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RESEARCH AND CONTRIBUTIONS TO THE SIMULATION OF FLEXIBLE MANUFACTURING SYSTEMS

DOMENIUL: INGINERIE SI MANAGEMENT

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Acknowledgment

Even if the habilitation thesis must prove the scientific independence of the researcher, this does not mean that the content of the thesis is the exclusive result of his solitary effort. On the contrary, this requires collaboration, understanding and communion which can be found while working alongside colleagues or benefit from the experiences of partners or strangers whose scientific papers animates knowledge. Thanks are not shown here for free and cannot fully express the appreciation and gratitude that is due.

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Abstract

Today's world is dominated by innovation and progress. As a sequel of rapidly growing worldwide research, we constantly hear that the only certainty is change. The life-span of products tends to shorten, great producers trying to stimulate the request for the products or services they offer.

At the same time, the production of material and spiritual goods has represented along the years, one of the most important and constant preoccupations of mankind. Thus, it has become a permanent activity, which has evolved into a more and more organized one, and which has allowed the satisfaction of the growing needs of mankind.

The area of productions is an ever present-day topic. The higher the living standard of people, the higher the consumer's demands towards the products they use. Producing goods tends to become quite scarce an activity in more and more countries. Global production and the borders of the producing country do not matter anymore, having in view that the goods can be sold in all corners of the world. The producers seek competitive advantages on all continents in order to set their production points. The top producing countries are generally the Asian ones, which offer the advantage of cheap labor force, there are other factors that have to be taken into consideration before opening a production point in a certain location. Monetary (fiscal) and political stability could be another criterion in choosing a country that should host the production systems.

The most important component of any production system is the decision-making one, which is made of managers who set up the strategies and combine the art of leadership with personal intuition. It is difficult to anticipate the request of the market, even if the decisions, in what production is concerned are taken as a result of complex marketing studies. A good manager knows how to adapt when taking the best profit generating decision, and ensures the sustainability of the organization. The adaptability of the firm to the market must be ensured by top-management, an entity responsible for the overall balance between request and offer. The companies have understood that adaptability comes from flexibility and have managed, to develop a profitable system, even if they don't have serial production. This means, that production must be programmed so that the effort of changing according to the requirements of the environment and the adapting of the machines to the task should be minimum and in the end different products with different characteristics should result.

Nowadays, when we speak of the globalization of the markets, competition has become multidimensional. The demand of merchandise imposed that industry should have the ability to make in a short period of time top-quality diverse products, at a competitive price. What is more, the producers must obtain benefits in order to continue their investments, which is a sine qua non condition for development. Financial crashes smoothen the pace of development and at the same time they may "fortify" the strong, the ones who know to adapt rapidly to the, given context. The economic crash also brings about the forced optimization of those who want to survive. The large corporations restructure their staff and activities, in an attempt to reach the highest point in performance. The need to survive, as the proverb tells us: "what doesn't kill us makes us stronger", may lead to new discoveries and may strengthen worldwide players as opposed to the disappearing inadaptable ones. The danger of the monopoly in many fields of activity is more real than ever.

A rapid response to this challenge is offered by the FMS, with flexibility as a main characteristic feature the FMS, though little known at worldwide scale, is not a very new concept. The high cost of implementing such a system is the main impediment in buying and using it. As a result of not knowing them, the potential of these systems is not yet well exploited. The manufacturing system differ from the regular production systems by the property of "flexibility", which actually change their entire functioning, being able to produce a family of products with similar characteristics, but different from each other. A FMS is generally implemented in order to reduce the production-time and to generate a large diversity of products out of a well-defined typological area.

Diversity in production is the reaction to the demands of the market that tends to ask for personalized products, even products that are unique, which should exclusively satisfy a particular client. We may this consider flexibility as being a key-factor of organizations which deal with the production of goods. Well - organized serial production is profitable, but tends to be "morally worn-out" nowadays, because it can satisfy a small part of the demands, creating many identical products in a world that wishes diversity and personalization.

The established principles of economy define scale economy as being performed by production at the lowest costs. Applying flexibility in production, one cannot see this mechanism. The market studies of the marketing departments within large corporations prove the desire of the consumer to own personalized products perfectly adapted to his needs. Those who survive are the ones who manage to make more complex and personalized products at the lowest costs.

Creating flexibility in manufacturing is a long term investment, and the indicators proving its profitability will be seen only on medium or long terms. If one sees the problem from this angle, the FMS prove themselves to be useful and profitable.

Thus, the Flexible Manufacturing suits better the present day profile of the demand of products on the market, in other words, it shapes better the fluctuations of the market. Within this aspect, the arguments go both ways (in two directions), on one hand, the market is not of the producer, but of the consumers, the clients being the ones who tell the type, the quality, the quantities, the dead-lines, the terms and eventually the price. On the other hand, in a world that integrates itself and unifies, as a paradox, the individuals wish to assert and promote their identity and this way, the demand of products diversifies and gets personalized. Flexible manufacturing is able to answer significantly in both directions.

The actuality of this subject consists in:

- The ability of the producers to constantly adapt to the frequently occurring changes of the market. Once a new domain arises, the system is ready to adapt and create a competitive advantage.
- They economize resources, like manpower, which is partially or even completely replaced by industrial robots. One needn't worry about these costs when operating with such a system.
- By saving energy or other resources, these systems more sensitive towards protecting nature and the environment.

However, the disadvantage that tends to keep away the investors from such systems is represented by the high implementation costs, as well as by identifying the best programming method, according to the needs of the producer.

The investment costs are justified, because acquiring flexibility supposes providing the factory with top performance machines like: industrial robots, computer numeric control machines, automated conveyors and transporters and calculation systems of high performance.

After the investment, one would naturally expect a radically changed result in the profitability of the company that has adopted this system. This is not always a certainty, though, because one also needs to invest in the programming area. A performant, yet inadequately programmed system, may generate costs that are even higher than those of a rigid system.

Flexible manufacturing represents then a dynamic field of research that continuously offers new theoretical and practical solutions, and, irrespective of the subsequent difficulties, they have got the attention of the researchers, and absorb a great researching effort.

Having all this in mind, we are not surprised by the emerging intersection of multiple research that come from different areas of knowledge in this field of great scientific interest. The FMS represent, by even their definition and genesis, joining points of several disciplines. However, as a paradox, in the specialized literature it is often stated that until now, a formal method hasn't yet unanimously been accepted in order to generate a FMS.

Furthermore, one cannot but mention the fact that the results obtained in FMS are not entirely certain yet, a part of them being practically visible, another part still awaiting acknowledgement.

This is then an area of great novelty and potential in a context in which until the present this seems to be the only way in which production can answer the challenges of the future. There aren't significant common denominators for defining FMS, neither for designing them, nor for programming them for that matter. We could even say the same for the choice of the classes of products and for many other aspects. This area of research, scarce in consensual elements, naturally reprsents an intriguing environment for the researchers of this field.

On the other hand, the FMS are large targets that absorb a consistent investment. In this context, any reasoning or any entropic limitation of the stages of the birth and life of a FMS may generate considerable economical effects. This fact represents a powerful impulse towards research.

A FMS gives the consumer multiple benefits. Among these, the following must be mentioned:

- Diversified products, favored by every client;
- Products of high quality;
- Low costs in some cases, due to the optimization of the FMS;
- Rapid response to the demand.

Knowing the fact that investing in a FMS is an effort for most economic agents, one must know the demands this system will have to answer, even from the early stages of designing the system. Having in mind the calculations, the system can be dimensioned and its components can be adjusted so that it could face the demands and the types of products. A high flexibility leads to high transition costs and to not using the machines at a maximum capacity.

After the system is established, its management is very important, so that the system would have as little inefficient time as possible and the products would be diverse and of high quality. A long term, profitable FMS must follow a thorough programming of the production task. According to the complexity of the products of the system, the management effort of the flexible manufacturing grows. Flexible manufacturing actually means always producing the goods required by the market and the performance of programming these systems lays in bringing together all the characteristics of the required products. Reaching a balance between the demand and the production capacity is a challenge for many companies. The ideal moment is when the market is satisfied and the system works within certain acceptable economic parameters.

In the implementation and functioning stages o FMS appear different costs, according to which the whole production is defined. A lucrative production is one with low costs and qualitative parameters as high as possible.

In the functioning stage of flexible systems, the most significant costs, according to the specialized literature, are the "transition costs" that represent the defining "demand" of this system. Besides the regular costs of all production systems (energy, manpower, materials, etc), the transition costs represent the time in which the system makes the effort of adapting itself to the making of the new task.. This time is necessary for the changing of the tools, taking the data out of the computers, checking the new tools, solving errors, etc.

Starting from these costs, the specialized literature deals with the whole reasoning of the FMS, having as a main point their reduction. The production time of a modern enterprise is much lower than 40 years ago, and the performance of a system is beginning to depend on factors other than the technology of the enterprise. Only 8% of the time necessary for the production of a piece represents the actual operation time in which the tool works on the material. The rest of 92% represent logistics and organization, when the pieces or the materials are transported, the machines are prepared, the tools are adjusted, or other activities concerning the preparation or completion of production are performed. Thus we can notice the necessity of reducing the auxiliary time in order to increase the general performance of the enterprise.

Last, but not least, flexible manufacturing represents a fascinating research area, which not only points out the limitless significant aiming points, but also shows a multitude of aspects that are compatible with various domains in the field of knowledge. Thus, the topic of flexibility synchronizes with the development of calculation technique, of automation, cybernetics, robotics, logistics, mathematical design and so on. In this context, one can state that this is a "universal" topic that can absorb very different knowledge, skills and abilities.

The research performed by the author both in his doctorate paper and afterwards, tries to optimize some of the implementation stages and the exploitation of these systems and to bring novelty and usefulness to the theories already present in the specialized literature.

Performance is achieved by the correct choice of the task, so that the costs are as low as possible, as close to the serial production as possible; this could be achieved by minimizing the transition costs.

Motivating the research in the field of FMS programming had as a starting point the above argumentation and had the following underlying ideas:

- The research of the efficiency of the last- generation systems such as the flexible ones is an impulse that raises the enthusiasm of any researcher;
- After heavily investing in flexible production, obtaining non-profitable parameters seems a paradox which should be eliminated by devising new system management methods.
- Programming the FMS is the element that gives coherence to their functioning
- Current programming methods are classical and do not combine solutions offered by superior mathematical methods, such as the theory of mathematical games.

The opportunity of this paper is also given by a surprising situation existing in the specialized literature: although the FMS represent the peak of technological complexity, they do not have a unanimously accepted mathematical apparatus that should represent a scientific basis for their constitution and for the monitoring of their functioning, this issue being the preoccupation of many researchers in the field.

The Habilitation thesis represents a synthesis of the research and the results obtained by the candidate after acquiring the doctorate degree of the Technical University of Cluj Napoca, confirmed by the degree no.182/27.06.2005. **This thesis briefly presents the main results obtained by the author as a sequel of the doctorate research in the area of FMS functioning. The thesis has been structured in five chapters.**

The first chapter presents the actuality of FMS development in the context of flexibility, the stages of FMS programming and the ways the FMS work. The second chapter follows the issue of mathematical game theory in a general manner (pointing out its applications, from early times up to the present, types of games and their applicability) and from a particular perspective

– an application in management. The third chapter is the main part of the thesis and it presents the most significant results obtained by the author in the area of programming and simulation of FMS functioning, with the help of math game theory.

Thus, the paper presents the results obtained by using game theory in the analysis of a FMS production task and in a FMS programming. The fourth chapter presents, through an application, a possible future direction in research: FMS structuring with the help of value analysis. In the end, the fifth chapter presents the results of the research activity and the candidate's research skills, as well as future research directions and professional development of the candidate. All the original contributions are presented in the context of the present stage of the scientific research of FMS programming and management.

The author of the present thesis stands out by hs expertise and experience within the Technical University of Cluj-Napoca. The main areas where the author has conducted his research since 2005, could be mentioned as follows:

1. **The programming and simulation of the production systems' functioning (operation, optimizing production systems).**
2. **Using the mathematical game theory in shaping management processes.**
3. **Research conducted in order to point out the common grounds of management and religion.**

In this respect, in order to illustrate the candidate's professional skills and achievements, the numerous accomplishments obtained after his doctorate degree, since 2005, must be mentioned: **Six published books** with topics focusing on the research area, **over thirty six scientific works** published in journals or presented at prestigious international conferences, **membership in the public presentation committee of eight doctorate research papers, membership in the committee that oversees and evaluates more than 40 PhD candidates** and the participation as a member/director of **nine contracts** in the previously mentioned research areas. The candidate has also supervised more than 100 Bachelor's degree graduation papers and 30 MA degree theses since 2005.

Since 2005, in the Department of Management and System Engineering and also in the Department of Management and Economic Engineering of the Technical University of Cluj Napoca, the candidate has been responsible for delivering courses in the following domains: Engineering of Production Systems, Industrial Management, Operations Management, Quantitative Analysis. The activity as a professor has been performed at the same time as the research activity.

An important step in the candidate's academic career was the 2007 title of lecturer. This confirmed the necessary experience required for the following step: coordinator/ leader of a research group and coordinator of doctorate research papers. In the following years and up to the present, the candidate has performed an intense research activity, collaborating with younger colleagues and Doctorate candidates of the Management and Economic Engineering Department. Since 2007, the candidate has been a member of the coordinating and evaluation committees of more than 40 Doctorate candidates and a member in the committee of public presentation of 8 Doctorate research papers.

