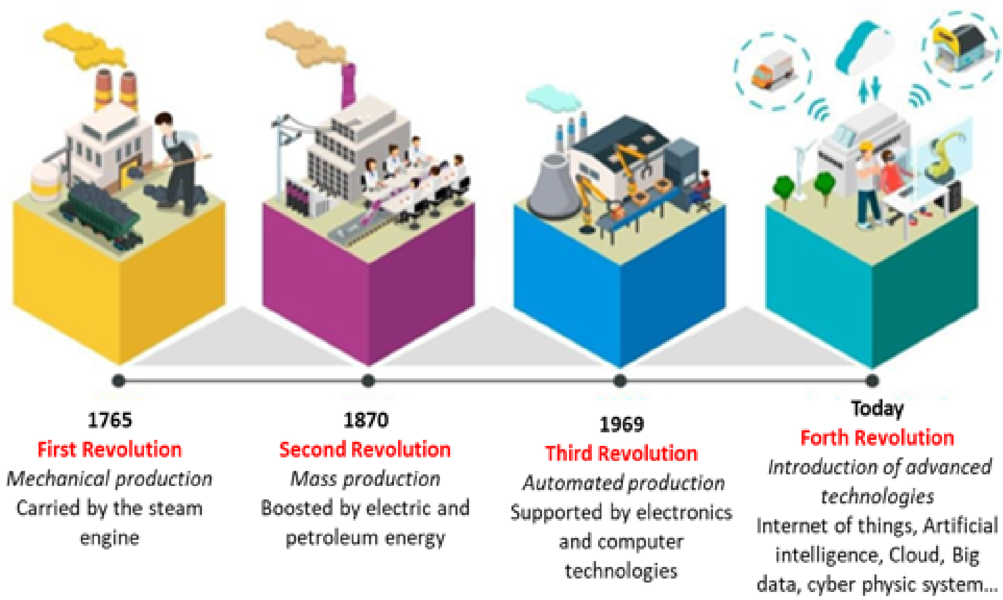

Figure 1

Evolution of the industry

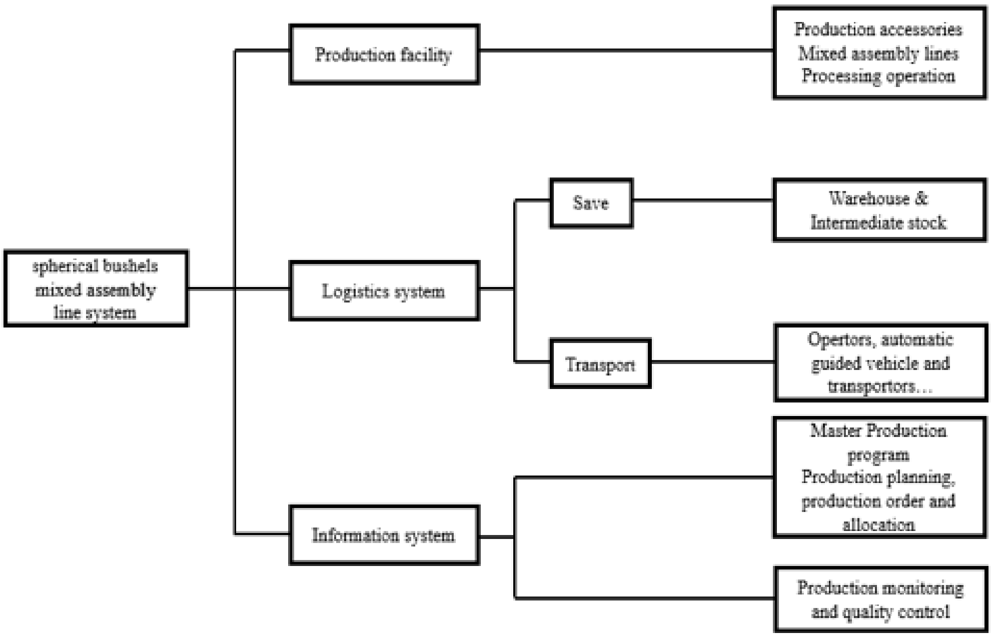

Figure 2

Composition of the workshop for spherical bushels mixed assembly and accessories production

