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Axa prioritară: nr. 1: "Educaţia şi formarea profesională în sprijinul creşterii economice şi dezvoltării societăţii bazate pe cunoaştere"
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Titlul proiectului: Integrarea cercetării româneşti în contextul cercetării europene-burse doctorale.
Cod Contract: POSDRU/88/1.5/S/60370
Beneficiar:Universitatea Lucian Blaga din Sibiu

Eng. Rareș Lucian Marin

PhD. Thesis

Abstract

Scientific coordinator:

Prof. Eng. Paul Dan Brîndașu, PhD.

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Transportation of Priority Parts in the Manufacturing Processes, Based on Intelligent

Evaluation Committee:

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List of Abbreviations

A

AGV	Automated Guided Vehicle
ALB	Assembly Line Ballancing Problem
AS/RS	Automated Stock/Recieve System

B

BTO	Build to Order
BTS	Build to Stock

C

SP	Shortest Processing Time
EDD	Earliest Due Date
CPS	Cyber Physical Systems
CRM	Customer Relationship Management

E

ECC	Electric Carrying Conveyor
ECU	Electronic Control Unit
EPC	Electric Pallet Conveyor
ERP	Enterprize Resource Planning

F

FIFO	First in First out
FIPA	The Foundation for Intelligent Physical Agents
FJSP	Flexible Job Shop Scheduling Problem

G

GSM	Global System for Mobile Communication
GUI	Graphical User Interface

M

MES	Manufacturing Execution Systems
MILP	Mixed-Integer Linear Programming
MTO	Make to Order
MTS	Make to Stock

O

OEM	Original Equipment Manufacturer
OLE	Object Linking and Embedding
OPC	OLE for Process Control

OPC UA	OLE for Process Control Unified Architecture
P	
PLM	Product Lifecycle Management
FCFS	First Come First Served
R	
CR	Critical Ratio
RFID	Radio Frequency Identification
S	
SCADA	Supervisory Control and Data Acquisition System
SCM	Scupply Chain Management
SFFr	Sistem de Fabricație Fractal
HMS	Holonic Manufacturing Systems
T	
TL	Remaining working time for a work
TS	Remaining time until due
U	
UBFr	Base fractal
W	
WIP	Work in Process

Keywords:

physical prioritization, flow shop, feeder, series production, transportation, transportation systems, transportation devices, customization, decentralization, simulation, intelligent agents, continuous production.

Introduction and literature review

Our world can be considered a system that has the intrinsic purpose to reach an equilibrium state, maintain the equilibrium state and evolve until another disequilibrium state appears.

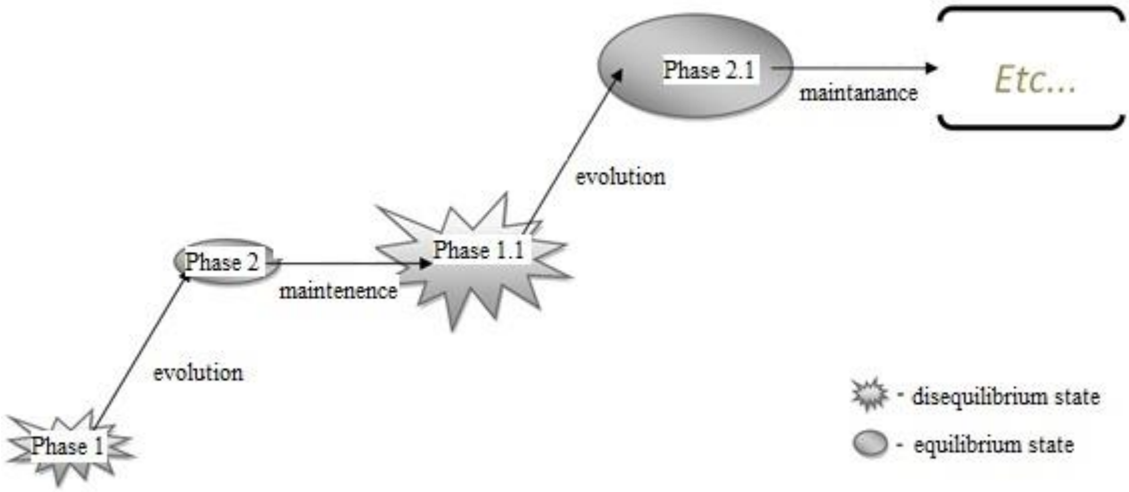

Figure 0.1 – Sequential representation of general systems evolution

The production environment has faced many important changes in the last years: switching from one economy with local perspective to one economy with global perspective and with markets that demand high quality products at low costs, extremely customizable and with short life span leading to a “mass customization” [PAU04]. This “mass customization” raises many challenges starting from the production planning level and continuing with the production process where, due to rigid systems involved that need programming and detailed sequencing of production, activities that use one important segment of the lead time, activities that are complex and difficult to implement and are very often relying on the decision of dedicated employees. These decisions are fully dependent on employee’s experience and on his skills in finding the best solutions in the shortest time. This process is a not reliable one given the fact that it is prone to human error.

During the last years, people have sought solutions to these problems with high emphasis on: decentralization, smart product, production environment capable to integrate and manage the smart products evolution, taking advantage on high processing power provided by the IT industry.

Based on these facts, starting in 2012, Germany began the fourth industrial revolution called “Industrie 4.0”, by exhibiting the first demo of this concept at the International Fair in Hannover. Industrie 4.0 aims to interconnect by using the Internet of objects, systems and environments that will be generically called

CPS (Cyber Physical Systems), leading to 2020 from intelligent objects (which are in trend at the present moment) to intelligent environments like the smart city concept. Another important feature of the new industrial revolution is changing of paradigm from a PC based world to a world based on multiple devices connected to multiple clouds, this new foreseen environment being generically called the Internet of Things.

Some of the main goals of this new industrial revolution are: intelligent entities, intelligent machines or CPS, augmented operator, unique identities, decentralization, communication, and autonomy.

At this moment, one challenge related to implementation of intelligent products is building of environments where these intelligent products can optimally evolve [FAR12].

The companies that implemented these standards will have to prove new benefits to the client in order to make their own products more attractive, given the fact that the products are almost at the same level of quality compared to competitor products, thus at company level being almost at the same level compared to other companies that implemented similar standards. Another important advantage against competition is, as previously mentioned, the time until product delivery. The faster the product can be delivered, the bigger the advantage against competition. It is very difficult for a company to decrease the product delivery time as long as the production capacity is not increased. As well, not all the clients in portfolio demand short delivery time for their products. Considering these aspects, de product delivery time can be decreased only for the products demanding short delivery time, assigning higher priority only for these products and by this avoiding the need for increasing production capacity.

The prioritization topic becomes more and more complex given the fact that the company products are very customizable. For instance, the German automotive company BMW has such a wide range of options that leads to a theoretical number of millions of possible constructive variants [MEY04]. This variety of models implies planning, activity that needs more than 50% of the lead time [TIM09].