The research and development activity performed by the candidate all throughout his career (1993-2014) is rich and full of important achievements that can be mentioned as follows:

- **12** published books (sole author of two and main author of four);
- **97** scientific articles presented at national and international conferences, or published in specialized magazines as follows:
  - **2** articles published in ISI Thomson Reuters magazines;
  - **23** articles published in ISI Thomson Reuters conference volumes;

  - **15** articles published in magazines and volumes of several scientific events included in international data bases
  - **57** articles published in B+ journals or/and presented at prestigious international conferences
- **3** grants won in national competitions, with the candidate as project director
- **2** international grants as project responsible;
- **2** national grants as grant responsible;
- **2** international projects with the candidate as a member of the research team;
- **9** national projects with the candidate as a member of the research team.

Career development directions that need habilitation

It is considered that the research conducted by the author of this habilitation thesis is thoroughly focused , having a well defined main objective. Thus, the author will consider of utmost importance the topic- focused collaborations, as well as the dissemination of the acquired knowledge towards the interested scientific and industrial parties. The possible solutions provided by the author for the problems highlighted as not being consistently dealt with up to the present moment, represent a sufficiently solid motivation for the author to continue his research on the 3 directions previously mentioned.

As a potential future career development within the Technical University of Cluj-Napoca, we point out:

- Offering opportunities for education and improvement: a large part of the results of the research will constitute the material for the completion of certain courses (master and post graduate courses) at the Technical University of Cluj-Napoca and of certain courses for industry specialists.
- Continuing the collaboration with firms and companies whose activities have common grounds with the results obtained by the author in the previously mentioned areas of research, this being a catalyst in their development.
- Stimulating the promotion of the aims of the research areas in the academic environment by scientific works and reports, and in the interested industrial environment by focused presentations which could generate funding. There will be attempts to strengthen the ties with important researchers in the field at a national and international level. We will also try to propose new collaborations within HORIZON 2020.
- Increasing the number of research projects as manager and also developing new national and international ties (mainly European), thus attracting extra-funding. This objective may also be reached by extending the teaching and the research partnerships with universities and private companies in Europe and other countries.
- Attracting a large number of young graduates towards research as Doctorate candidates and post- graduates both in our country and abroad;
- Creating a powerful research center around the “Operations’ Management” staff within the Department of Management and Economic Engineering.

Rezumat

Lumea din ziua de azi este dominată de inovație și progres. Auzim mereu, urmare a cercetărilor tot mai ample la nivel mondial, ca singură constantă este schimbarea. Ciclul de viață al produselor tinde să se micșoreze, marii producători încercând să stimuleze cererea produselor sau serviciilor oferite.

De asemenea, producția de bunuri materiale și spirituale a constituit, în decursul timpului, una din cele mai importante și constante preocupări ale oamenilor. Astfel, aceasta a devenit o activitate permanentă, din ce în ce mai organizată, care a permis satisfacerea nevoilor crescânde ale umanității.

Domeniul producției, este o temă mereu actuală. Cu cât crește nivelul de trai al popoarelor, cu atât cresc și pretențiile consumatorilor față de produsele pe care le consuma. A produce tinde a deveni o activitate destul de rar întâlnită în tot mai multe țări. Producția globala și granițele tarii în care se produce bunul nu mai contează, având în vedere ca acesta se poate comercializa în orice colț al pământului. Producătorii caută avantaje competitive pe toate continentele pentru a-și fixa punctele de producție. Țările fruntașe în ceea ce privește producția sunt, în general cele asiatice, care oferă avantajul forței de munca ieftină, care atrage orice investitor.

Pe lângă forța de munca, sunt și alți factori care trebuie analizați înainte de a deschide un punct de producție într-o locație. Stabilitatea din punct de vedere fiscal și politic ar putea constitui un alt criteriu care determină alegerea unei țări care să găzduiască sistemele de producție.

Cea mai importantă componentă a oricărui sistem de producție este latura decizională, compusă din manageri, care stabilesc strategiile și îmbină arta de a conduce cu intuiția personală. Este greu a se anticipa cerințele pieței, chiar dacă deciziile de producție se fac pe baza studiilor complexe de marketing. Un bun manager știe să se orienteze în adoptarea deciziei optime ce generează profit și asigură sustenabilitatea organizației. Adaptabilitatea firmei la piață trebuie să fie asigurată de managementul de top, entitatea responsabilă cu echilibrul de ansamblu dintre cerere și ofertă. Companiile au înțeles că adaptabilitatea se obține prin flexibilitate și au reușit să își dezvolte un sistem care să genereze profit, chiar dacă producția nu este de serie. Adică, producția trebuie programată astfel încât efortul de schimbare, la mesajul din mediu și flexibilizarea utilajelor la sarcina de lucru să fie minime, iar în final, să rezulte produse cu caracteristici diferite.

În condițiile actuale, când se produce globalizarea piețelor, concurența a devenit multidimensională. Cererea de mărfuri a impus industriei să posede capacitatea de a fabrica produse diversificate, de calitate, în scurt timp și la prețuri competitive. In plus, industriașii trebuie să obțină beneficii, pentru a continua investițiile, condiție sine qua non pentru dezvoltare.

Crizele financiare domolesc puțin ritmul de dezvoltare, dar pot să îi întărească pe cei puternici, care știu să se adapteze în cel mai scurt timp contextului dat. Tot starea de criza duce la optimizarea forțată a celor care vor să supraviețuiască. Marile corporații își restructurează personalul și activitățile, încercând să atingă maximul de performanță. Nevoia de a supraviețui, conform proverbului „ce nu te omoară te întărește”, poate duce la noi descoperiri și poate să întărească jucătorii de pe piața mondială, alții mai neadaptabili dispărând. Pericolul apariției monopolurilor în tot mai multe branșe este mai realist ca niciodată.

Un răspuns prompt la aceste provocări îl oferă sistemele flexibile de fabricație, cu principala lor caracteristică, flexibilitatea.

Sistemul flexibil de fabricație deși prea puțin cunoscut la nivel mondial nu este un concept foarte nou. Costul ridicat necesar implementării unui astfel de sistem este principalul impediment în achiziționarea și exploatarea sa. Ca și o consecință a necunoașterii, potențialul acestor sisteme încă nu este bine exploatat. Sistemele de fabricație se deosebesc de sisteme productive obișnuite prin proprietatea de „flexibilitate" care, practic, schimbă întreaga sa funcționalitate fiind capabilă a produce o familie de produse, cu caracteristici asemănătoare, dar diferite între ele. Un sistem flexibil de fabricație se implementează în general cu scopul de a reduce timpii de producție și de a genera o diversitate de produse cât mai mare dintr-o gamă tipologică bine definită. Diversitatea în producție este reacția la nevoile pieței, care tinde a cere produse personalizate, chiar unicate, care să mulțumească în mod exclusiv un client. Putem aprecia, deci, flexibilitatea ca fiind un factor cheie al organizațiilor ce se ocupă cu producția de bunuri. Producția de serie bine organizată este profitabilă, dar tinde a fi „uzată moral" în zilele de astăzi, tocmai pentru faptul că poate satisface o mică parte a cererilor, creând multe produse identice într-o lume care dorește diversificare și personalizare.

Principiile consacrate ale economiei definesc economia de scară ca fiind realizată de o producție care este susținută cu cele mai mici costuri de producție. Aplicând flexibilitatea în producție, nu se întâlnește acest mecanism. Studiile de piață ale departamentelor de marketing din cadrul marilor corporații dovedesc dorința consumatorului de a deține produse personalizate, adaptate perfect pentru nevoia sa. Rezistă cei care reușesc să realizeze produse cât mai complexe și mai personalizate, la costurile cele mai scăzute.

Crearea flexibilității fabricației este o investiție pe termen lung, iar indicatorii care să constate profitabilitatea îi vom constata doar pe termen mediu sau lung. Dacă se abordează în acest mod problema, SFF-urile se dovedesc utile și profitabile.

Așadar, fabricația flexibilă se pliază mai bine pe profilul actual al cererii de produse de pe piață. Cu alte cuvinte, modelează mai bine fluctuațiile pieței. În cadrul acestui aspect, argumentația se bifurcă pe două planuri. Este vorba, pe de o parte, că în prezent, piața nu mai aparține producătorului ci piața este a consumatorului, clienții fiind aceia care dictează tipul, calitatea, cantitățile, termenele și, implicit, prețurile produselor. Pe de altă parte, într-o lume care se integrează și se unifică, în mod paradoxal, indivizii vor să-și afirme și să-și promoveze identitatea și, ca atare, se diversifică și se personalizează cererea de produse. Fabricația flexibilă este capabilă de răspunsuri semnificative în ambele direcții.

Actualitatea acestui subiect consta în:

- Capacitatea producătorului de a se adapta mereu schimbărilor frecvente care apar pe piață. Odată cu apariția unei noi cereri, sistemul este pregătit să se adapteze și să își creeze un avantaj competitiv.
- Economisesc resurse, cum este cea umană, care e înlocuită parțial sau chiar total de către roboții industriali. Nu mai contează așadar acest cost când se operează cu un astfel de sistem.
- Prin economia de energie sau alte resurse, aceste sisteme devin sensibile la protecția naturii și a mediului înconjurător.

Dezavantajul însă, care tinde a îndepărta investitorii de aceste sisteme este cuantumul ridicat al costurilor de investiție necesar la implementare, precum și identificarea celei mai bune metode de programare, în funcție de necesitățile producătorului.

Costurile de investiție sunt justificate, deoarece a dobândi proprietatea de flexibilitate, presupune utilarea întreprinderii cu mașini unelte performante: roboți industriali, centre de comandă numerică, benzi transportoare automate și sisteme de calcul de înaltă performanță.

După efectuarea investiției, s-ar aștepta, în mod normal, un rezultat radical schimbat în ceea ce privește profitabilitatea companiei care l-a implementat. Acest lucru nu este însă întotdeauna o certitudine, deoarece trebuie investit și în zona de programare a acestora. Un sistem performant, dar programat inadecvat, poate să genereze costuri mai ridicate decât cele ale unui sistem rigid.

Fabricația flexibilă reprezintă, așadar, actualmente, un câmp de cercetare dinamic din care se degajă continuu noi soluții practice și teoretice, și, în pofida dificultăților pe care le antrenează, suscită interesul cercetătorilor și absoarbe un mare efort de cercetare. Nu este surprinzătoare, în acest context, afluența cercetărilor care se intersectează, venind dinspre mai multe domenii ale cunoașterii, în această arie de mare interes științific. Sistemele flexibile de fabricație (SFF) reprezintă, prin însăși definiția și geneza lor, puncte de confluență între mai multe discipline. Cu toate acestea, în mod paradoxal, în literatura de specialitate se vehiculează frecvent afirmația că până în prezent nu există încă o metodă formală, unanim acceptată, pentru constituirea unui SFF.

De asemenea, este notabilă mențiunea că rezultatele obținute în sistemele flexibile de fabricație nu se situează în întregime pe terenul ferm al certitudinilor, o parte fiind omologate de practică, dar o altă parte așteptând încă consacrarea.

Este, deci, un teren cu un mare potențial de noutate, în contextul în care, până în prezent, pare unica cale prin care fabricația poate răspunde provocărilor viitorului. Nu există numitori comuni semnificativi nu numai pentru definirea SFF, dar nici pentru proiectarea lor, programarea funcționării lor, alegerea nomenclatorului de produse care se vor realiza în sistem și multe alte aspecte. Acest spațiu de cercetare, rarefiat în elemente de consens, reprezintă, în mod firesc, o incitantă arie de cercetare pentru cercetătorii domeniului.

Pe de altă parte, sistemele flexibile de fabricație sunt obiective de mari dimensiuni care absorb un efort investițional consistent. În acest context, orice raționalizare, orice limitare de entropie pentru fazele nașterii și vieții unui SFF poate genera efecte economice considerabile. Acest fapt este un puternic impuls pentru cercetare.

Un sistem flexibil de fabricație generează, pentru un consumator, multiple beneficii. Printre acestea merită să fie amintite următoarele::

- Produse diversificate, după placul fiecărui client;
- Calitate ridicată a produselor;
- Costuri scăzute în anumite cazuri, datorită optimizării funcționării SFF-urilor;
- Răspuns rapid la cerere.

Cunoscând faptul că a investi într-un sistem flexibil este un efort pentru majoritatea agenților economici, încă din stadiul de proiectare a sistemului trebuie cunoscute cerințele la care acesta va fi supus. Pe baza calculelor, se poate dimensiona sistemul și ajusta componentele lui astfel încât să facă față volumului cererii și tipurilor de produse. O flexibilitate foarte mare duce la costuri de tranziție ridicate și neutilizare la capacitatea maxima a mașinilor.

După constituirea sistemului, este foarte importantă gestionarea lui astfel încât să existe cât mai puțini timpi ineficienți și produsele să fie cât mai înalt calitative și mai diversificate. Un sistem flexibil de fabricație profitabil pe termen lung trebuie să urmeze o programare riguroasă a sarcinii de producție. În funcție de complexitatea produselor ce se fabrică în sistem, crește efortul de gestionare a producției flexibile. O fabricație flexibilă înseamnă, practic, a produce mereu produsul care e cerut pe piață, iar performanta programării acestor sisteme se bazează pe aducerea la un numitor comun a caracteristicilor produselor cerute. Obținerea unui echilibru între cerere și capacitatea de producție este o provocare pentru multe companii. Momentul ideal este acela în care se atinge un punctul în care piața e satisfăcută, iar sistemul funcționează în cadrul unor parametri economici acceptabili.