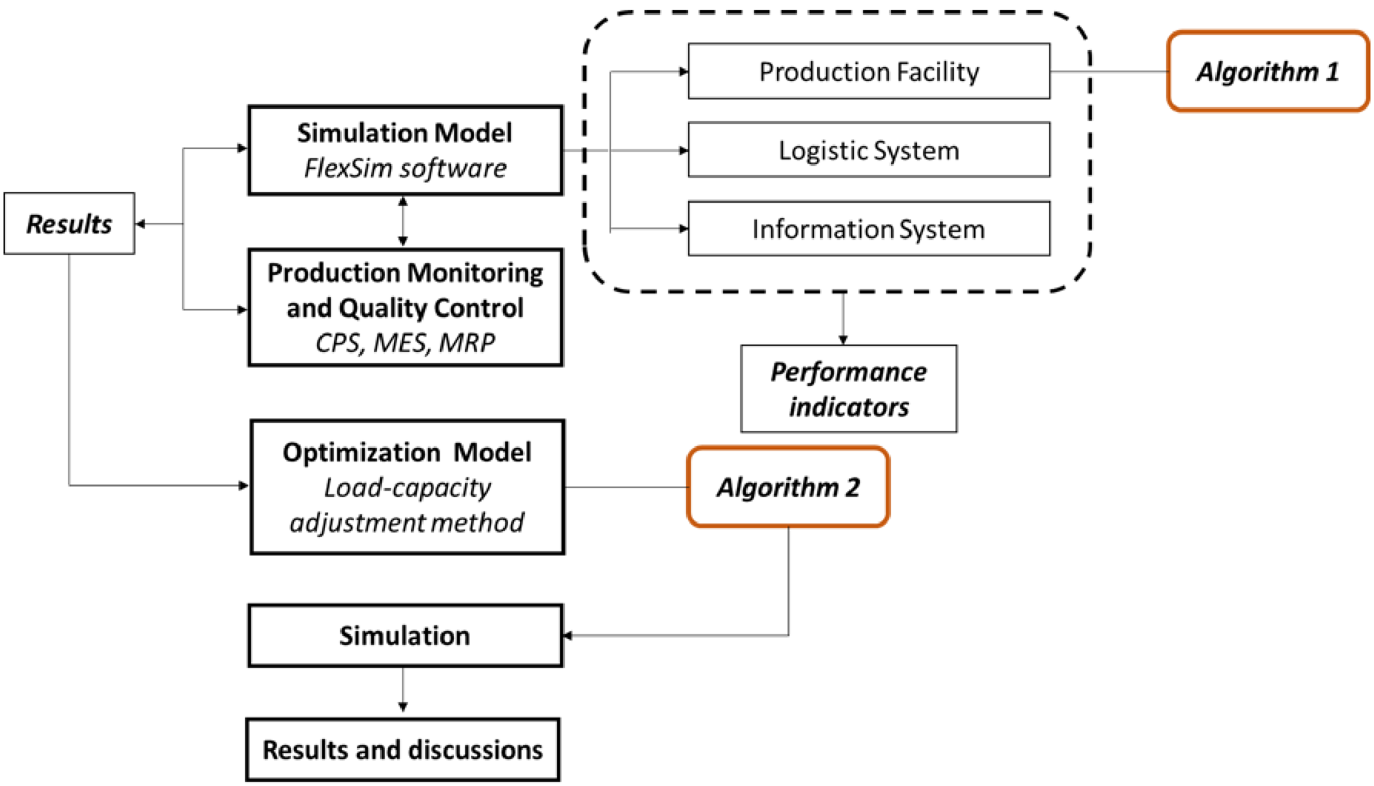

Figure 3

Overall approach and vision of the global problem

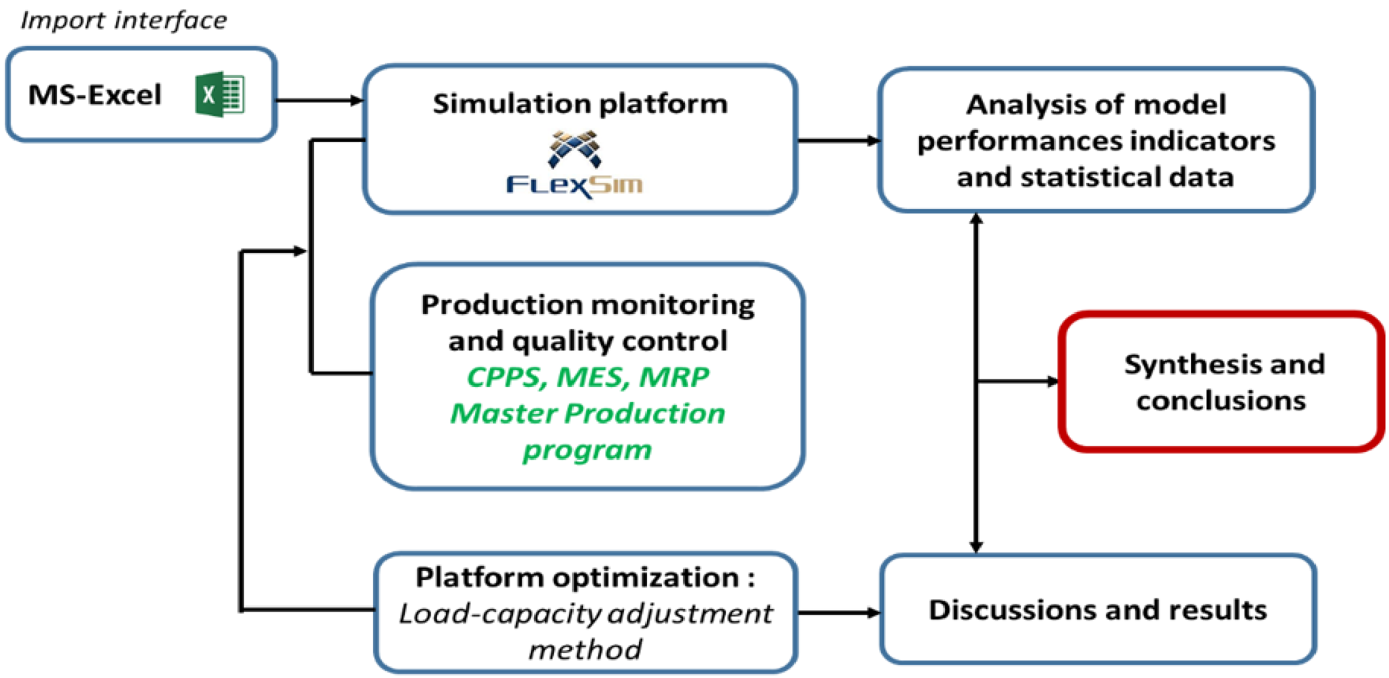

Figure 4

Proposed method's flowchart