Another actual challenge is finding solutions for efficient prioritization, optimal planning, programming and production sequencing, generation of manufacturing architectures that will allow prioritization at any moment without affecting the company efficiency (productivity, costs, times, etc.).

The issues described above are widely approached in the literature usually by using mathematical models. Some of these models can be detailed by using the following references: genetic algorithms [CAR11] [XIA10], parallel genetic algorithms [FAN09], modified genetic algorithms [SUN10], optimization by using bio-geographical algorithms [HAB11], artificial algorithms of bees swarms [QUI11] [WAN11], taboo search algorithms (TS) [BRA93], particle swarm optimization (PSO) [GAO06], optimization based of ants colonies (ACO) [LIO07], evolutionary algorithms [KAC02] [KAC021], different hybrid algorithms [NAS11] [XIA05] [ZHA09] [HON08] [LIJ10], etc.

At mathematical level, there are already described in the specialized literature some of the algorithms:

- Models based on linear programming with mixed variables (MILP) [CEM09];

- Models generated for specific purposes [YUN12]

For a wider range of mathematical models for FJSP, check Table 1 from Demir and Isleyen' work. [YUN12].

Even if a great amount of effort is invested in the generation of theoretical aspects of the issues related to production tasks planning simple or flexible, Demir and Isleyen point the fact [YUN12] that generation of mathematical programming of these models is not an efficient solution because of NP-complex structure of machine programming and on the fact that researchers should be aware of the relative efficiency of this programming models!

One dynamic production system that involves a time variable mixture of products, a variable waiting time and a variable production flow time will never reach a stable state [RUE06]. Issues like sending the process related information and WIP control in real time to the actual production process are present very often among production companies and are very difficult to solve by using algorithms; thus, the solutions to this issues are crucial for manufacturing processes of mixed models on today's production lines [LEI09].

In conclusion, the systems can be considered to be formed of equilibrium and non-quilibrium phases that can be sequentially described by moving from a non -equilibrium phase to one equilibrium phase by evolution and from one equilibrium phase to a non-equilibrium phase by gathering new information and the necessity of new methods.

In order to move from one non-equilibrium phase to one equilibrium phase it is necessary to use methods and tools. The smarter the tools and methods are, the quicker the equilibrium state is reached.

Today, we strive to reach an equilibrium state by creating products and services that revolve around one single entity: the consumer. The consumer's need have increased a lot so the trend is to switch from the mass production currently used to a mass customization production.

Mass customization raises a series of issues like: difficult production planning because of high complexity generated by the high number of differences between products, difficult optimization of production flow because of a high number of sub-parts needed to be produced, and the issues related to production management, issues generated by the first two aspects.

Today, a series of mathematical models were developed in order to manage this type of issues, but these models will not solve the above-mentioned production related issues because of the highest range of complexity specific to these issues and because of the impossibility to reach one equilibrium phase of these production lines.

Considering this aspects, our purpose in this work is to produce a thorough analysis of the elements that significantly influence the customized production: the types of production suitable for mass customization, the transport devices and systems currently used, the prioritization issues and

Following this analysis, our goal is to identify the transport devices and systems, as well as the prioritization methods that are suitable for mass customization and also to identify the methods that are insufficient exploited in order to reach this goal (smart products, CPS, autonomous entities, decentralization, etc.). The final goal will be to define a new method for mass customization, to describe it and to analyze its performance.

Ph.D Dissertation Objectives

Given the evolution of the systems together the with the evolution of manufacturing paradigms, arising at the same time with changing customer needs from standard products to highly customized products, the approach in this thesis meets several goals of the new industrial revolution.

Because the production trend is oriented to a "mass customization", the research field of this thesis focuses on prioritizing methods in flexible assembly systems with continuous flow used in medium and large series production.

Based on the analysis, synthesis, theoretical and practical training conducted throughout the dissertation, but also taking into account the previous experience in pattern-making and simulation of flexible manufacturing and assembly lines gained during the preparation of the dissertation, the main objectives of this thesis are:

1. Highlighting and summarizing the current state of the main elements of flexible manufacturing lines (shown in the previous chapter):
   - Highlighting and summarizing the current state of the flexible manufacturing lines typologies;
   - Highlighting and summarizing the current state of the conveying entities used on flexible manufacturing lines;
   - Highlighting and summarizing the current state of the systems and entities intelligence used in flexible manufacturing systems;
   - Highlighting and summarizing the current state of the prioritization methods on flexible manufacturing lines.
2. Analysis in terms of possible prioritizing configurations of the flexible manufacturing lines, typologies of conveying entities, of the system's intelligence and of participating entities.
3. Determination of the configurations of the flexible manufacturing lines, conveyors and intelligence necessary to create an environment suitable for middle and high flexible manufacturing serial priority oriented. Addressing flexible manufacturing lines oriented on prioritization of architectural point of view, to the detriment of mathematical methods.
4. Description of a new manufacturing concept oriented on prioritization. Establish rules that will govern the new manufacturing concept.
5. Modelling a conceptual manufacturing system able to handle stochastic commands like: time of entry into the system, number of features that need to be materialized on the product and priority.
6. Programming of the intelligent agents and entities to manage stochastic flows of components. Creating a manufacturing environment which would allow

enabling physical prioritization without affecting performance compared to a usually flexible system typology and even improve them.

7. Simulation of the components flows through the new conceptual system. Performance analysis of the new manufacturing conceptual system.

Research methods that we intend to use in order to achieve thee exposed objectives:

- The analogy with the nature of manufacturing systems for a practical material flow display;
- Modeling manufacturing systems in special modeling environments to display the configurations of the analysed manufacturing systems;
- Simulation of the manufacturing systems in special simulation environment to analyse the production performances of the presented system.
- Factorial experimentation on proposed and existing manufacturing lines to quantify performances

Feeder concept

The term "feeder" refers to the components supply manner of workstation. In this paper, the term "feeder" is used as the buffer power of supplying the workstations.

Principle

In a glass of mineral water can be seen as gas bubbles of a larger diameter advance the smaller diameter gas bubbles to reach the surface of the glass. Also, by throwing a large rock in the water can be observed as large bubbles appear immediately after throwing the stone at the surface, followed by an effervescent effect created by smaller bubbles. Considering this natural phenomenon we will created an analogy for the flow of components in manufacturing systems.

Next we will name the principle of operation of the new system **the principle of the gas bubbles**. [MAR14]

It is considered a liquid container in which gas bubbles are introduced systematically by the bottom part. These will reach the liquid surface, will remain in contact with the atmosphere for a period, after which they will break. It is considered that the larger diameter bubbles will reach the surface of the liquid before the smaller diameter bubbles when placed simultaneous because of their higher flotation. Each gas bubble will disappear from the system (it will break) after a certain time of exposure to the atmosphere, which may be different for each bubble at hand. It is assumed that after the disappearance of a bubble in the container, its place will be taken at the liquid surface by the bubble with the largest diameter in the area, before the smaller diameter ones due to its high flotation and higher motion speed. The container will not clutter to allow large bubbles to reach the surface without being blocked because of excessive density.