În cadrul implementării și funcționarii sistemelor flexibile de fabricație apar diferite costuri, în funcție de care se definește întreaga producție. O producție performantă este cea cu costuri scăzute în parametrii calitativi cât mai ridicați.

În etapa de funcționare a sistemelor flexibile, cele mai semnificative costuri, conform literaturii de specialitate, sunt „costuri de tranziție”[1] și reprezintă „consumul” definitoriu al acestui sistem. Pe lângă costurile obișnuite pentru orice sistem de producție (energie, forța de muncă, materiale etc.), costurile de tranziție reprezintă timpul în care sistemul face efortul de a se adapta fabricației noii sarcini de lucru. Este vorba despre timpul necesar schimbării sculelor, preluării datelor din calculator, verificării sculelor noi, rezolvării unor erori etc.

Pornind de la aceste costuri, lucrările de specialitate abordează întreaga raționalitate a SFF-ului prin prisma reducerii lor. Timpii de prelucrare în întreprinderea modernă sunt mult reduși față de acum 40 de ani, iar performanța unui sistem începe să depindă de alți factori decât de dotarea tehnologică a întreprinderii. Doar 8% din totalul timpului în care se prelucrează o piesă este timpul efectiv de operare, în care scula prelucrează materialul. Restul de 92% reprezintă timpii logistici și de organizare, în care sunt transportate piesele sau materialele, sunt pregătite mașinile, ajustate sculele, sau alte activități de pregătire sau de completare a producției. Astfel se constată necesitatea scurtării timpilor auxiliari, pentru a ridica performanța generală a unei întreprinderi.

În sfârșit, dar nu la urmă, fabricația flexibilă reprezintă un domeniu fascinant de cercetare, care nu numai că evidențiază repere semnificative până la linia orizontului, dar etalează și o multitudine de aspecte compatibile cu mai multe domenii ale cunoașterii. Astfel, tema flexibilității se găsește în sincronism cu dezvoltarea tehnicii de calcul, automatizării, ciberneticii, roboticii, logisticii, modelărilor matematice și altele. S-ar putea afirma, în acest context, că este o temă "universală" spre care pot converge cunoștințe, competențe și abilități foarte diferite.

Cercetările efectuate de către autor atât în cadrul tezei de doctorat cât și ulterior, încearcă să optimizeze unele din etapele de implementare și exploatare a acestor sisteme, și să aducă un plus de noutate și de utilitate teoriilor deja prezentate în lucrările de specialitate. Performanța se obține prin alegerea corectă a sarcinii de muncă astfel încât costurile să fie cât mai scăzute, cat mai apropiate de producția de serie; acest fapt se poate realiza prin minimizarea costurilor de tranziție.

Motivația cercetării în domeniul proiectării SFF a pornit de la argumentarea mai sus exprimată și a avut la bază următoarele idei:

- Cercetarea funcționalității unor sisteme de ultimă generație, cum sunt cele flexibile, este un impuls care crește entuziasmul oricărui cercetător;
- După realizarea unei investiții de proporții, în flexibilizarea producției, a obține parametrii neperformanții pare un paradox care ar trebui eliminat prin elaborarea a noi metode de gestionare a sistemelor;
- Programarea sistemelor flexibile de fabricație este elementul care dă coerență funcționarii acestora;
- Metodele actuale de programare sunt clasice, și nu îmbină soluții oferite de metode matematice superioare, cum ar fi teoria jocurilor matematice.

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Oportunitatea acestei lucrări este dată și de o situație surprinzătoare existentă în literatura de specialitate, și anume că deși sistemele flexibile de producție reprezintă un vârf al complexității tehnologice, el nu dispune de un aparat matematic unanim acceptat, care să pună

[1] Abrudan, I., *Sisteme flexibile de fabricație. Concepte de proiectare și management*, Editura Dacia, Cluj-Napoca, 1996.

pe baze științifice constituirea lor și urmărirea modului lor de funcționare, această problemă fiind un obiect de preocupare pentru mulți cercetători din domeniu.

Teza de abilitare sintetizează activitatea de cercetare și rezultatele obținute de candidat după obținerea titlului de doctor al Universității Tehnice din Cluj-Napoca, confirmat prin diploma de doctor nr. 182 din 27 iunie 2005. **Teza de abilitare prezintă, succint, principalele rezultate obținute de către autor în urma continuării cercetărilor întreprinse în cadrul tezei de doctorat în domeniul modelării funcționării sistemelor flexibile de fabricație.**

Teza de abilitare a fost structurata pe 5 capitole. Primul capitol prezintă actualitatea dezvoltării sistemelor flexibile de fabricație (SFF) în contextul flexibilității, etapele proiectării SFF și modalitățile de funcționare ale SFF. Capitolul al doilea abordează problematica teoriei matematice a jocurilor la modul general (evidențiind aplicațiile sale, din cele mai vechi timpuri, până în prezent, tipurile de jocuri și aplicabilitatea acestora) și în particular printr-o aplicație în domeniul managerial. Capitolul al treilea este capitolul de consistență al tezei și prezintă cele mai semnificative rezultate obținute de către autor in domeniul modelării și simulării funcționării sistemelor flexibile de fabricație cu ajutorul teoriei matematice a jocurilor. Astfel, sunt prezentate rezultate obținute prin utilizarea teoriei jocurilor în analiza sarcinii de producție dintr-un SFF și în programarea SFF. Capitolul patru prezintă, în cadrul unei aplicații, o posibilă direcție viitoare de cercetare și anume configurarea SFF cu ajutorul analizei valorii. In fine, ultimul capitol, al cincilea, prezintă rezultatele activității de cercetare și competențele de cercetare ale candidatului precum și direcții de cercetare viitoare și de dezvoltare profesională a candidatului. Toate contribuțiile originale sunt prezentate în contextul stadiului actual al cercetării științifice din domeniul proiectării si managementului sistemelor flexibile de producție.

Autorul prezentei teze de abilitare se remarcă prin experiența sa în cadrul Universității Tehnice din Cluj-Napoca. Principalele direcții de cercetare în care autorul și-a desfășurat activitatea din 2005 și până în prezent pot fi grupate astfel:

1. **Modelarea și simularea funcționării sistemelor de producție; optimizarea proceselor productive.**
2. **Utilizarea teoriei matematice a jocurilor în modelarea proceselor manageriale;**
3. **Cercetări privind interferența dintre management și religie.**

În acest sens, pentru a susține capacitățile și performanțele profesionale ale candidatului, trebuie menționate cantitativ realizările obținute după obținerea titlului de doctor (2005 - prezent): **6 cărți de specialitate**, peste **36 de lucrări științifice** publicate în jurnale și/sau prezentate în cadrul unor conferințe internaționale de prestigiu, **membru în comisia de susținere publică a 8 teze de doctorat, membru în comisia de îndrumare și evaluare a peste 40 de doctoranzi** și respectiv participarea ca membru/director la **9 contracte** pe direcțiile de cercetare menționate anterior.

De asemenea, candidatul a coordonat peste 100 de lucrări de licență/diplomă și peste 30 de lucrări de disertație.

Din anul 2005 până în prezent, în cadrul Catedrei de Management și Ingineria Sistemelor și apoi a Departamentului de Management și Inginerie Economică din UTCN, candidatul a fost responsabil al cursurilor la disciplinele: Ingineria sistemelor de producție, Management industrial, Managementul operațiilor, Analiza cantitativă. Activitatea didactică s-a desfășurat în paralel cu activitatea de cercetare.

Un moment important al carierei universitare a candidatului îl reprezintă obținerea titlului de conferențiar universitar în anul 2007. Aceasta a confirmat atingerea gradului necesar de experiență pentru pasul următor, acela de coordonator de colectiv de cercetare și de coordonator de teze de doctorat. In perioada următoare, până în prezent, candidatul a desfășurat o intensă activitate de cercetare, în colaborare cu colegii mai tineri și doctoranzi ai departamentului Management și Inginerie Economică. Astfel, din 2007 până în prezent, candidatul a fost membru în comisiile de îndrumare și evaluare a peste 40 de doctoranzi și membru în comisia de susținere publica a 8 teze de doctorat.

Activitatea de cercetare-dezvoltare desfășurată de candidat pe tot parcursul profesional (1995-2014) este una bogată și cu rezultate importante, materializate în:

- **12** cărți de specialitate (autor unic la două dintre ele, prim autor la alte 4);
- **97** articole științifice prezentate la conferințe naționale și internaționale și/sau publicate în reviste de specialitate, din care:
    - **2** articole publicate în reviste cotate ISI Thomson Reuters;
    - **23** articole publicate volume de conferință indexate ISI Thomson Reuters;
    - **15** articole publicate în reviste și volumele unor manifestări științifice indexate în alte baze de date internaționale;
    - **57** articole publicate în jurnale B+ sau/și prezentate la conferințe internaționale de prestigiu;
- **2** granturi internaționale în calitate de responsabil de proiect câștigate prin competiție;
- **2** granturi naționale în calitate de responsabil de proiect câștigate prin competiție;
- **3** contracte de cercetare cu terții în calitate de director;
- **2** proiecte internaționale în calitate de membru în echipa de cercetare;
- **9** proiecte naționale în calitate de membru în echipa de cercetare;

Direcții de dezvoltare a carierei care necesită abilitarea

Se consideră ca cercetarea realizată de autorul acestei teze de abilitare este riguros direcționată, având un obiectiv central. Astfel, autorul va acorda o importanță deosebită colaborărilor orientate pe tematică și în aceeași măsură transmiterii cunoștințelor câștigate, înspre mediile științifice și industriale interesate. Potențialele soluții întrevăzute de autor, la problemele sesizate ca fiind inconsistent tratate până în prezent, constituie o motivație suficient de solidă pentru a continua în mod natural cercetările autorului pe cele trei direcții enunțate anterior.

Ca potențial de dezvoltare ulterioară a carierei în cadrul UTCN se vizează:

- oferirea unor oportunități pentru învățământ și perfecționare: o buna parte din rezultatele cercetării, vor constitui baza completării unor cursuri (master, postuniversitare) din Universitatea Tehnica din Cluj-Napoca și a unor cursuri de perfecționare pentru specialiștii din industrie
- continuarea colaborărilor cu societăți comerciale și companii ale căror domenii de activitate se intersectează cu rezultatele obținute de autor pe direcțiile de cercetare menționate, acesta constituind un catalizator în derularea acestora:
- impulsionarea promovării obiectivelor direcțiilor de cercetare în mediul academic, prin lucrări științifice și rapoarte, iar în mediul industrial potențial interesat prin prezentări orientate, posibil generatoare de finanțări. Se va încerca întărirea legăturilor cu cercetătorii de referință din domeniu pe plan național și internațional și lansarea unor direcții de colaborare în cadrul HORIZON 2020.

- creşterea numărului de proiecte de cercetare în calitate de director/responsabil, respectiv prin dezvoltarea de noi colaborări la nivel național și internațional (european, în principal), pentru atragerea de fonduri suplimentare. Acest obiectiv se poate realiza inclusiv prin extinderea acordurilor de colaborare atât pe linie didactică, cât și pe linie de cercetare cu universități și companii private din Europa și din spațiul internațional
- atragerea unui număr mai mare de tineri absolvenți în activitatea de cercetare în calitate de doctoranzi și postdoctoranzi, din țară și străinătate.
- crearea unui centru de cercetare puternic în jurul colectivului de "Managementul operațiilor" din cadrul Departamentului de Management și Inginerie Economică .

1. Flexible Manufacturing Systems

If in the 1950s and the 1960s, the product could be considered the most important element in a production system which was centered on the goods, at present production focuses on the consumer, who establishes the rules of the game.

The stress is not on the quantitative production, but on making what the client asks for, in order to satisfy his needs with top-quality products at accessible prices. This is the only way an enterprise could be considered sustainable.

Since the appearance of the first machine used in production, the technical progress of machine construction was given by highly important factors: productivity and precision. These factors determined the passage from universal machinery to automated ones, which are strictly specialized for the use of operators, to industrial production equipment. The strictly specialized machinery did not allow, however, the swift, low cost passage from the making of one type of product to the making of a different one. Due to the ever quicker process scientific and technological development, the new manufacturing system could appear, a system that can now satisfy both the growth of diversified production and the growth of work productivity at significantly lower costs.

Along history, the manufacturing systems used in the machine construction industry have shown a rapid development. The evolution of these systems was marked by the number of pieces that had to be made, according to what the system's destination was: production of unique goods, medium serial production or large scale serial production.

Flexibility, as a main feature of the manufacturing systems, is considered to be a part of the most recent research area that concentrates most of the production focused research. The FMS were shaped some 35 or 40 years ago, once with the issue of the first industrial robot and subsequently, of the computer. At the core of these systems lays the desire of the consumer to personalize his product according to his wishes. Even if the term "flexibility" characterizes any machine whose designing stage attempts to include more and more tasks, the flexibility of the system means a difficult task for the entire system, if certain optimal parameters are followed. In what the actuality of the term is concerned, the term is one of the four main characteristics of the modern enterprise: competitiveness, adaptability, flexibility and reactivity.

Organizationally speaking, flexibility is defined as the ability of an organization to undergo limited changes, without major ruptures. The concept of structural flexibility is linked to the ability of the organization's structure and facilities and to the reaction ability of its members to adapt themselves to changes. These could arise from the organization as such, or may represent a reaction to the contextual social, economic, political changes.