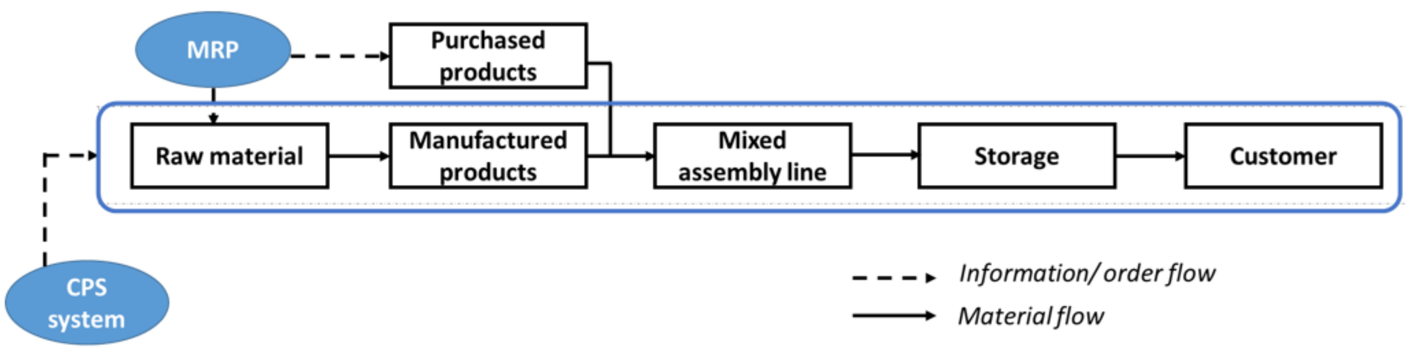

Figure 5

Model of the production process of spherical bushels in Industry 4.0

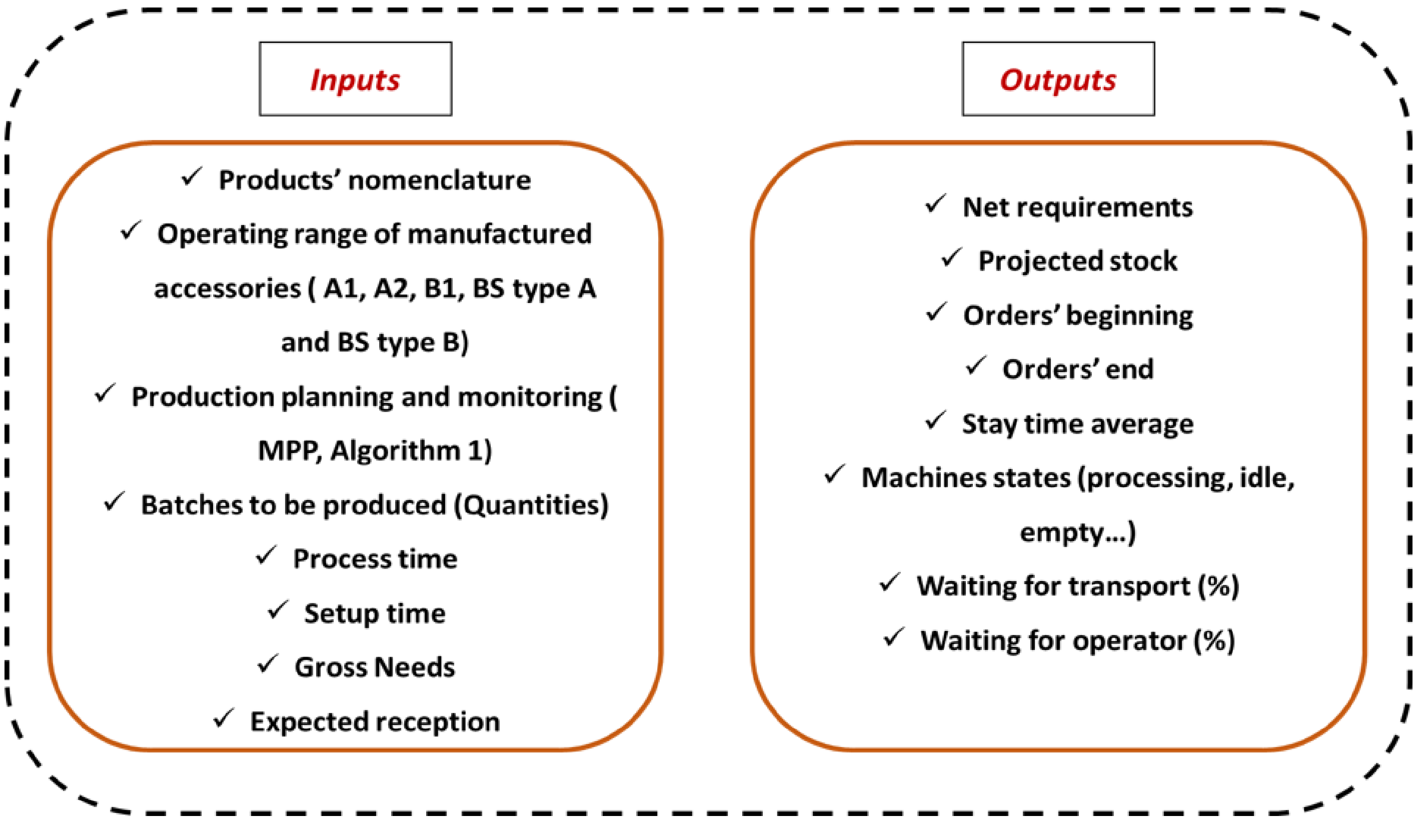

Figure 6

inputs and outputs of the simulation platform

Figure 7

Modeling of the spherical bushels production workshop for the FlexSim software in Industry 4.0