By analogy to the natural phenomenon stated above, we consider: the container as being the manufacturing system, the liquid as being the conveying system, the bubbles as being the components that need to be processed , the size of the bubbles as being the priority degree of the components, the surface (atmosphere) as being the manufacturing zone, the time of exposure of the bubbles to the atmosphere until their disappearance as being the processing time.

Architecture of the feeder manufacturing system

The feeder manufacturing system consists of: workstations placed on both sides of the transport system, query nodes, and a transport system with cyclical configuration . In the system there is only one main input and output, but there may be secondary outputs.

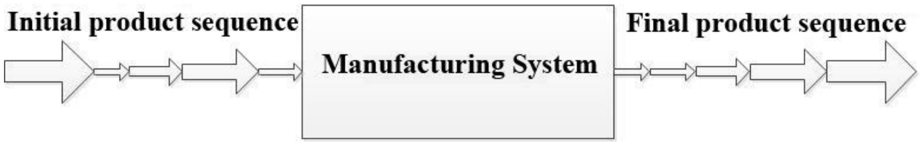

Figure 1 - Generalized principle of feeder manufacturing

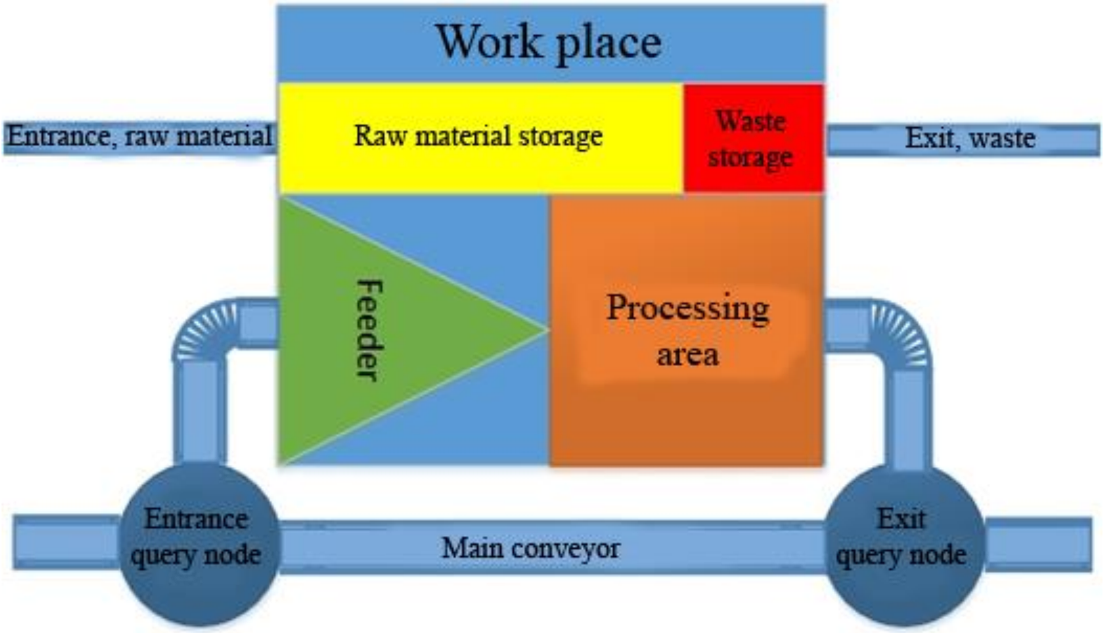

Figure 2 - Workplace structure in a manufacturing system with feeders

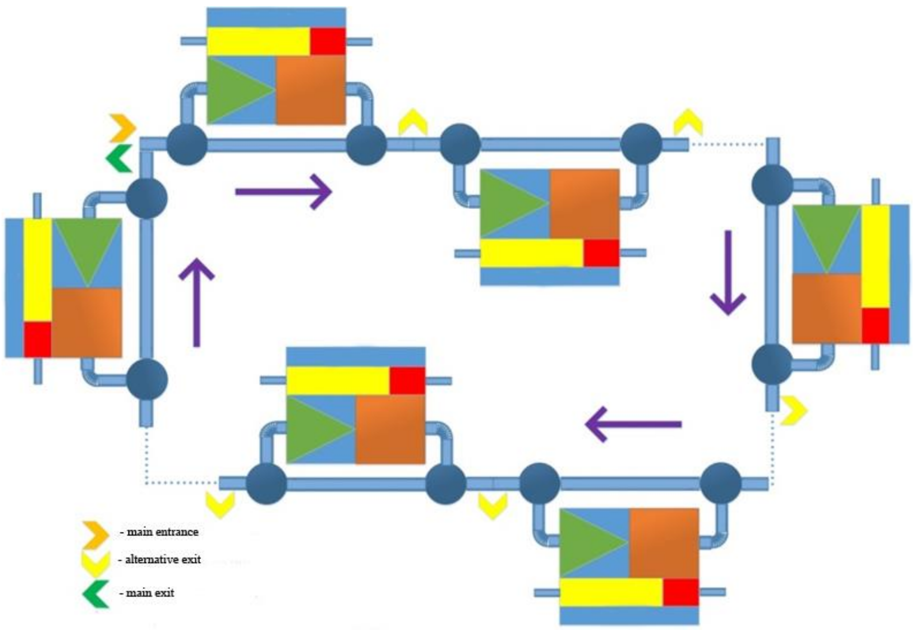

Figure 3 - Architecture of a manufacturing system with feeders

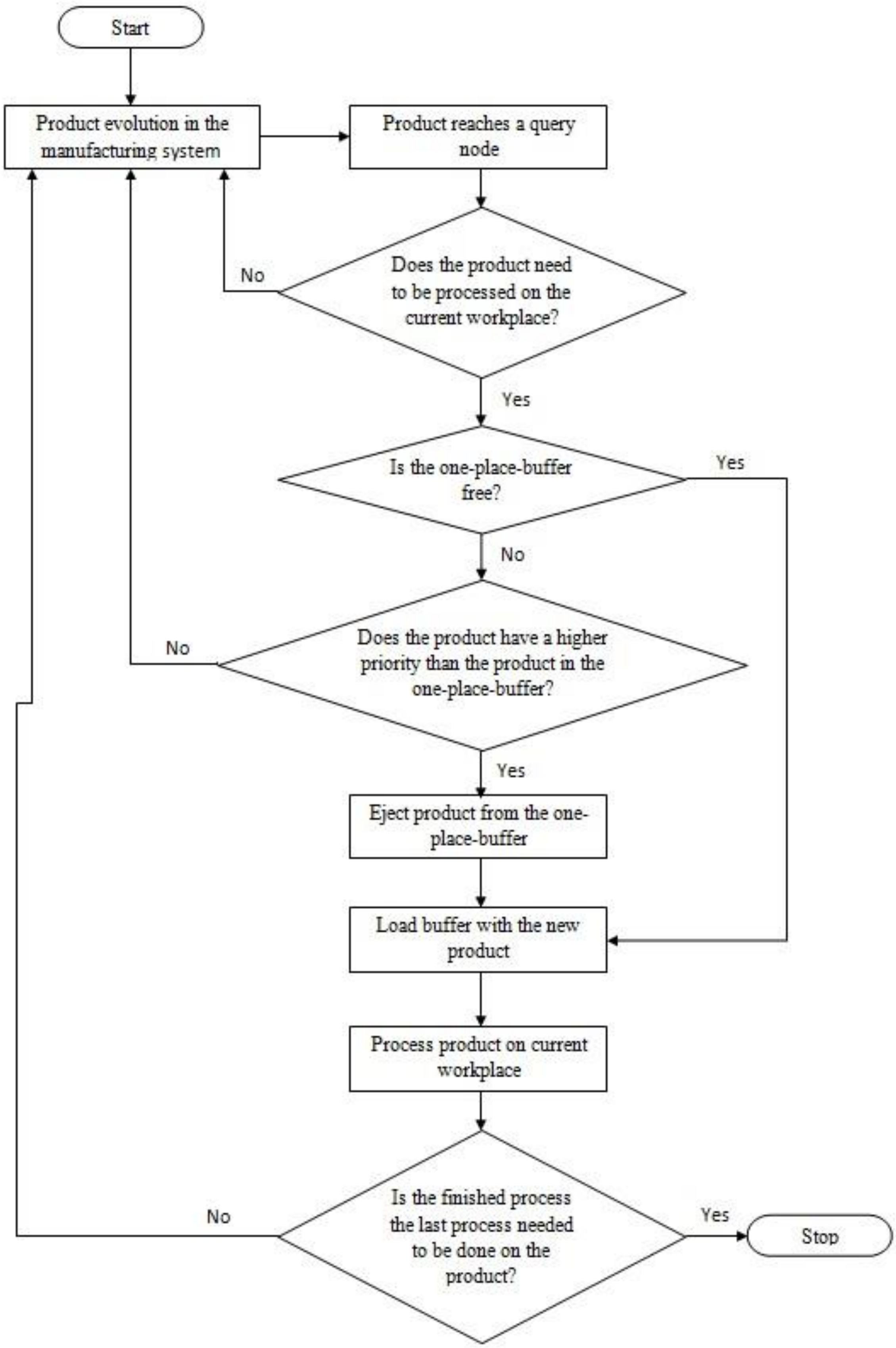

Figure 4 - Comunication in a feeder manufacturing system

Experimental models, results and interpretation

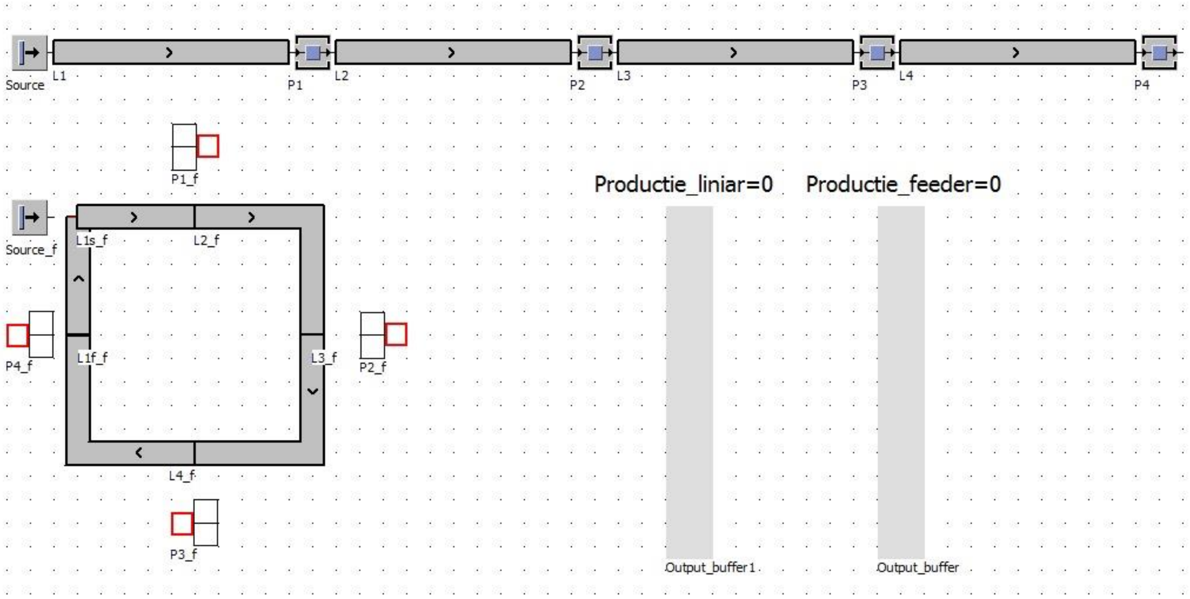

Figure 5 - Experimental models

Two experimental models were designed with the purpose to run simulations and test the model designed after the feeder concept performance: a linear production line model built according highest flexibility concepts used nowadays and a feeder production line. Both production lines have same physical parameters but the feeder line is configured after feeder concept design.