The flexibility of a system consists in its' ability to adapt to a wide range of possible contexts. A flexible system must be able to undergo changes that should enable it to continue its activity in random contexts.

If in the previous centuries, production focused on discovering new technologies and work methods, regardless of the energy and manpower costs, nowadays the FMS aims at reducing these costs, and at increasing the working capacity and the range of products made by the system. This is how new, more economic machines appear, which being robot assisted, minimize the involvement of humans in production. A flexibility that is higher than a certain limit, means an increase in the costs, due to the system's effort to adapt to the manufacturing tasks.

In the beginning, the FMS mainly executed mechanical operations of turning of metal parts, hereby becoming a more viable alternative to the traditional organization on machine groups of component-manufacturing units, from the point of view of the consumed resources. In the early '90s, a new revolutionary concept is introduced to the market in the area of flexible manufacturing, called "Flexible Manufacturing Cells", also known as Chronos.[2] These cells allowed their configuration according to the specific demands of each client, in order to optimize the mechanical processing of any family of components, at low investment costs for the equipment and making them ready to be delivered. What is more, the new Chronos allowed the expansion of the working ability of the manufacturing cell to supplementary modules that could be assembled in a short period of time. The modules include: installations, pallet handlers, conveyors, charge and discharge stations, pallet depositing systems.

In the 1990s, more and more American companies adopted the new flexible systems, this developing the specialized market with almost 27%[3] between 1989 and 1992. The explanation for this rapid market development phenomenon can be found in the increasing desire to change the existing manufacturing systems and in the interest in automation, which allowed the producers of the time to achieve reduced production at lower costs for each of the produced units.

However, there also were inconveniences in adopting this new type of manufacturing, such as the initial investment in a FMS, investment that financially challenged many of the producers of the time. The large bulk of the investment was going to cover physical technological equipment (almost 60%), the rest of 40% representing future programming costs.

Another inconvenience that limited the booming development of the market was that the vast majority of these systems showed a slightly limited flexibility, being able to produce a small range or even a family of the products required by the large companies. Due to the requirements of a FMS, these systems were mainly absorbed by the mechanical processing industry.

Although at this stage a FMS succeeds in answering certain criteria of system efficiency, in order to become sufficiently competitive on the market, they keep trying to improve the quality of the products made in such a system, as well as to reduce the production – generated costs of these goods. This results in an increasing efficiency of the system.

Although automated production succeeds only now to make a statement on the market, we may say that this concept is not entirely new for the enterprises. We may say that even in the early '50s, the large producers showed real interest towards automation. In the following years, this interest grew smaller, reappearing in the early '60s. The tendency resisted on the market, and in the early '70s, the companies were not very much inclined to adopt the idea of automation. In the early '90s, the interest towards the "automated factory" grew significantly stronger.

But, this time, the dream of the factory of the future is closer to reality than ever, firstly due to the technological performances in computers and secondly, due to the improvements in robotics or in other fields of Advanced Manufacturing Technologies. Another factor that favored this expansion could be the experience gained by the equipment producers and by the using companies, especially in using and adopting the advanced technology, as well as in adjusting the other components of the manufacturing system, such as: the people and the organization.

The main reason behind this growing interest towards the FMS and for other types of automated factories is the rapid growth of competition, mainly at an international level. Among the major advantages that could be brought about by adopting a FMS, we can mention the

[2] Bibu, N.A., *Managementul Sistemelor Flexibile de Montaj*, Editura Sedona, Timişoara, 1998, pag 94.
[3] Bibu, N.A., *Managementul Sistemelor Flexibile de Montaj*, Editura Sedona, Timişoara, 1998, pag 94.

reduction of production costs and the adaptability to a continually changing exterior context. The automated systems, such as the processing and the adjusting FMS, offer the advantage of improving the company's position in both directions. Another reason for the growing interest in the FMS, would be the reduction of the life-span of the product and its increasing complexity, which is a more and more visible tendency of our present days. Due to the specifics and the requirements of a FMS, it was mainly used for mechanical processing and for processing parts and components, making use of computer numerical control cells and machines which are interconnected by automated systems of handling and transport.

Along their evolution, the existence of the FMS was centered on three distinct generations, according to the chosen constructive and functional solutions, as well as according to the organization of logistics. We can hereby identify three main FMS generations[4]:

- *The first generation* – (FMS 1) – characterized by treads and racks for depositing tools, or transfer lines that would automate the material flow. The investment in such a system that contains computer numeric control machines interconnected by a transportation system for the materials is very large. However, in order to reduce the costs of the equipment, flexible manufacturing cells appeared. These were position around 2-3 machines at most, being automatically provided with tools and parts to be processed, having an autonomous organization system and a partial serial linking.
- *The second generation* – (FMS 2) – differed from the first generation by the introduction of the industrial robot as a means of handling and transport. There appeared manufacturing systems with mobile or stationary robots which could serve the entire vicinity of machines, as well as the warehouses for materials, pieces, tools and verifying devices.
- *The third generation* – (FMS 3) – introduced for the first time the robocar to the system. With its help, the warehouse could be integrated with the transport systems. The robocar transports the pallets with parts and tools from the warehouse to the working area, where they are taken from by the robots serving the machines.

At present, there are numerous FMS in most of the large enterprises all over the world. They serve mainly the machine-construction industry, the automobile, plane and boat construction industry and the industries producing goods with a multitude of components. In Romania, (The Dacia-Pitesti Factory), we also have such functional systems; yet, few systems make an entirely flexible factory, most of them being only lines or flexible cells.

Regarding the definition of a FMS, we cannot assert that there is a universally accepted definition, but[5] after consulting 55 definitions, we may say that in most cases, the FMS are considered to be systems with commanded programming for the adjustment of the machines, where the system adapts (changes its elements) according to the tasks or to the disturbances / errors occurring from within or from outside the system. Such systems adjust themselves in exterior parameters and synchronize their work on their own, in order to avoid over-charges or non-operated machines – unutilized resources. Generally speaking, the computer appears as a commanding system in any FMS.

As stated above, multiple definitions of FMS are used worldwide, without reaching a common, generally applicable variant. Every enterprise or theoretician adds a small personal contribution that enriches the contents of the definition. This is why I will try to present a definition that I consider to be essential. According to I. Abrudan, after consulting several definitions belonging to different and various domains (technical, economical, managerial), the FMS represents "the ability of the manufacturing system to adapt quickly and economically to

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[4] Ciobanu, L., *Elemente de proiectare a sistemelor flexibile de fabricatie*, Editura Bit, Iasi, Romania, 1998;

[5] Abrudan, I., *Sisteme flexibile de fabricatie. Concepte de proiectare si management*, Editura Dacia, Cluj-Napoca, 1996, p.21

changes occurring in the exterior context or within, changes that may be pre-determined or accidental, predictable or unpredictable and that may be of long term or only temporary”[6]. This definition conclusively explains the basic function of flexibility and expresses all the events where this is present.

So, the most important characteristic of the FMS is its ability to adapt quickly and economically to a given situation. The transition period of the system is the most important cost-generator that limits production, The shorter it is, meaning the faster the system adapts, the lower the production costs are. The changes that need to be addressed, may occur within the system or outside; the exterior ones are the production tasks and the ones coming from inside the system could be seen as breakdowns or system errors.

Comparing a rigid manufacturing system with a FMS, we can notice that the latter holds some advantages that come from the way it was created and designed to function. A FMS comprises all the elements of a classical system (processing elements, logistics, control and command components), this being the reason why the system needs a complete integration of all the four previously mentioned subsystems into a single one that should take up all the functions of the four subsystems, thus providing the user with a high degree of flexibility. This implies the necessity to use computer numerical control machines, automated transporters, industrial robots and implies the existence of a communication network between these components that should concentrate the entire information flow generated by the system towards a command and control factor – the main computer.

Having in view the previous description of what a FMS should have, we realize that the value of the investment to be made by the company is a very high one. Investing in equipment and technology represents a major disadvantage of this manufacturing system. However, if we take into account all costs generated by the lack of such a system, we may say that they are considerably higher than the investment itself. Another problem arising from adopting such a system is related to the typology of products created by the company, especially to the annual series of every product. We must mention the fact that a FMS suits a medium serial production, and not at all mass production or the production of one-of-a-kind goods, which refers either to the making of an increasingly large number of the same type of product, or to the making of more diverse products in a very small quantity.

In addition, we will sketch the general characteristics of a FMS (fig. 1.1).

[6] Abrudan, I., *Sisteme flexibile de fabricatie. Concepte de proiectare si management*, Editura Dacia, Cluj-Napoca, 1996

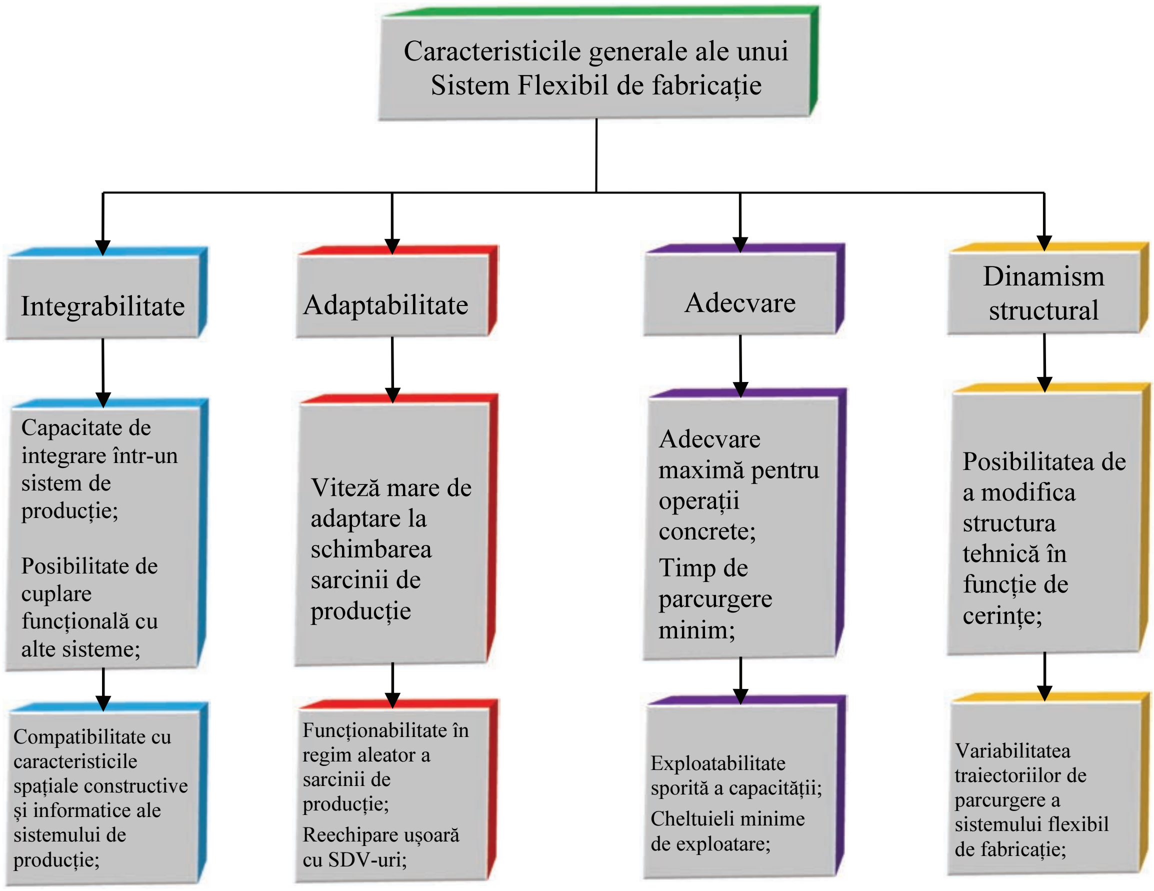

Fig. 1.1. The general characteristics of a FMS[7]

The ability of a FMS is to address the error and to adapt to change (the production task) in order to generate value (to continue making goods). The FMS adapts only to a family of types (groups or families of products), meaning similar products, however not being able to generate completely different products and to maintain at the same time the economic parameters at a competitive level.

Adopting a FMS may represent a very large investment that cannot be justified in any enterprise. Along the years[8], there have been both successes and failures in using these systems. There aren't many enterprises that can currently afford to use flexible cells, but certain multinational companies with significant financial power are successfully using them.

All the efforts regarding the research about the FMS aim at finding the most suitable solution, however still theoretical, to answer all the unknowns of the system and to achieve its precise programming within proper boundaries. The production of one-of-a-kind goods wishes to be as cheap as the serial one from the point of view of the production costs. We could mention a gradual evolution of these systems from the point of their appearance and up to the present moment. There have been several obstacles, but the main problem was to produce more and more complex goods within the same system. In the beginning, the production was performed

[7] Adapted and modified by the author from Popa Luminita, *SFF asistate informatic*, Editura Pastel, Braasov, 2007, p.28

[8] Adapted from Lungu, F., *Cercetări ;i contribuții privind managementul sistemelor flexibile de fabricație*, Teză de Doctorat, Universitatea Tehnica din Cluj-Napoca, 2005

manually, then it became mechanized and at present it is almost completely automated due to the computer and the industrial robots. Integrating the computer in the manufacturing process gave birth to a new generation of equipment and processes which are able to control the production flow more easily.

The production task is indicated at one point by the demand of the market. The production system makes the required goods, delivering them to the client afterwards. Another demand may then occur on the market, one that may not correspond to the current adjustments of the production system. This is where flexibility comes in, giving the system its ability to change, so that it may produce the goods required by the market.