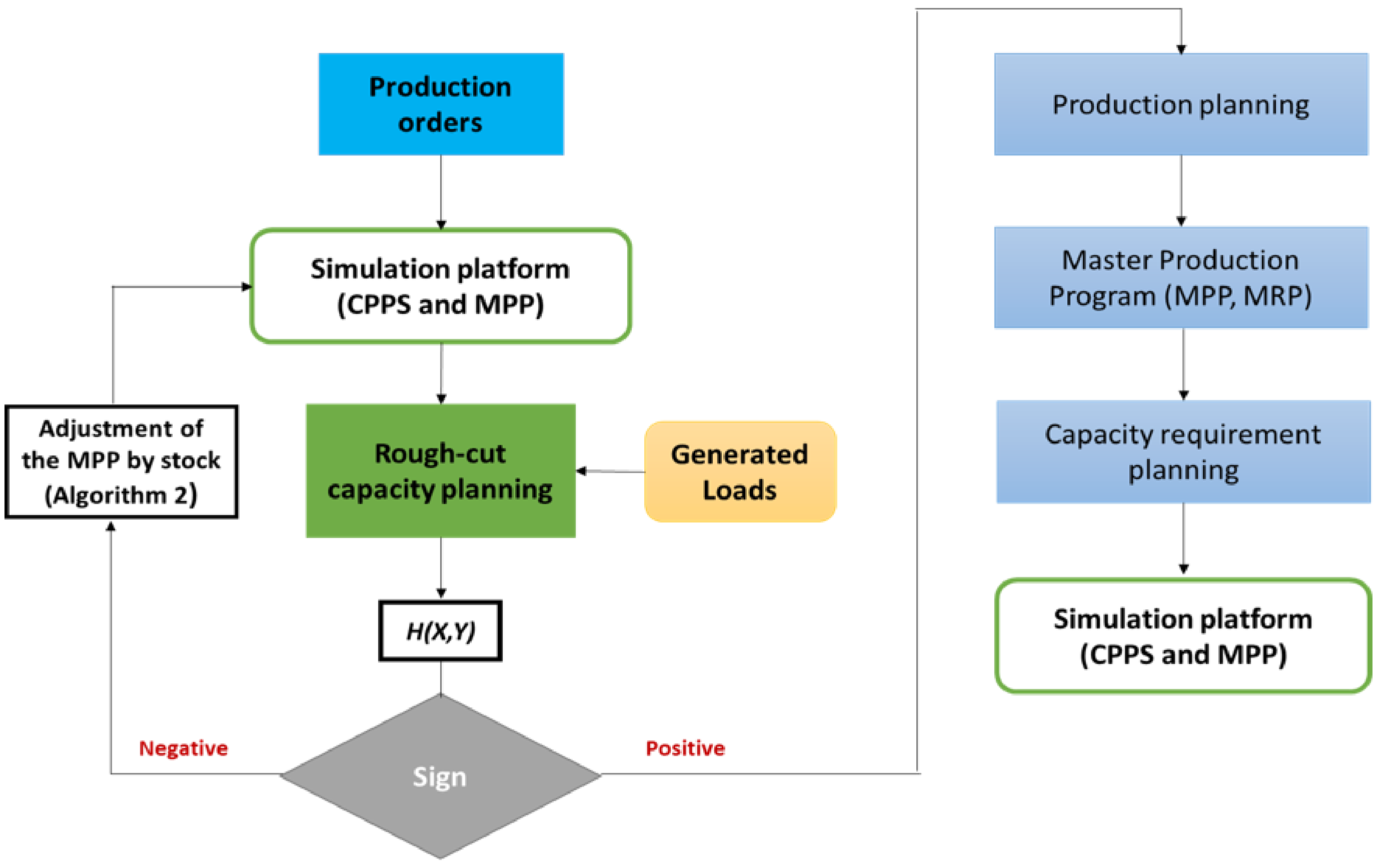

Figure 8

Optimization approach of the MPP through the load-capacity adjustment method by stock

Figure 9

Tree structure of the spherical bushel type A (BS ¾” FF)