Table 1 - Parameters used for testing

Parameter	Level				
	1	2	3	4	5
TP (processing time)	random	=	↘	↗	
PR (priorities)	random	↗	↘		
CR (characteristics of products)	random	1c	2c	3c	4c
		C1	C1, C2	C1, C2, C3	C1, C2, C3, C4
		C2	C1, C3	C1, C2, C4	
		C3	C1, C4	C1, C3, C4	
		C4	C2, C3	C2, C3, C4	
			C2, C4		
			C3, C4		

Three parameters were used for testing:

- processing times of workplaces, with the following levels:
  - random processing times between workplaces;

- equal processing times for all workplaces
- decreasing processing times from the first workplace towards the last;
- increasing processing times from the first workplace towards the last.

- Priorities of the sequence of products:
  - Random priorities for the products in the sequence that needs to be processed;
  - Increasing priorities from the first product towards the las product;
  - decreasing priorities from the first product towards the las product.
- Characteristics that every product needs to have processed – every workplace in the system it is considered to be able to process only one specific characteristic:
  - Every product in the sequence can have random number and type of characteristics that need to be processed;
  - All products need to have processed one characteristic;
  - All products need to have processed twocharacteristics;
  - All products need to have processed three characteristics;
  - All products need to have processed four characteristics.