An interesting statistics[9] shows that 60% of the investments for adopting a FMS were used for the hardware, meaning the equipment (technology, physical items, tools, machines, robots) and 40% were used for software (production management, planning and control programs)

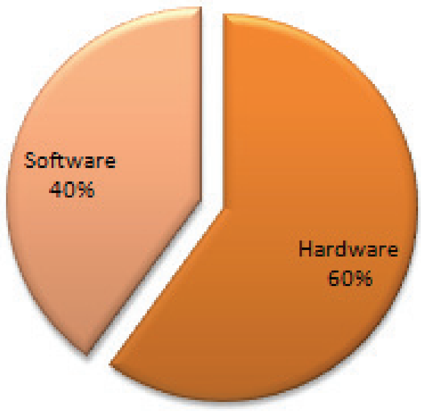

Fig.1.2 The allocation of the investments in implementing a FMS

It is a well known fact that the investments in purchasing a robot or a processing center are very large and are only recovered in a long time. The previously mentioned statistics shows that even the programming part of the system is a complex and expensive one. The investment consists in the activity of the highly specialized workforce which adjusts the system for a proper operation. This is a new impulse for the research in this field in order to find solutions for the reduction of costs.

As to where they could be used, the FMS produce small or medium batches of goods in industries such as: aeronautics and space industry, machines and tools production, the production of electric and electronic equipment, the automobile industry, and so on.

[9] Bibu,N.A., *Organizarea sistemelor flexibile de montaj in industria constructiilor de masini*, Teza de Doctorat, Timisoara, 1997, p.91

1.1. Advantages and disadvantages off the flexible manufacturing systems

Every user of a FMS could perceive differently its strong points and downsides, but I tried to mention a series of generally valid advantages and disadvantages[10]:

Advantages:
- The increasing reactivity in assimilating new products as a main favorable consequence of adapting to the needs of the market;
- The rise in the standard of man-power qualification by aligning it o mainly intellectual activities – this being a disadvantage for those adopting the system, because specialized personnel is expensive, both from the point of view of education and of the wages.
- Reducing long term investments in new machinery, due to their high productivity which allows the acquisition of a smaller number of machines and the use of the existing ones at full capacity;
- The need to modernize the buildings, the machines and the materials necessary for the production;
- Reducing the product-related costs, due to low production, transport and handling related expenses;
- The previous advantage also generates the reduction of unqualified or poorly qualified employees;
- The increase in the quality of the goods , the offer being a response to the demand of every consumer ;
- "transparent" production processes, everything being managed and reported by the computer and supervised in the key points even from the programming stage;
- Eliminating the errors and having a precise programming of activities with the help of computer simulations.
- The increase in the quality of the entire system, meaning both the products and the production itself;
- The increase in the work productivity and in the degree of capitalization;
- The orientation of production towards the idea of the green factory, by reducing energy consumption and of the installed power;
- Reducing the time necessary for the production;
- Reducing the unprocessed material sock;
- Reducing the area of the production premises;
- The fast reaction to random situations that may occur on the market. This advantage is the result of the reduced time required for preparation and completion, but also of the reduced stocks.
- Eliminating the subjective factor of common errors, by eliminating the human factor;
- The control of production is instant and continuous, giving almost zero flaws in the finite product;
- Due to the computer controlled components, any flaw in the production chain is quickly identified and addressed as such;
- The reports on the depreciation of the system components are accessible at any time, without bureaucracy and complicated procedures specific to other types of systems;

[10] Adapted from Abrudan I., *Sisteme flexibile de fabricatie. Concepte de proiectare si management*, Editura Dacia, Cluj Napoca, 1996, p 31-32 and adated from Stegerean, R., *Sisteme modern de conducere a productiei*, Editura Dacia, 2002, p.193-194

- The costs related to the preparation, completion and manageability. of production are smaller than in the case of classical production, due to the computer, because the costs regarding its programming are much lower and easily repeated, as compared to the manual adjustment of a technological equipment.

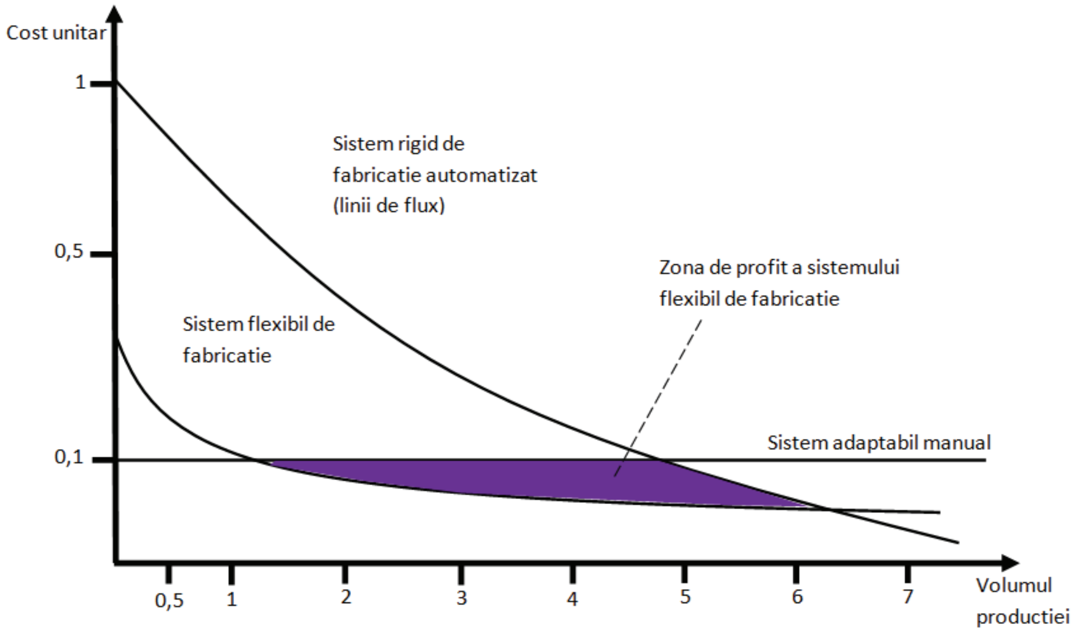

Fig. 1.3 The profit zone of the FMS compared to the manually adjusted systems and the rigid automated production systems[11]

Disadvantages

- Probably the main disadvantage of these systems is the large investment costs necessary for the acquisition;
- The technical implementation problems are not entirely clarified;
- The decision of implementing a FMS is a difficult one, due to the future significance it should have for the enterprise. The strategy should be redefined.
- When implementing a FMS, all the departments of the enterprise should agree and understand the functioning of scheme of such a system;
- Due to the inadvertences of a classical system, not all FMS acquisitions could turn out successful;
- Concept errors may occur, due to the programmers who are not able to anticipate the proper flexibility degree – this disadvantage could be eliminated by computer simulations;
- Not finding the answer to the question: “How far does flexibility go?”
- Implementing a FMS means massive personnel cuts, this creating social problems;
- The absorption of manpower might be a problem, so the decision must be taken according to the political and social context of the respective country;
- Many times, the anticipated costs are exceeded;
- Creativity disappears, the products being “devoid of their soul”;
- Due to the lack of the human factor (intelligence and reason”, backlogs may occur, because of the instructions in the main program;

[11] Adapted from Dobrin, C., *Flexibilitatea în cadrul organizației*, Editura ASE, București, 2005, p.84

- A perfect correspondence must exist between production supplies and the system's maintenance;
- FMS machines and equipment become easily obsolete, a new generation coming up on the market every two years;
- It is difficult to anticipate an exact evaluation of capitalization, due to the permanent changes in the demands of the market and the appearance of new generations of machines;
- The system implies a rearrangement of the work area destined to the highly qualified personnel (programming engineers, system engineers, economic analysts);
- There is a necessity in developing a marketing department which should predict the future production ;
- The complexity level grows together with the increase in flexibility (machine, cell, line, workshop, flexible factory);
- The system needs an interdisciplinary qualified staff to deal with every unpredictable event;
- It generates different working conditions, due to the problem of psychological stress (people work isolated from each other, separated from the regular social environment);
- Health-related dangers: radiations, man-robot collisions;
- The positive effects are long awaited for, and are obtained gradually, after knowing the system properly – from the machine to the enterprise as a whole;
- Competition increases, because several types of products are made, which could be the main objective of small serial production companies, but competition grows within the enterprise, because it can easily adapt to the family of products obtained in the typological core.

In conclusion, we may state that implementing FMS is a difficult decision which implies the analysis of several points of view. All the departments of an enterprise are implicated in the decision of adopting flexibility within the system and the process represents an almost complete change of the old principles. The advantages are numerous, but they are visible over a medium or even longer period of time, when the system is able to function according to proper, suitable parameters. Socially speaking, it can unbalance the situation, this being a strong point to consider in linking the implementation of such decisions to the social policies of the community.

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2. Considerations about the mathematical game theory

Game theory is mentioned for the first time in 1838 in Antoine Cournot's study on the behaviour in a game of two players. In 1938, the book entitled "Applications aux Jeux de Hazard" publishes Emile Borel's research and was followed by the "Theory of Games and Economic Behaviour" signed by John von Neumann and Oskar Morgenstern in 1044. The last two authors are actually considered the forefathers of the present day game theory. They defined game as being "any interaction between several agents, governed by a set of specific rules that establish the possible moves of every participant and the gains for every combination of moves". This description may be applied to almost any social phenomenon. Thus, people realise that the results of their actions are not only pre-determined by these facts, but also by the actions of the other participants in this interaction. From the behaviour of people in traffic to the decisions taken in production, from the war of prices to the decision of having children, everything seems to be scientifically analysed with the help of game theory. Although it did not raise up to all these expectations, game theory found lots of applications in the area of social sciences, including, or better say, in economy. Game theory uses three fundamental hypotheses: the players behave rationally, each of them knows that the others are rational; all the players know the rules of the game. In order to understand a certain game, one must first of all know the rules, because this is how one knows what is allowed or possible at a certain point. Then, it is necessary to know how the players choose a certain action out of the possible actions. The issue of action choice is linked to the first two hypotheses previously mentioned. The player who behaves rationally has certain preferences about "things": he prefers honey to sugar, classical music to jazz, etc. This particular player is rational because he would choose that action which will best suit his own preferences.

Because game is the prototype of all conflicts, the terms used in game theory are mainly the usual terms used in actual games. By these specific terms we identify: game, gain, strategy, etc.

Any term in game theory, however, has a purely mathematical character. In order to understand more clearly the idea of a game from a mathematical point of view, Rosu defined the game as being "any real conflict that we analyse schematically" [12].

Game theory is based on the balance existing in any economical system, that is: the sum of all losses equals the sum of all gains. Every participant depends on the decision taken by all the other players. Thus, we have to take into account the possible decisions of the others. Those who have developed "game theory" identified three basic principles: **do not attack first, do not answer the first challenge, and 'forgive" the second.**

As a recognition of the importance of game theory, in 1994, the Nobel Prize in Economy was awarded for contributions in this domain to the economists John Nash, John C. Harsanyi and Reinhard Selten.

In 2005, the Nobel Prize in Economy was also awarded to the Americans Thomas Schelling and Robert Aumann for their research in game theory. Their work helped define the possible effects of cooperation and conflict. They added new solutions and visions that

[12] Rosu, Al., *Teoria Jocurilor Strategice*, Editura Militara, Bucuresti, 1967, p.13

subsequently improved the usefulness of non-cooperative Game Theory. The main solution of the concept is the Nash balance, that designs a combination of strategies (one for each player) and verifies if the balance of each player is the best as opposed to the strategy of the others.

Looking at this subject from different angles, Aumann as a mathematician and Schelling as an economist, both thought that the game theory perspective had the power to reshape the analysis of human interaction. Schelling showed that many social-familiar interactions could be perceived as non-cooperative games that imply both common interests and opposing ones, and Aumann showed that long term social interactions could be analysed under all aspects using the formal theory of non-cooperative games.

Actually, according to some researchers, game theory represents the mathematical side of the strategy[13]. In this respect, the main theorem of the game theory is the Mini-Max theorem, which states that if all the players involved in a game choose the best possible move (according to a reasonable strategy), then the results of the game can be determined.

After being underlain and advertised, besides the military applications, the first applications appear in 1970, in Biology. Eight[14] theoreticians were awarded the Nobel Prize in Economy for applications of the Game Theory in this domain: John Maynard Smith was awarded the Crafoord Prize for adapting the model in Biology. Since then, game theory has had many applications in most of the social, economic and industrial domains.

The math game theory is considered a branch of applied mathematics, that analyses the contradictory behaviour of two players and deals with determining the decision-choice methods in competitions or conflicts. A conflict is a situation in which two or more factors act according to contrary aims (people, firms, political parties). We can exemplify these situations with the following: economic competitions, auction sales, parliamentary elections, and so on. Game theory also deals with cases when an activity comes into conflict with the natural events that occur at random (epidemics, droughts). In order to structure a formal, simplified model of the situation under research, we shall only select the main characteristics, neglecting the secondary ones.

This theory determines the best choices in situations in which the interests of several parties collide. Game theory[15] is the mathematics of conflicts. When initially used in the military, the two players were the two conflicting armies; if we were to apply it in a game of cards, on the one hand we would have the player and on the other hand – his luck. In a chess game, the two players are the two people using their strategies to win the game. So, the two interested parties could take different forms, according to the application, without the necessity of human presence: plants, computers, animals (R. J. Aumann 1987)

The criterion followed in a game may represent efficiency, meaning the largest gain obtained by every player, and since not both of them may win, one of them wants to win the most and the other, to lose the least. Mathematically put, a player is called **maximizing** and the other **minimizing**. Every enactment decision is according to the reaction of the opposite party.