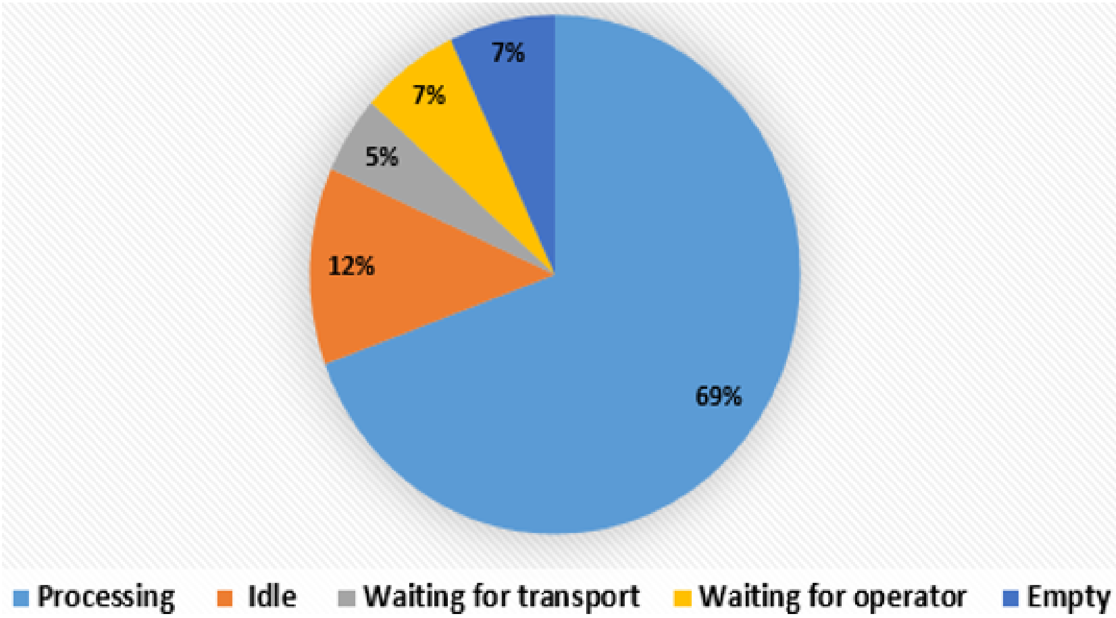

Figure 10

Performance indicators for the Body A1 production line

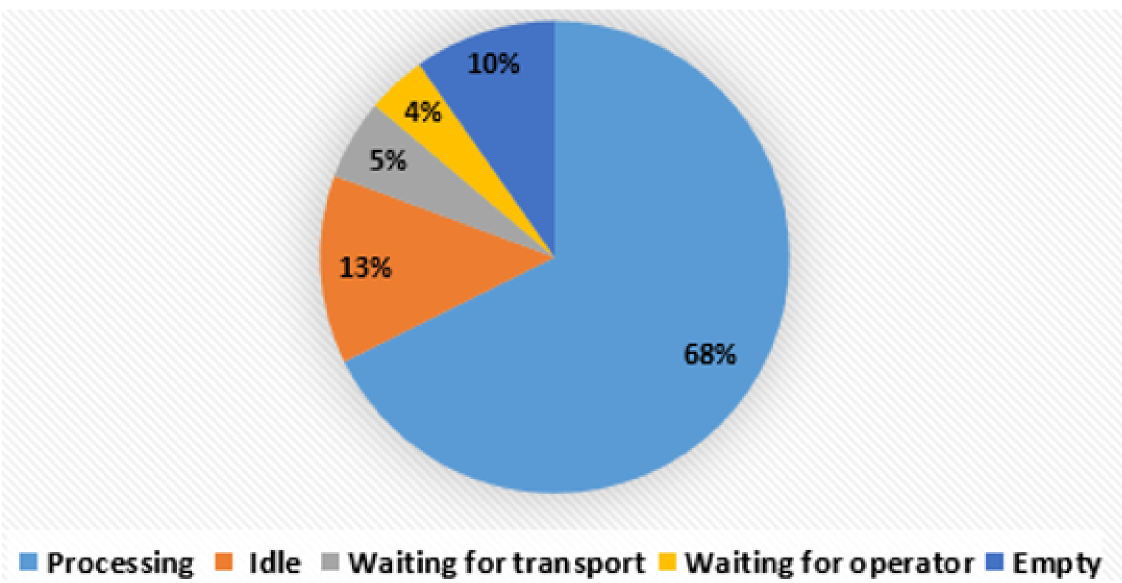

Figure 11

Performance indicators for the Body B1 production line

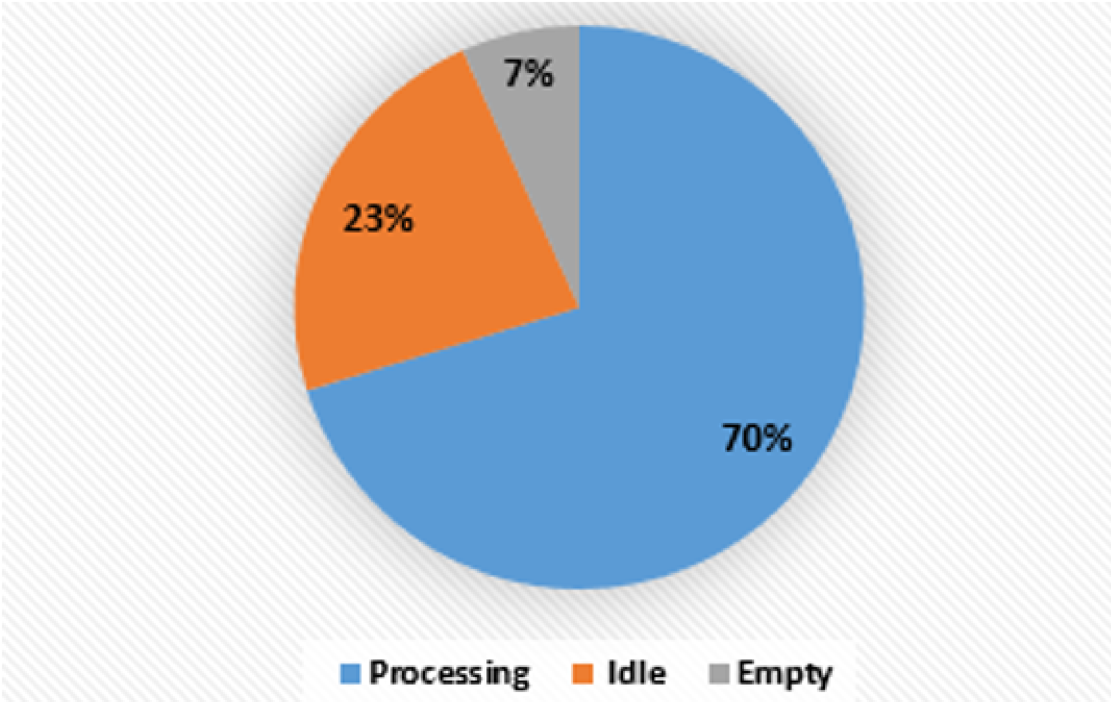

Figure 12