A factorial experiment was calculated and 60 experimental cases simulated on the experimental model presented in figure 5.

A priority gradient was defined according to the order of priorities of the products at the entrance in the feeder system and another gradient of priority was defined according the order of priorities of the same products at the exit from the feeder system.

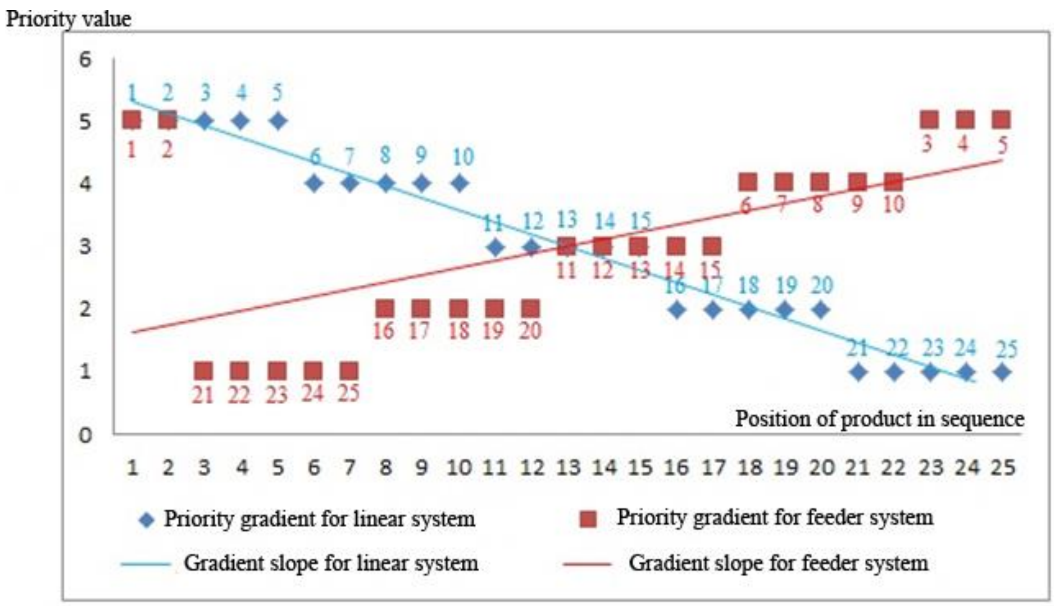

Figure 6 - Priority gradient exemplification

We present the gradient graphics for first 3 experiments. The **blue gradient** represents the entrance sequence of priorities and the **red gradient** represents the exit sequence o priorities from the feeder system.