[13]Schemde Arndt., *Index and Stability in Bimatrix Games*, Berlin, Heidelberg, Springer Press, 2005, Germania;
[14] Rosu, Al., Al.,*Teoria jocurilor strategice*, Editura Militară, București, 1967.
[15] Idem

Figure 2.1. Peaceful conflict situation [13]

The characteristics of a situation in which the math game theory can be additionally applied are:

a) Situations of dispute;
b) At least two players (people, parties, controlled systems);
c) Every player has a well determined goal;
d) The interests of the parties are contradictory;
e) Each acts and reacts to the opponent's action;
f) The situations may so be abstracted that a mathematical pattern may be structured.

If such a situation is identified, game theory may be applied and in order to reach a solution, all these have to be mathematically transposed, outlined, patterned and abstracted. These patterns will actually be a simplified situation imitating reality. Game theory gives general data and guidelines on which one can make decisions that need to be checked by simulation in order to be validated.

Generally speaking, a conflict arises when the persons who want to win the game may choose between multiple strategies that could maximize/minimize their attributes. Every strategy comprises the moves made by the player in order to win. In order to mathematically quantify the advantages of every player, for every strategy available to the player, we must associate a probability which reflects the degree of certainty in the development of the player's strategy[16].

A conflict is characterized by the existence of two or more participants and of a set of alternatives from which every party will choose one or several ways to react, with a probability determined according to a certain pre-established objective. The conflict in which "every participant follows a certain goal and is independent in choosing his own actions, yet dependent on results determined by the set of actions, is formalized in the game pattern."[17]

The pattern of a strategic game includes the set of actions that the players use repeatedly and in a finite number, following the rules previously established and which must be

[16] Lotfi Tadj, *A QBD approach to evolutionary game theory*, Applied Mathematical Modeliing Conference,p.913, 2003;

[17] Blajină, O., *Produse Software aplicate în programarea teoriei jocurilor*, Editura Albastră, Cluj-Napoca, 2006, pag.35;

characterized by a probability that should reflect the degree of division in the values of the game, in order to generate gains. The stages of the game are called matches. In every match, every player applies one of the moves that favours him, a move characterized by a probability. After each player ensures his move, the match ends, followed by a re-evaluation of each player's strategy in order to continue the game.[18]

In the case of repeated matches, the players may choose pure strategies with certain frequencies; in this situation, we consider that the players use a mixed or pondered strategy. The strategy that ensures the best advantage for every layer may be called optimal, because it makes the best of all the advantages the player may get when plying all the matches. After a number of n matches, the game is over, one player being declared the winner, the other one-the loser. We must also mention that there are games with an infinite number of matches, the winner and the loser alternating according to the strategy chosen by each of them.

In strategy games, the prize, or gain is the result of the direct confrontation between the strategies adopted by each player. Because the players do not wish to achieve the same thing, their objectives are different, this resulting in different gains. In order to establish the future winnings of every player, one must know the result of the two players' confrontation of pure strategies. Before establishing the gain of every player, the decision upon the pure strategies for every player is a must[19].

2.1. Domains where game theory may be applied

It is certain that game theory is useful in any important domain where at least two contrary events, no matter their nature, may occur. It is not difficult to bring arguments for the solutions offered by the strategy when the pattern is logically structured. However, the most positive results have been noticed in the following domains:

- Social sciences: anticipating the behaviour of a person influencing certain situations;
- Economy: establishing a set of actions in response to the competition; highlighting the influence of the demand and of the offer; the development strategies for a company or corporation; understanding the advantages of a merger;
- Biology: anticipating the biological effect of certain elements;
- Ecology: studying the impact of certain actions on the environment;
- Engineering: the influence of certain parameters on production, etc;
- Political sciences: anticipating the strategies of a political opponent and his influence on the others;
- International relations: studying the options and their consequences in the relationship between two parties with common or contrary interests;
- Computer programming;
- Philosophy;
- Sports: game-winning strategies for teams or individual players.

[18] Levin Simon, *Games, groups, and the global good*, Berlin, Editura Springer, 2009, Germania;
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2.2 Elements that characterize a mathematical game

A game has two fundamental elements:

- A process made of a succession of actions (moves) executed in turns by a finite number of people called players (partners), following certain rules. Such a process, which is actually carried out is called a match.
- A rule of establishing the values between the players. This rule allows every player to aim at getting a value as high as possible.

Take, for example, a game of n players, having a set of actions to use. The set of actions available for player i is A_i, $i \in \{1,...,n\}$. Every player may choose an action $a_i \in A_i$, $i \in \{1,...,n\}$. The action may be more or less useful to player i.

This efficiency of the established action may be mathematically described as a function $f_i(a_1,...,a_n)$ representing the gain of player i.

We have the following problem: how should player i choose action a_i, so that the gain $f_i(a_1,...,a_n)$ should be maximum, having in view that all the other players have the same objective?

If for a game of n players, there is a rel constant c, so that $f_1(a_1,...,a_n)+...f_n(a_1,...,a_n)=c$, the game is called "constant sum game". In a concrete situation, if c=0, the game is called "zero sum game".

By *game* or *strategy game*, we understand the situation in which there are a multitude of rational elements (called players or partners), who , inturns or independently, following an order and a set of rules, each make a decision (move) out of a given number of alternatives.

The player is the decision-making entity. Each player's aim miss is to maximize his usefulness by his actions. In some games, the so-called pseudo-players appear. Such a player is nature. Nature is a psudo-player whose actions randomly intersect the game, with a certain probability.

A player is called rational if he seeks to maximize his satisfaction according to his actions, also having in mind the decisions made by the other players.

The rules of the game also set the situations in which the game ends, as well as the payoff or the reward for each player. A game that was carried out is also called a *match.*

The players' actions in a match are called *moves*. These can be *free*- when we have a one-way choice, or *random*, when the decision is made at random or by chance and is determined by an aleatory mechanism, such as the die.

The set of rules that uniquely define the free moves in the given situation of the game is called a *strategy.* If one of the partners has m available alternatives, and the match ends by a choice, then the player has m *pure strategies* available. When the match is repeated, the players may choose pure strategies with certain frequencies or probabilities and this is the case of *mixed strategy*. Every player seeks to apply a strategy that should bring him the largest payoff, so he looks for an optimal strategy.

In conclusion, the math game has several components, as presented in the table 2.1.

Table 2.1. Basic terms in game theory [1]

Term	Explanation
Initial state[20]	The initial "game board", meaning the state of the system at the beginning of the game;
The set of actions/moves	The actions available to the player according to the given situation;
The terminal state	The image of the game in the end-it may be comprised of several terminal states;
The utility function	It gives the numeric value of the game, from a mathematical point of view;
Strategy	The way a player takes action in response to his opponent in order to reach his objective-in general, all the opponents options are known;
Pure strategy	If in a game, a player has m alternatives, and the match ends as a result of the choice of one of these, then the m alternatives are pure strategies;
Evaluation function	It returns the estimated utility for a game at one given point;
The match	A subdivision of the game which practically allows the move of every player involved;
Parties/players	The persons with contradictory interests;
Finite mxn game	A player has m pure strategies and the other has n;
Mixed/pondered strategy	The alternation of pure strategies in a game, with a certain frequency;
Zero-sum games	Games where, at the end of the matches, the sum which a player loses equals the sum won by the other, in other words, a player pays the other player.

For a regular math game, in the beginning the payoff matrix is created to illustrate each player's strategies according to his preferences and the opponent's action. The costs are organised as follows[21]:

- The strategies of the maximizer A are placed in rows
- The strategies of the minimizer B are placed in columns
- Inside the matrix there are the scores corresponding to each strategy.

Strategii A/B	B_1	...	B_j	...	B_m
A_1	a_{11}	...	a_{1j}	...	a_{1m}
.	.		.		.
.	.		.		.
.	.		.		.
A_j	a_{i1}	...	a_{ij}	...	a_{im}
.	.		.		.
.	.		.		.
.	.		.		.
A_n	a_{n1}	...	a_{nj}	...	a_{nm}

Fig. 2.2. The strategy matrix of the game

[20] Stoenan, C.,*Teoria jocurilor*, Universitatea din Craiova, Facultatea de Matematică și Informatică, 2010.
[21] Rosu, Al. , *Teoria jocurilor strategice*, Editura Militară, 1967, p. 17.

As a following interpretation we may say that strategy A_1 of player A has the following elements: $a_{11}, a_{12}, \dots, a_{1j}, \dots, a_{1m}$. ; at the same time, the B_1 strategy of player B comprises the following elements: $a_{11}, a_{21}, \dots, a_{i1}, \dots, a_{n1}$.

As seen, all strategies are known beforehand. On the rows we find the i strategies of player A, and in the columns we have the j strategies of player B.

In the case of a regular game, knowing all the pure strategies and the correspondence for these strategies is a must.

Hence, in order to define a game, we have the following elements

- *m* strategies for the first player A, $X=\{x_1,x_2, \dots, x_m\}$;
- *n* strategies for the second player B, $Y=\{y_1, y_2, \dots, y_n\}$;
- a goal function *f*, meaning the payoff function that must be defined for XxY

2.3 Classification of math games

Games could be classified according to several criteria:

a) According to how players communicate, games could be divided into:
   - Cooperative games
   - Non-cooperative games

The cooperative games are those in which players communicate freely before making decisions and can make promises (to which they will commit) before choosing the strategies. The non-cooperative games are those in which players do not communicate before making decisions.

b) According to the time-line of the games:
   - Static games;
   - Dynamic games.

The static game is that in which the decisions of the players are made simultaneously and then the game ends. The dynamic game is that in which the decisions of the players are sequential, time evolving decisions.

c) According to the nature of the information:
   - Games of complete information;
   - Games of incomplete information.

The game of complete information is a game where all the players know the number of the other players, all the strategies, all the payoff functions, as well as the set of rules.

The game of incomplete information is the game in which at least one of the players is unaware of one of the payoff functions of the other players, the rest of the elements being known (number of players, all the strategies and the set of rules)

d) In the case of dynamic games, according to the type of information, we have:
   - Games of perfect information;
   - Games of impoerfect information.

The dynamic game of perfect information is a game where each player knows the rules, the number of players, their strategies, as well as the time-line and the evolution of the game (the history of the game). The dynamic game of imperfect information is the game where at least one of the players is unaware of the history of the game, being aware of all the other elements.

e) According to the structure of the payoffs:
   - Zero sum games;
   - Non-zero sum games.

The zero sum game is the game where the sum of all payoffs is zero, meaning that the loss of some players represents the other's gain. The non-zero sum game is the game where the sum of all payoffs differs from zero.

f) According to the number of players:
   - Two player games;
   - Multiplayer games;
   - Games against nature.

Besides the ***regular game*** variant, or the strategy game previously presented, there are other types of games. One of them is the **game tree[22], or the extensive-form type**. Here the game is secret, meaning that the other player's moves are not known beforehand. Every player has to choose between an equal number of options. The options are according to the previous choices of the opponent. In the end, each player's choices are accounted for and the payoff function is established. Generally speaking, a payoff function has the following structure:
f (a,b,c,....,z)- where a represents the choice made with the first move, b represents the choice of the second move, and so on.

The image of a game tree is as follows:

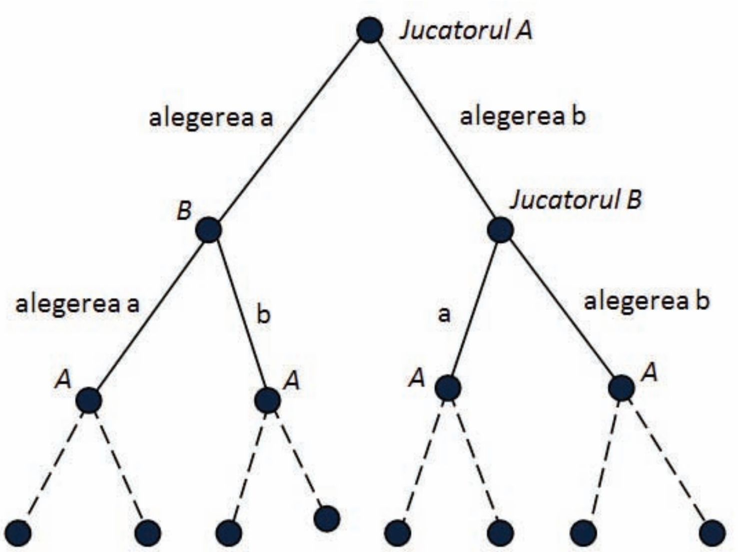

Fig.2.3 The game tree [1]

At the end of all options, when the result was accounted for, the best possible way is chosen, according to the usefulness of the game. This game could also be illustrated as a regular matrix game, but in this case, one should calculate all the pure strategies for each player.

The game tree, as presented above, has no information from the opponent. According to this criterion, games may be divided into:
- Games with no information (the game of cards);
- Games of complete information: when every player knows how his opponent will react in certain circumstances, for instance, chess.
- Games with a class of information: when part of the choices to be made are known, but not entirely.