Performance indicators for the Cuff A2 production line

Figure 13

Performance indicators of the assembly unit PMO1

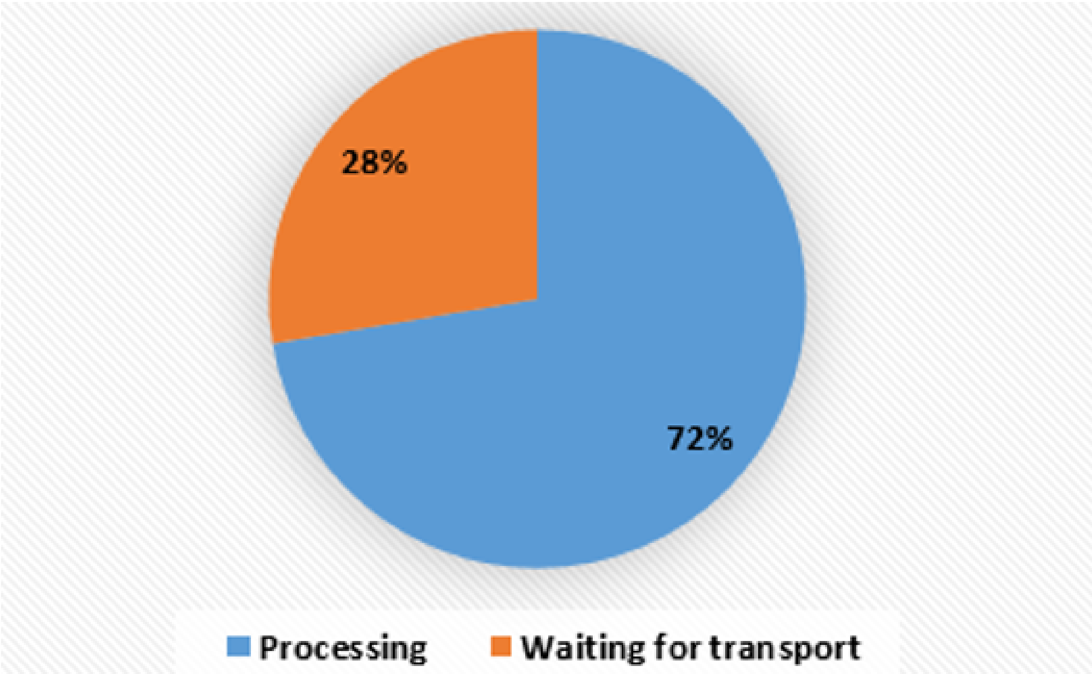

Figure 14

Performance indicators of the assembly unit PMO2

Figure 15

The generated loads by the accessories Body A1 and Cuff