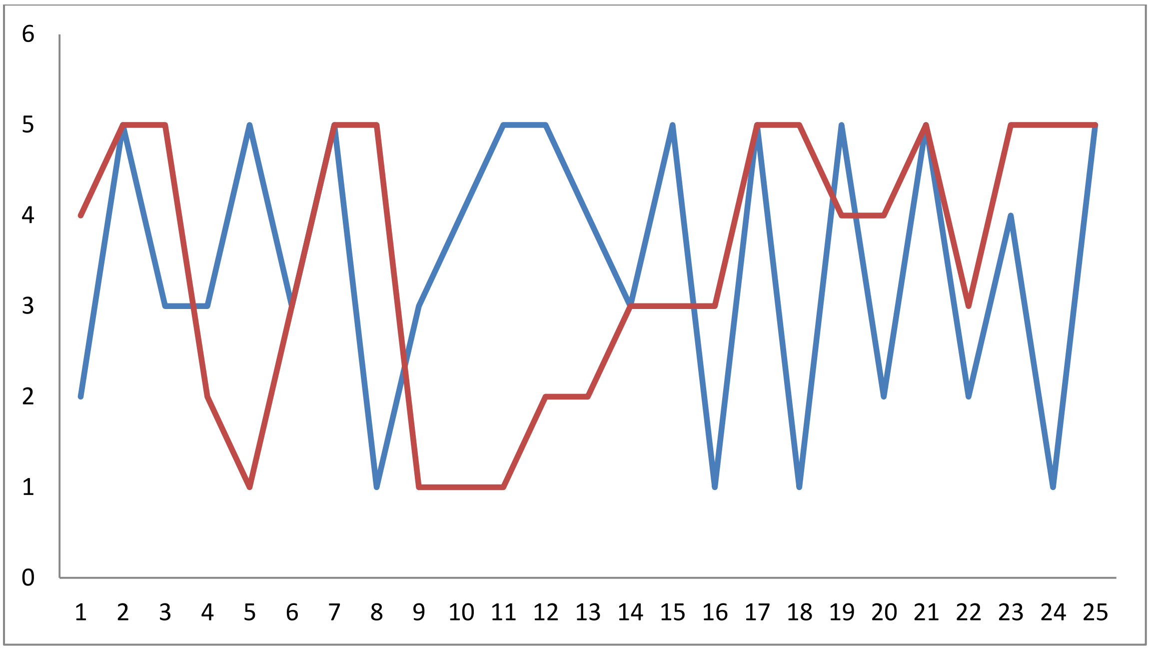

Figure 7 - Priority gradeint for experiment 1

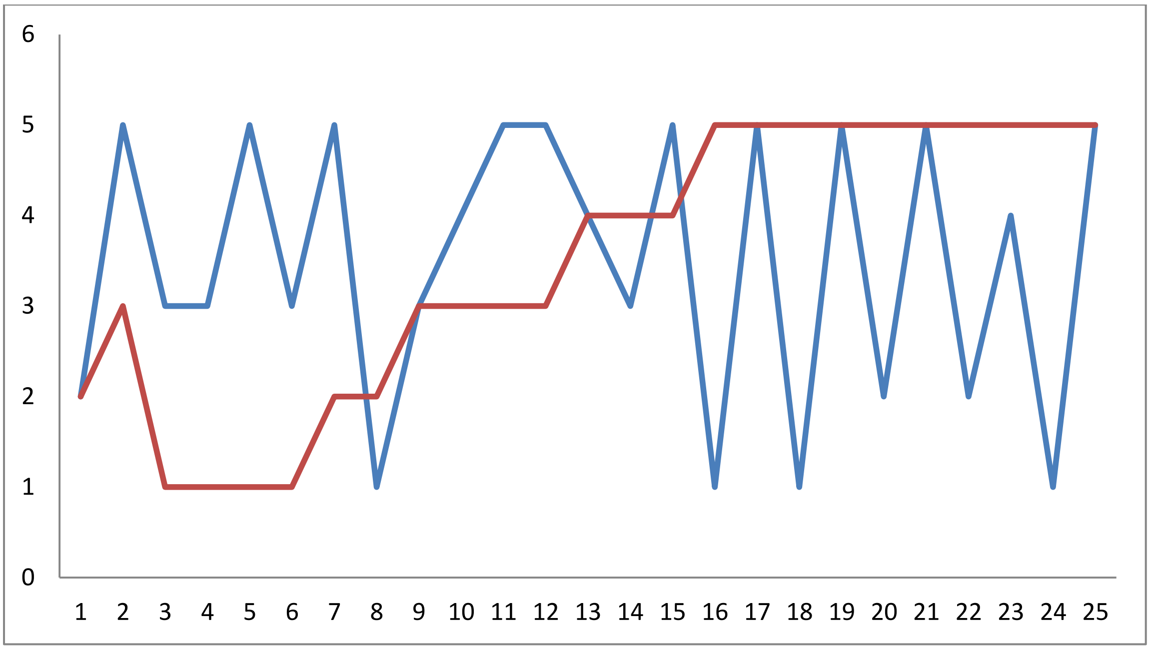

Figure 8 - Priority gradeint for experiment 2

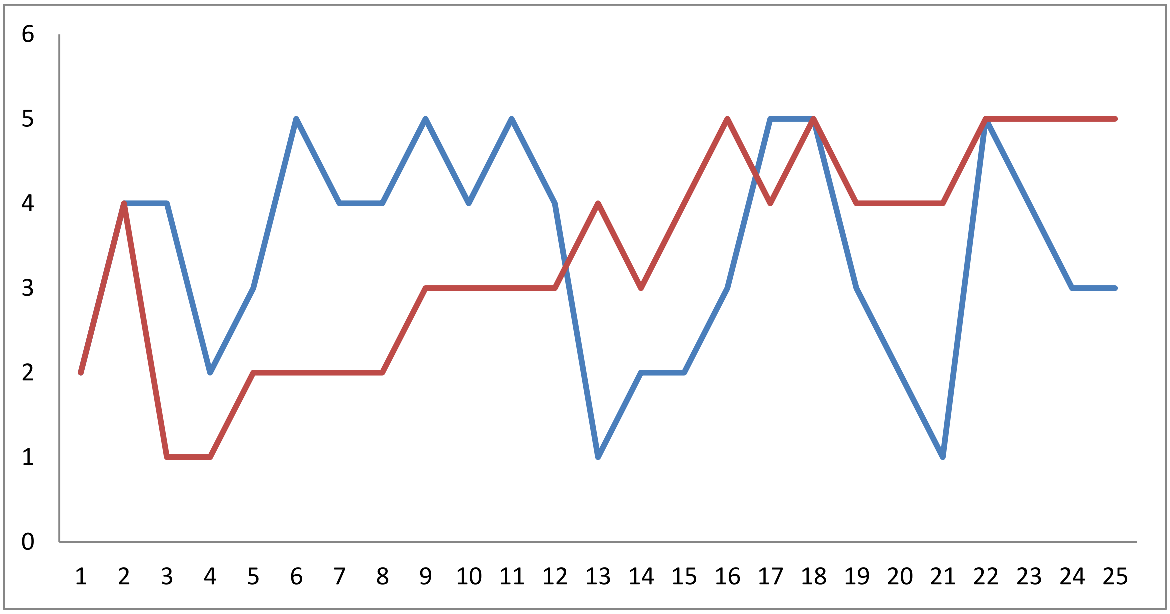

Figure 9 - Priority gradient experiment 3

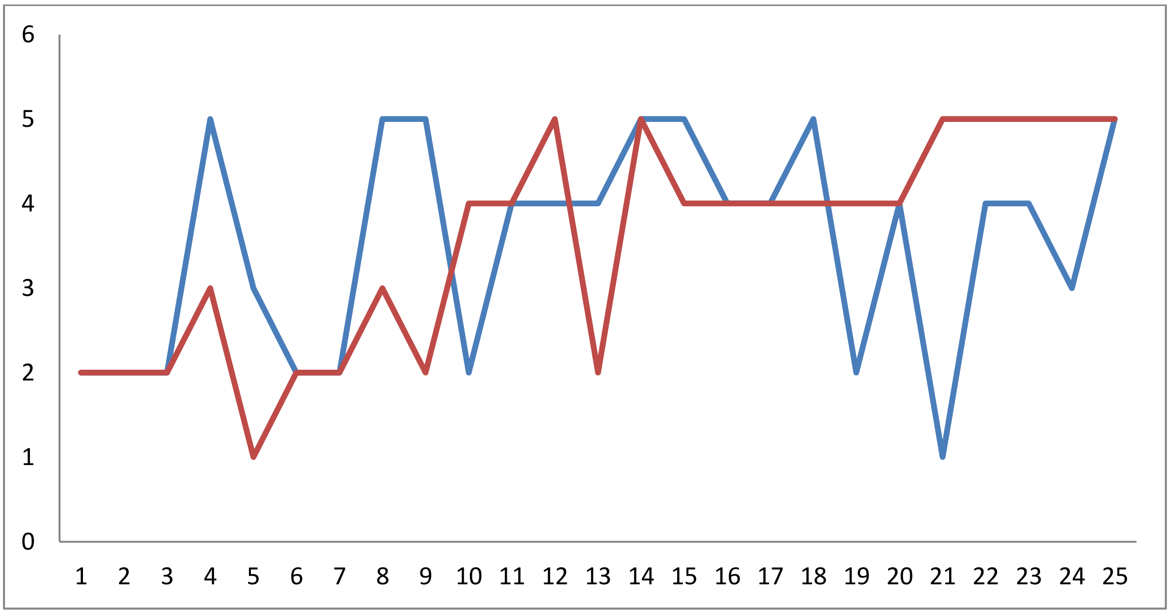

Figure 10 - Priority gradient experiment 4

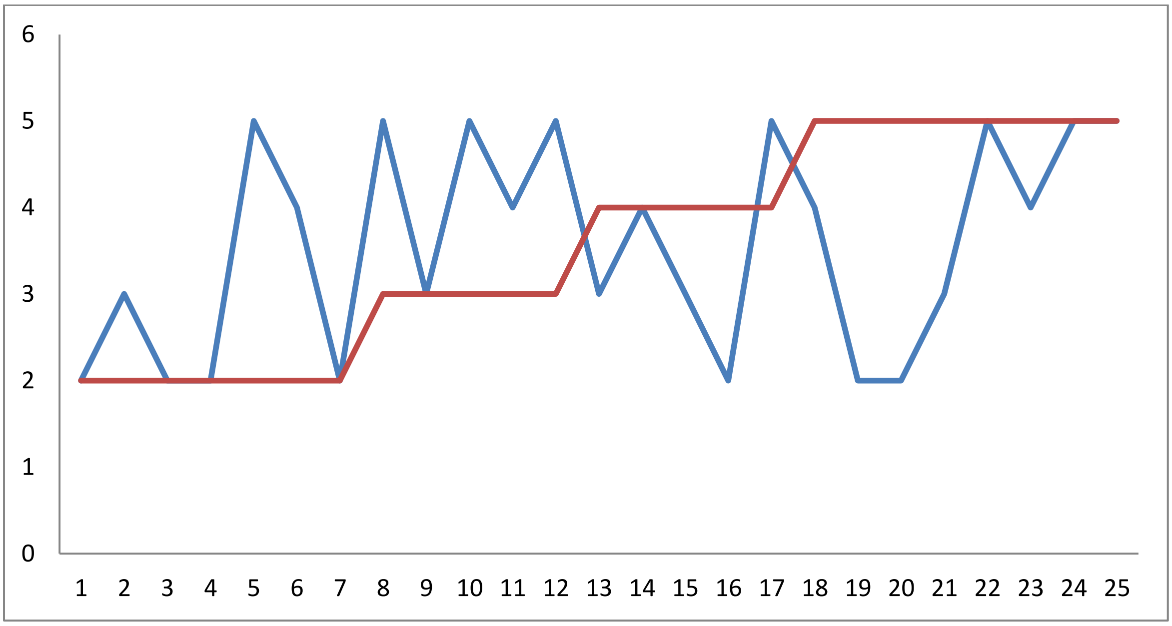

Figure 11 - Priority gradient experiment 5

To test the performance of the feeder production system we designed a factorial experiment based on a set of three parameters: the processing time of each workstation, priorities and characteristics of each component. These parameters are considered sequentially as follows: workstations sequence as it is found on the production line, in terms of processing time, the sequence of components in terms of priorities and characteristics, analysed at the entry and exit from the production line. After modeling and simulation of the feeder production system, the experimental results show that a clear prioritization is performed on the feeder manufacturing system, prioritization that can be seen on the gradient charts of priority showed in this section, charts showing an ascendant trend towards input sequence, a trend that means higher priority parts processing before lower priority parts or less significant.

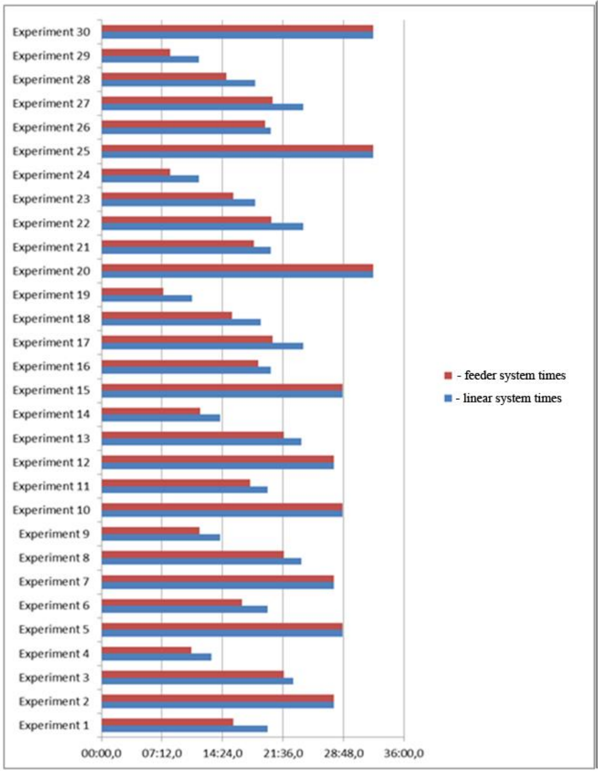

Figure 12 – Sequence production times (first part)

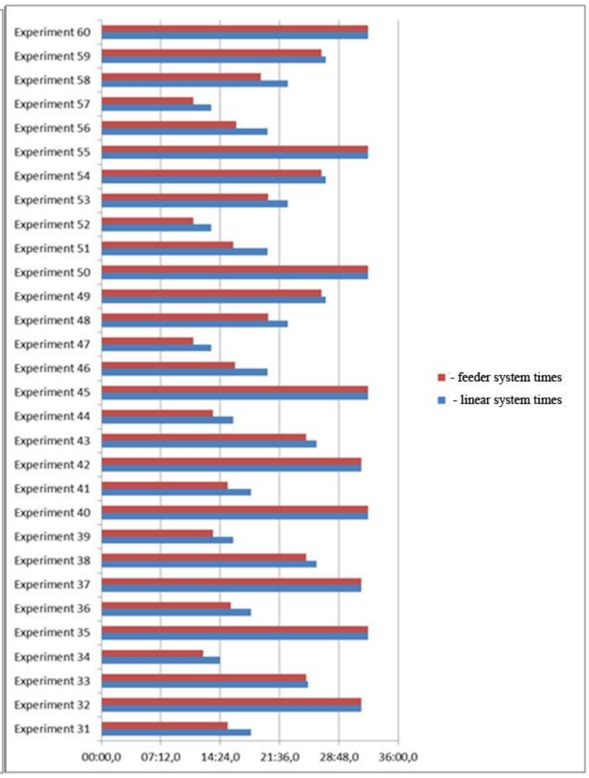

Figure 13 – Sequence production times (part two)

In terms of working time, in Figure 12 and 13 it can be observed clearly that the feeder manufacturing system end the processing components sequence in all cases faster or at the same time as the manufacturing system commonly used today and simulated also for comparison in this paper. These results which show lower or equal times of manufacturing with the feeder system compared to usual manufacturing system, corroborated with prioritization of components which is made during this time by the feeder manufacturing system clearly show superior performance of the new concept from the point of view of both the prioritization and time of manufacture. The results clearly show a good gradient priority to products manufactured with feeder system and a manufacturing time smaller by 15% for the component sequence of feeder manufacturing system.