According to the number of players[23], we have:
- One player games: also called the Robinson Crusoe game, mainly used in theoretical applications

[22] Rosu, Al., *Teoria jocurilor strategice*, Editura Militară, 1967, p. 20
[23] Baru, P., *Eine anwendungsorientierte Einführung in die Spieltheorie*, Lucrare de licență, Universitatea Babeș-Bolyai, 2006.

- Two player games;
- Games of n players, $n \epsilon N^*$

According to the sum of the payoffs, there are situations in which:

- The sum is constant, but is distributed among the players (eg. Poker)
- The sum varies, according to the development of the game.

Math games may also be classified according to the number of strategies adopted by one player, as follows:

- Games with a limited number of strategies;
- Games with an unlimited number of strategies.

According to the time-line of the game:

- Games with determined duration;
- Games with undetermined duration.

Another characteristic according to which games may be classified is the cooperation between the players. There are games where:

- The two players cooperate – rarely used and often leading to coalitions, that is the grouping of several players' interests against another coalition or other players
- Every player follows his own interest and wants to maximize his gain – the non-cooperative games, which are the most frequent ones.

According to the structure of the game, there are:

- Symmetrical games;
- Non-symmetrical games – according to the number of strategies of every player.

According to the way the moves are made:

- Static games: strategies are applied simultaneously;
- Dynamic games: the players apply their strategies in turns.

2.3.1 The matrix strategy games

The matrix games are the most frequently seen and have multiple applications with important results. These games are of the previously presented type, in which there are two players (A and B), having m and n pure strategies. Hence, we will have an m x n game[24].

The costs matrix is constructed: the m strategies are placed in rows and the n strategies are placed in columns. The costs are the m x n consequences, that is the effort made by the system to alter from one stage to another. The game is sequential, meaning that every player uses in turns a pure strategy. Since several pure strategies are chosen, we may consider it a mixed strategy game.

In this game, a function must be chosen, to make the correspondence between the strategies of the two players.

$$f(a_i, b_i) \qquad (2.1)$$

where

$$a_i \epsilon\ X = \{a_1, a_2, \ldots, a_i, \ldots, a_m\}\ si\ b_i \epsilon Y = \{b_1, b_2, \ldots, b_i, \ldots, b_n\} \qquad (2.2)$$

The X, Y sets represent the sets of the two players' pure strategies. If a player chooses a startegy i, the second player will choose the j variant, after consulting the costs matrix, which accounts for the gains / losses of every player.

The figures in the costs matrix may differ according to the circumstances of the game. Sometimes, there may be probabilities which do not express a sure payoff. Sometimes, there might be certainties, that is a positive variant, any other variant being negative, or which could have qualitative values, meaning appreciations that cannot be numerically expressed.

[24]Rosu, Al.,*Teoria jocurilor strategice*, Editura Militară, 1967, p. 26

In matrix games the most frequent situation is of the ***minmax*** type. This situation refers to the fact that a player wishes to maximize his gains, the other being aware he could lose, wishes to minimize his losses. This could be applied both to static and dynamic games, both to zero-sum and to non-zero sum games. In the case of zero-sum games, the following applies: “Whatever the zero-sum game with finite strategies and two players, there is a V value and a mixed strategy for each player, so that:

a) Following the second player’s strategy, the first player’s gain is V , and
b) Following the first player’s strategy, the second player’s gain is –V”[25].

Thus, the players rely on the ingenuity of the opponent, trying to anticipate his moves and to maximize his gain. Each player tries to choose the largest payoff, regardless of the opponent’s action.

A mathematical game is called a ***saddle point***. When:

$max_i min_j a_{ij} = min_j max_j a_{ij} = v$ (2.3.)

The smallest loss of the minimizing player equals the smallest gain of the maximizing player.

For a situation in which we have a f (x,y) function of two real variables, $x \epsilon X$ si $y \epsilon Y$ și $X \epsilon R$ si $Y \epsilon R$, (x_0, y_0) , is a sa point if

$f(x, y_0) \leq f(x_0, y_0) \leq f(x_0, y)$ or (2.4.)

$f(x, y_0) \geq f(x_0, y_0) \geq f(x_0, y)$ (2.5.)

A mathematical game of sa point has the costs matrix as follows:

$$\begin{array}{c c c}
 & \begin{array}{cccc} B_1 & B_2 & B_3 & B_4 \end{array} & \text{min (linii)} \\
\begin{array}{c} A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} & \begin{bmatrix} 7 & 2 & 5 & 1 \\ 2 & 2 & 3 & 4 \\ 5 & \mathbf{3} & 4 & 4 \\ 3 & 2 & 1 & 6 \end{bmatrix} & \begin{array}{c} 1 \\ 2 \\ \mathbf{3} \\ 1 \end{array} \\
\text{max (col)} & \begin{array}{cccc} 7 & \mathbf{3} & 5 & 6 \end{array} &
\end{array}$$

punct sa

Fig. 2.4 Saddle point matrix

In this case, value 3 corresponds to the sa point, being the intersection of A_3 with B_2.

A frequent situation in game theory the ***dominance***. According to this, a row or a column may be deleted when these are clearly dominated by other rows or columns. For a better understanding of the principle, the following payoff matrix was devised. We notice that some rows have smaller values than all the values of another row. Similarly, this may happen to columns[26]:

[25] http://ro.wikipedia.org/wiki/Minimax accesat la data de 01.10.2010.

[26] Ciucu, G., Craiu, V., s.a., *Statistică matematică și cercetări operaționale*, vol. III, Editura Didactică și Pedagogică, București, 1982.

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{ccccc} B_1 & B_2 & B_3 & B_4 & B_5 \end{array} \\ \begin{bmatrix} 3 & -5 & 4 & 2 & 1 \\ 2 & 3 & 1 & 0 & -1 \\ 4 & -1 & 0 & 1 & 3 \\ 5 & 0 & 3 & 2 & 4 \end{bmatrix} \end{array} \qquad \begin{bmatrix} -5 & 2 & 1 \\ 3 & 0 & -1 \\ 0 & 2 & 4 \end{bmatrix}$$

Fig. 2.5 The dominance principle[27]

Here we notice that strategies B1 and B3 are dominated by B4 and A3 by A4. The relevant matrix to continue calculations after applying the dominance principle is presented at the right.

There are several types of games and principles that may be adapted in order to reach a good solution, but every principle is specific to a practical situation. For the FMS, we will use the previously presented matrix game theory and we will apply the presented principle where necessary.

2.3.2. Solving matrix games by linear programming

Having the game G = (A, B, f) with matrix A = (a_{ij}), $i = \overline{1,m}$, $j = \overline{1,n}$ of value v.

If player P_1 uses the strategies Ai, with the probabilities x_i, $i = \overline{1,m}$ he may hope his gain would be at least equal to v, for any strategy Bj, j = 1,n, of P2.

We may write the system of inequalities:

$$(I)\begin{cases} a_{11}x_1 + \ldots + a_{m1}x_m \geq v \\ a_{12}x_1 + \ldots + a_{m2}x_m \geq v \\ \qquad \ldots \\ a_{1n}x_1 + \ldots + a_{mn}x_m \geq v \\ \quad x_1 + \ldots + x_m = 1 \\ \qquad x_i \geq 0; \\ \qquad i = \overline{1,m} \end{cases} \tag{2.6}$$

If player P2 uses the strategies Bj with the probabilities yj,j=1,n, he expects a loss at most equal to v and we may write the system of inequalities:

$$(II)\begin{cases} a_{11}y_1 + \ldots + a_{m1}y_m \leq v \\ a_{12}y_1 + \ldots + a_{m2}y_m \leq v \\ \qquad \ldots \\ a_{1n}y_1 + \ldots + a_{mn}y_m \leq v \\ \quad y_1 + \ldots + y_m = 1 \\ \qquad y_j \geq 0; \\ \qquad j = \overline{1,n} \end{cases} \tag{2.7}$$

[27] Rosu, Al., *Teoria jocurilor strategice*, Editura Militara, 1967, p. 52

In order to change the two systems into linear programming patterns the v value of the game has to be positive. Hence, we will assume that v > 0 (if not the matrix A will be modified into $\overline{A} = \left(\overline{a_{ij}}\right) \overline{a_{ij}} = a_{ij} + k > 0$, $(\forall) i = \overline{1,m}$, $j = \overline{1,n}$ and k>0.

The conditions for xi and yj to be probabilities become:

The notations are: $X_i = \frac{x_i}{v}$, $i = \overline{1,m}$, $Y_j = \frac{y_j}{v}$, $j = \overline{1,n}$

$$X_1 + \ldots + X_m = \frac{1}{v} \tag{2.8}$$

$$Y_1 + \ldots + Y_n = \frac{1}{v} \tag{2.9}$$

The player P_2 wishes to obtain the smallest loss v, meaning the highest value of $\frac{1}{v}$, so his goal is to have $\max g = Y_1 + \ldots + Y_n$.

Then, the systems (I) and (II) of the two players can be written as a set of dual linear programming problems, as follows:

$$(\mathrm{I})\begin{cases} [\min]\mathrm{f} = \frac{1}{\mathrm{v}} = \mathrm{X}_1 + \ldots + \mathrm{X}_\mathrm{m} \\ \mathrm{a}_{11}\mathrm{X}_1 + \ldots + \mathrm{a}_{\mathrm{m}1}\mathrm{X}_\mathrm{m} \geq 1 \\ \ldots \\ \mathrm{a}_{1\mathrm{n}}\mathrm{X}_1 + \ldots + \mathrm{a}_{\mathrm{mn}}\mathrm{X}_\mathrm{m} \geq 1 \\ \mathrm{X}_\mathrm{i} \geq 0 \\ \mathrm{i} = \overline{1,\mathrm{m}} \end{cases} \tag{2.10}$$

$$(\mathrm{II})\begin{cases} [\max]\mathrm{g} = \frac{1}{\mathrm{v}} = \mathrm{Y}_1 + \ldots + \mathrm{Y}_\mathrm{m} \\ \mathrm{a}_{11}\mathrm{Y}_1 + \ldots + \mathrm{a}_{\mathrm{m}1}\mathrm{Y}_\mathrm{m} \leq 1 \\ \ldots \\ \mathrm{a}_{1\mathrm{n}}\mathrm{Y}_1 + \ldots + \mathrm{a}_{\mathrm{mn}}\mathrm{Y}_\mathrm{m} \leq 1 \\ \mathrm{Y}_\mathrm{j} \geq 0 \\ \mathrm{j} = \overline{1,\mathrm{n}} \end{cases} \tag{2.11}$$

By solving one of the two problems, we obtain the optimal mixed strategies of both players, as well as the value v of the game:

$$v = \frac{1}{[\min]f} = \frac{1}{[\max]g} \tag{2.12}$$

2.4. The manager's exerted activity assimilated with a mathematical game [22], [23]

The working time of the manager represents an economic resource. A conflict of interests arises from the fact that this resource may be used in several ways. A particular use of this resource will be called activity. A revenue results as a sequel of using the resource in a certain activity. This term has a lot of meanings, varying from finite product to a sum of money, or simply satisfaction. The size of the revenue depends on the quantity of the resource used in the activity, but also on its type.

The challenge lays in dividing the resource among competing activities, so that a compromise between the working time and the wages should be reached [22], [23].

There are two opposite tendencies that have to be dealt with and conciliated: the wish to earn as much as possible and the desire to work as little as possible.[22]

The two players are: the salary [S], and the working time [T]. The salary represents the maximizing player and the working time-the minimizing player [23].

The working time owns the pure strategies $T_1, T_2, \ldots, T_n$, and the salary has the pure strategies $S_1, S_2, \ldots, S_m$.
The stake of the conflict is the optimization of the management process.

The value of the game will highlight the balance limiting the working time without diminishing the salary under a certain accepted level.

2.4.1 The suggested math game

In the above description of the game, we have all the necessary elements for a regular game. The number of players is finite and so we have two elements. In the math game theory, we start from the game matrix and we aim at determining the propositions in which each player should use his strategies. The matrix of the game will contain all the elements that are necessary for a regular game: the players, the available strategies and the payoff functions.

The rows and the columns of the matrix indicate the doable strategies of the players (the pure strategies) and the cells of the matrix will contain each player's gains, according to his chosen strategies.

When making a decision, the choice is based on the criterion of reducing the working time to a minimum. This criterion can be expressed by the linear function

$\sum x_i$, i=1,…,6

where: x_1 – time for predictions;
x_2 –time for organizing;
x_3 –time for coordination;
x_4 –time for training;
x_5 –time for control;
x_6 –time for other activities;

This game has two players: the working time and the salary. The «working time» player has the set of actions $T = \{T_1, ..., T_6\}$, and the «salary» player has the set of actions $S = \{S_1, ..., S_5\}$.

The gains and losses of every player are taken from the following reference: [22].