A2 on the manufacturing station, the loads sum and the function objective H

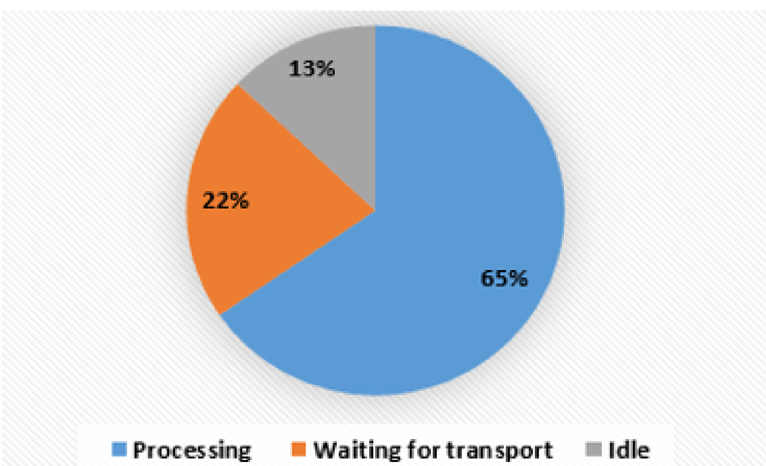

Figure 16

Performance indicators of the assembly unit PMO1

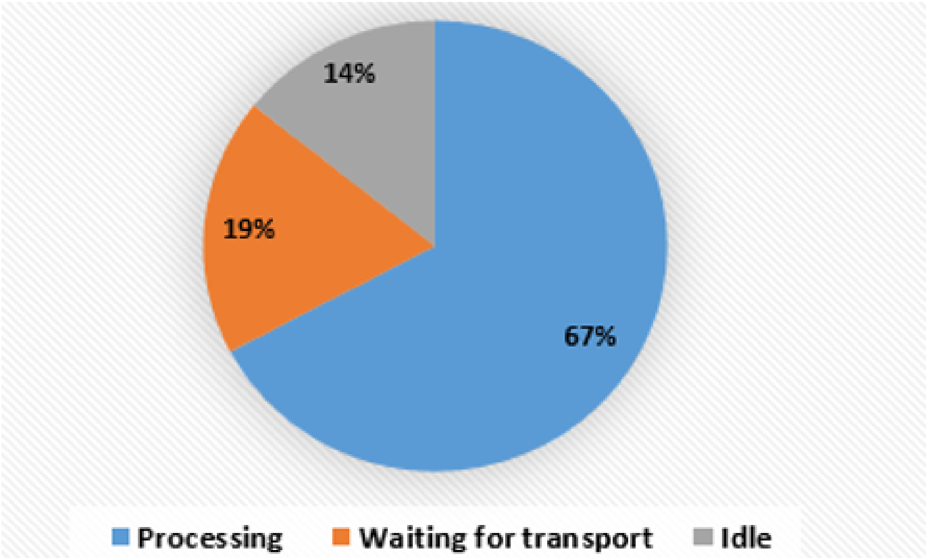

Figure 17

Performance indicators of the assembly unit PMO2