Thesis structure, original contributions and future research directions

Ph.D dissertation Structure

The paper includes 6 chapters, presented in 308 pages, 142 figures, 132 tables, 8 annexes, 181 references and is summarized below.

Chapter I presents aspects of customer satisfaction and the importance of understanding as to their precise needs. It is not enough but that just the needs to be understood precisely, it is also necessary that the needs to be translated accurately and in the finished product. A very important aspect in the manufacturing of a good is the time between placing the customer's order and receiving the product by the this. This time is defined as the *lead time* and can act upon by several methods. We approach two general mechanisms that may influence lead time:

- Operating mechanisms of the companies, as: ERP, MES, SCADA, SCM, CRM;
- The development mechanisms of the product, where we remind a current holistic philosophy for manufacturing has at its centre the product, and is also known as PLM philosophy.

Further research direction focuses on **the system and transport entities influences from the manufacturing systems**. The properties of the transportation systems are defined as being: flexibility, adaptability and agility, efficiency, in order to meet the market demands that passed in the recent years from a local economy to a global one, demanding parts that require high quality products at low costs, highly customizable and short life cycles, running practically from mass production to mass customization production [PAU04]. This type of decentralized mass production raises issues with both production planning and production level itself due to rigid systems that require extensive programming and sequencing of production, activities which occupy a large percentage of lead time, are complicated to apply and is often based on decisions of particular persons engaged in such activities, decisions concerning the employee's experience and ability to find the best solutions in a short time; This process is quite uncertain and is subject to human error.

In the recent years they're searching for solutions to these problems focusing on: decentralization, intelligent product, production environments able to integrate and manage the development of intelligent products, operation at the high processing capacity reached by the IT industry today.

Chapter II presents aspects regarding mass production, flexible production lines, focusing on the production batch or production Job Shop and continuous production or production Flow Shop. It is highlighted the problem of Job shop scheduling systems, which is considered the highest degree of difficulty in computer science, which translates the problem in flow shop type production, but with the addition of the constraint access to working parts depending on conveyors routes.

Forward, we analyse the conveyors and conveying systems which these use. Because without goods there will be no object for carriers, treating the current state of conveyors and transport systems begins with the classification of the transported goods. After a short history, we analyse the conveyors and transport systems by the following criteria: conveyors consistency, the path and the type of action to the production site, the method of operation, type of action, the order of the conveyor, an than we present a number of commonly used conveyors for the production and storage process.

Further, the research is moving towards the direction of assembly line type flow shop thanks to the special problems which stand on these lines for the manufacture of customized products. In this section we analyse:

- The evolution of intensive industrialization since the first assembly line (Ford Motor Company - 1908) and preliminary theories;
- Information technology and its impact on the production methods;
- Flow Shop Type assembly lines configuration;
- Balancing assembly lines;
- Types of assembly lines according to the manufactured product:
    - Lines for unique designs;
    - Lines for mix designs;
    - Lines for multiple designs;
- Control of the assembly lines;
    - Tactat;
    - Netactat sincron;
    - Netactat asincron;

The problem of manufacturing customized products is treated in detail in the next section, which describes:

- BTS (Build to Stock) and BTO (Build to Order) production approaches.
- BTO implementation difficulties.
- Virtual prioritization and its methods;
- Physical prioritization and its methods;

- Steps of fulfilling an order from its placement to delivery of the product to the customer;
- Decentralized manufacturing and it methods.

In concluding Chapter II we present a flexible manufacturing system based on intelligent agents developed by Daimler Chrysler, which deals with pre-production sequencing and prioritization to pre-production, and fulfils 99.7% of the theoretical optimum production (preforms / hour).

Chapter III presents the objectives of the phD thesis, summarized below:

- Defining a concept of priority manufacturing of products on the assembly lines;
- Defining a generalized manufacturing system capable of satisfying the defined concept;
- Defining the intelligence of the manufacturing system (agents);
- Defining the communication diagram underlying the rules of the manufacturing system;
- Testing the new concept and the defined rules by constructing a simulated model and its testing using factorial experiment.

Chapter IV presents the principle of gas bubble, principle which defines the priority manufacturing of products by analogy to the natural phenomenon of flow-through of the liquid by gas bubbles of different diameters, which influences the time at which the bubbles reach the surface, so bubbles of large diameters reach the surface before the smaller diameter bubbles due to their higher flotation. It presents the programmed manufacturing and sequencing and FIFO manufacturing using the gas bubbles model in order to be observed compared to our natural style, requiring further action (in the case of manufacturing by programming and sequencing) or does not have the desired results (for FIFO manufacturing).

It defines a feeder manufacturing system, whose principle is set out in the first step, through a gas bubble conceptual model. In the next phase, the general principle of the feeder system and feeder manufacturing system architecture comprises of:

- Transportation system;
- Jobs;
- Interrogation points at the entrance and exit of the workstation;
- feeder.

In presenting the transport system an analysis of the arrangement of workstations in series or in parallel on the production line is made, and also an analysis that considers the mileage of parts where exists alternative outputs from the system after each workstation .

The following stages describe the process of the production system running the feeder and the communication diagrams that define the rules of the new manufacturing system.

Chapter V presents the experimental analysis of the feeder manufacturing system. Are presented the used experimental parameters and are defined two experimental systems:

- An experimental system build based n the actual functioning rules of the continuous flexible systems, respectively: linear system, netactat, out of step;
- A feeder system with exactly the same parameter as the liner system but with the following differences: each workstation has a feeder and the transportation system is cyclic.

The factorial experiment is defined as the range of 60 experiments in order to cover all possible situations depending on the finite experimental parameters.

The results clearly show a good gradient priority to products manufactured with feeder system and a manufacturing time smaller by 15% for the component sequence of feeder manufacturing system.

Original contributions and future research directions

Theoretical researches on the study and identification of existing problems in the following fields of interest:

- Functioning mechanisms of the companies (ERP, MES, SCADA, SCM, CRM);
- Control mechanisms of the companies (PLM process and its instruments);
- Flexible production lines;
- Continuous and discontinuous manufacturing;
- Conveyors ans transportation systems;
- The assembly problem on Flow Shop manufacturing lines.
- Balancing assembly lines;
- Manufacturing of personalized products in current context;
- Production 2000+ production system analysis.

Original, theoretical and applicative contributions:

- Classification of transportation systems based on the type of action of the conveyor;
- Classification of conveyors:
  - By order;
  - By action area;
- Generalized models of the flow shop configuration lines:
  - Linear;
  - Circular;
  - Circular-mix;
  - Linear-selective;
- General diagonal model of the conveyor systems.
- Calculation of distances to be made by the parts of the production line if:
  - The layout of workstations is in series;
  - The layout of workstations is in parallel;
  - Components emerge from alternative output from the system;
- Defining the principle of operation of the feeder production system in analogy with nature, on the principle of gas bubbles;
- Defining the generalized manufacturing principle of feeder system;
- Defining the generalized architecture of the feeder manufacturing system;
- Defining logical schemes operating hubs query input and output;
- Defining the structure and operation of the feeder;
- Defining the communication diagram in the feeder manufacturing system;
- Defining critical case for the productivity of the feeder manufacturing system;
- Develop simulations to determine the performance of the feeder manufacturing system:
  - Experimental study and description of the linear manufacturing system and of the feeder manufacturing system.
  - Experimental modelling of the linear manufacturing system and of the feeder manufacturing system.
  - Analysis of the representative parameters and experiments design;
  - Design of simulation;
  - Integration of representative parameters into the simulation and conducting the experiments;
  - Centralize and analyse the results.
  - Design a factorial experiment to determine the performance of the feeder manufacturing system.
  - Extract and analyse the results.

Future research directions:

- Analysing the feeder manufacturing system using alternative outputs of the system.
- Analysing the feeder manufacturing system using alternative cycle in the system.
- Using mixed models with features of arrangement type not only of combinatorial type.

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Professional experience

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German	A1	Elementary user	A1	Elementary user	A1	Elementary user	A1	Elementary user	A1	Elementary user

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