Knowing the sets T and S which are available to the players and knowing all the elements of the payoff matrix, the game is completely defined:

	$T1$	$T2$	$T3$	$T4$	$T5$	$T6$
$V1$	5	3	2	4	5	2
$V2$	4	2	4	3	1	3
$V3$	5	5	3	4	2	1
$V4$	5	3	5	4	3	1
$V5$	5	4	3	2	3	2
$V6$	3	3	3	4	4	1

Fig. 2.6. Matrix of the game [22], [23]

The game does not have a sa point, so it may be solved by transforming it into a linear programming problem, as follows:

$$\min \sum x_i \tag{2.13}$$

having the following restrictions:

$$\begin{cases} 5x_1 + 3x_2 + 2x_3 + 4x_4 + 5x_5 + 2x_6 \geq 1 \\ 4x_1 + 2x_2 + 4x_3 + 3x_4 + 1x_5 + 3x_6 \geq 1 \\ 5x_1 + 5x_2 + 3x_3 + 4x_4 + 2x_5 + 1x_6 \geq 1 \\ 5x_1 + 3x_2 + 5x_3 + 4x_4 + 3x_5 + 1x_6 \geq 1 \\ 5x_1 + 4x_2 + 3x_3 + 2x_4 + 3x_5 + 2x_6 \geq 1 \\ 3x_1 + 3x_2 + 3x_3 + 4x_4 + 4x_5 + 1x_6 \geq 1 \\ x_1 \geq 0; \\ x_2 \geq 0; \\ x_3 \geq 0; \\ x_4 \geq 0; \\ x_5 \geq 0; \\ x_6 \geq 0; \end{cases} \tag{2.14}$$

By solving the pattern, we have the have the following solution:

x_1=0.085; x_2=0.038; x_3=0.095; x_4=0.066; x_5=0; x_6=0

The goal function's value is 0.285.

Replacing

$$\begin{aligned} v &= \frac{1}{z} = \frac{1}{0.285} = 3.50 \\ X_1 &= 3.50 \cdot 0.085 = 0.30 \\ X_2 &= 3.50 \cdot 0.038 = 0.13 \\ X_3 &= 3.50 \cdot 0.095 = 0.33 \\ X_4 &= 3.50 \cdot 0.066 = 0.23 \\ X_5 &= 0 \\ X_6 &= 0 \end{aligned} \tag{2.15}$$

According to these results, managers should divide their time as follows:

- prediction 30%
- organisation 13%
- coordination 33%
- training 23%
- control 0%
- others 0%

Thus, in order to reach a compromise between the working time and utility of work, we should exclude control and the activities that do not comply with the five functions of management from the structure of the working time [23].

On the other hand, according to Mintzberg, the utility of the working time for a high level manager has the following structure:

Table 2.2. The structure of the working time for a high level manager

no.	The structure of the working time	Percentage of the working time [%]
1	Scheduled meetings and appointments	59
2	Office work	22
3	Unscheduled meetings	10
4	Phone calls	6
5	Company/field inspections	3

The matrix associated to the game is the following [31]:

	$T1$	$T2$	$T3$	$T4$	$T5$
$V1$	5	4	3	2	1
$V2$	4	5	3	2	1
$V3$	5	2	3	1	2
$V4$	5	3	4	2	1
$V5$	4	4	1	5	2
$V6$	5	2	4	1	3

$$\min \sum x_i \tag{2.16}$$

having the following restrictions:

$$\begin{cases} 5x_1 + 4x_2 + 3x_3 + 2x_4 + 1x_5 \geq 1 \\ 4x_1 + 5x_2 + 3x_3 + 2x_4 + 1x_5 \geq 1 \\ 5x_1 + 2x_2 + 3x_3 + 1x_4 + 2x_5 \geq 1 \\ 5x_1 + 3x_2 + 4x_3 + 2x_4 + 1x_5 \geq 1 \\ 4x_1 + 4x_2 + 1x_3 + 5x_4 + 2x_5 \geq 1 \\ 5x_1 + 2x_2 + 4x_3 + 1x_4 + 3x_5 \geq 1 \end{cases} \tag{2.17}$$

$$v = \frac{1}{z} = \frac{1}{0.245} = 4.08$$

$$\begin{aligned} X_1 &= 4.08 \cdot 0.175 = 0.71 \\ X_2 &= 4.08 \cdot 0.052 = 0.21 \\ X_3 &= 4.08 \cdot 0.017 = 0.06 \end{aligned} \tag{2.18}$$

By solving the math game, the manager's time has the following structure31]:

- scheduled appointments 71%
- office work 21%
- phone-calls 6%

In conclusion, unscheduled appointments and company inspections must be taken out of the working time structure.

The manager's activity-deficiencies and causes:

In the manager's work, no matter where he is placed hierarchically and irrespective of the importance of his position, many deficiencies occur, among which the following can be mentioned:

a) the frequent prolongation of the 8 hours working day;
b) the unsuitable structure of the working day, because:

- the predictive, documentation work in his field of activity, as well as in management, has a very small part in the overall working time;
- the time destined to meetings is still in a very high proportion (production-related operational meetings);
- the excessive fragmentation of the working day: according to some specialist, over 40% of the high-level managers' time budget is made of sequences of up to 10 minutes; such a situation generates what specialised literature calls "the jigsaw effect"

Methods for optimising the manager's work

Diminishing or eliminating the causes that produce such deficiencies means that action must be taken in several main directions:

The scientific programming and organisation of the manager's activity:

a) following a minimal set of programming and organisation rules, such as:
    - using the early morning hours to solve difficult, important problems and towards the end of the working day to use time in order to solve less demanding issues;
    - concentrating effort towards key-issues, vital for the success of the respective domain.
b) Ensuring a proper structure for the working day:
    Specialists recommend, according to the ABC analysis, that high-level managers should find certain time sequences, as follows:
    - 180 minutes – solving highly important and difficult matters, without being disturbed (2-3 A type problems);
    - 2-3 60 minute modules (whole hours);
    - Solving problems that require continuity and focusing (2-3 B type tasks);
    - 30-40 minutes – phone-calls, visits, urgent matters;
    - The rest of the time: solving problems of lesser importance – documentation, attending meetings, and so on.
c) Using a varied set of work programming tools:
    In order to find the above mentioned elements, the manager must resort to several methods and work-programming techniques, such as:
    - The daily and weekly schedule;
    - The daily and weekly activity chart;
    - The file containing problems to be solved;
    - Handouts;
    - Distinct sheets of paper for individual problems;
    - The organizer.

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3. Simulation of Flexible Manufacturing Systems functioning

3.1. Questions and solutions for FMS management

By flexibility, as a feature of the FMS, we understand the ability of this system to keep up with the changes that may occur in: the typology and the production workload, the rate of operation of the modules it is made of, the parameters of the technological process, the tools, machines and verifying devices used, and so on.

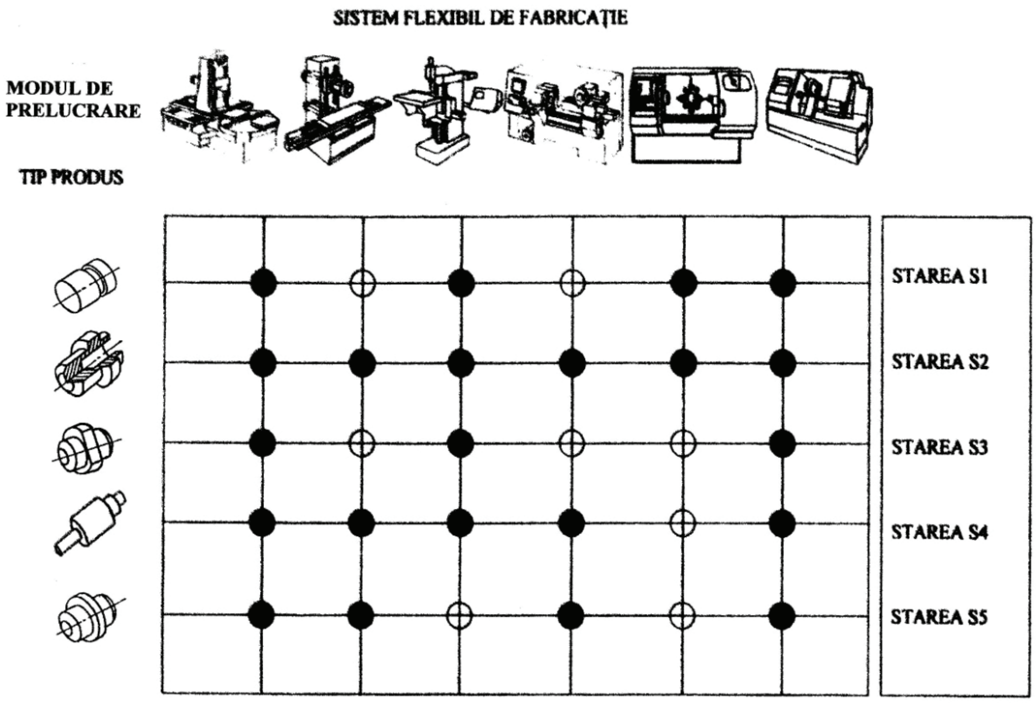

Fig.3.1. The system status [29]

At a small scale, however, flexibility is associated with the change of the type of product made by the system. When a certain type of product is made, an entire set of system abilities is activated (machines, tools, verifying, and adjusting devices, etc). The system is thus in a state that is suitable for the making of the respective product. If another product enters the system, then another set of abilities is generally activated, meaning that the system passes onto another state. Fig.3.1 represents the states of the system in the simplified situation when the activated abilities, which differ from one product to another, are only the machines. The darkened circles represent the machines used in making the P_i type of piece, and the blanks represent the machines that are not used. The passage of a system from one state to another (each state corresponding to a certain type of product) supposes an effort for the system. This effort could at least mean the time necessary for the adjustment of the machines, but normally, it also means other components. This could be called a generic effort, a transition cost (c_{ij}), by transition meaning a passage of the system from his S state, to another – S_1: (Fig.3.2). The inversion of the indexes/parameters, comes from the logics of FMS programming seen as math games. The FMS functioning, in the context of the permanent change of the product type to be made, supposes a different kind of transition which takes the system from one state to another. If we divide the overall transition effort to the numbers of transitions, we have the average transition cost (ATC)

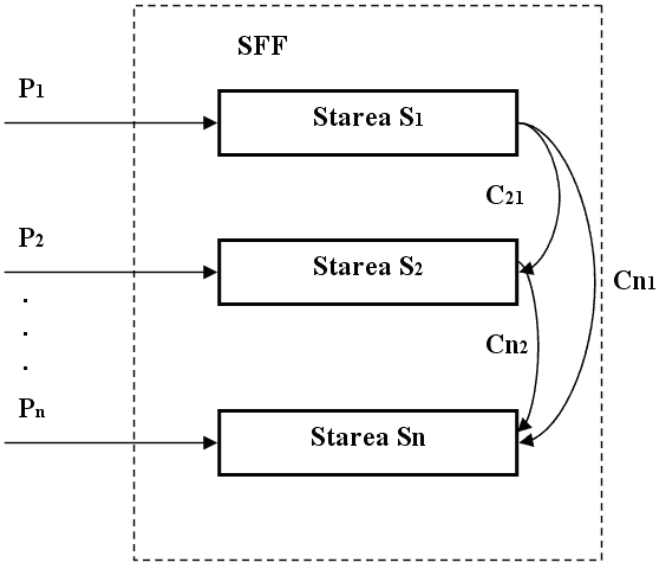

Fig.3.2. The system transitions [29]

The flexibility of a FMS must be understood in real terms, meaning that one system alone cannot produce both ice-cream and airplane engines. This is why we always speak of flexibility within the same family of products. Hence, a series of questions.

Question no. 1: What is a family of products? Where is the limit that separates a family of products from another? How different or how similar should the products belonging to the same family be? How do we measure the differences/ the similarities between the products?

If we answer this question by saying that the difference/ the similarities between different types of products can be measured by the characteristics of these products, we find ourselves asking another question.

Question no. 2: What are the characteristics that best describe that particular piece? How many are they? Are they equally important? How do we bring them together into a global indicator that should entirely describe that particular type of product (component, piece)? A solution here may be represented by the encoding system which describes a piece by combining morphological, technological and economical characteristics of the piece. If we established the characteristics that best describe the types of pieces, we must find a method to combine them in order to build a global indicator that should measure the difference/similarities between the types of products. In [6], difference/similarity indicators were imagined, being first called correspondence coefficients and after a processing step, they became affinity coefficients. With these elements we may ask the following question.

Question no. 3: Can these difference/similarity coefficients also measure the system's effort when it passes from making one type of product to making another one? Do these coefficients reflect the transition costs? Or, does the difference/similarity between the pieces also measure the transition cost? If the answer is affirmative, then we ask ourselves one last question that actually closes the circle, bringing us back to the first question.

Question no. 4: Up to what limit of the transition cost can we shape the typological set that will be made by the system? Which of the analysed products, that are expected to be made within the system, will actually remain on the list in order to be produced and which ones will be taken off? In other words, if the circles in Fig 3.3 represent types of products, which of the A, B and C lines represent the list of the system's products? How is this limit established?

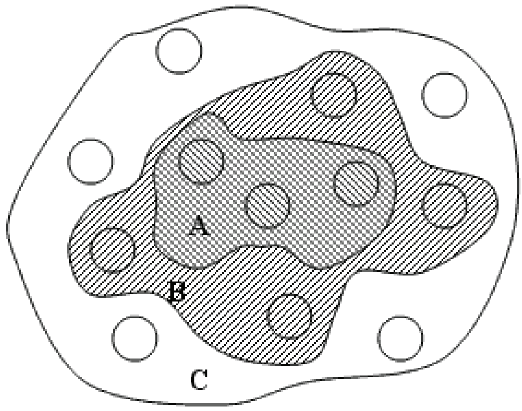

Fig.3.3 the system's list of products [29]

At this point, we may devise the matrix in Fig. 3.4, which will be called the transition costs matrix. Here, the columns represent the system's states (S) and the rows represent the products entering the system at one point. The elements of the matrix, in the intersection of S_1 and P_2, are understood as follows: if the part P_2 enters the FMS in order to be produced and the system is at its S_1 state, then the system's effort to adapt to the state suitable for the making of P2 (hence, to reach S_2), or, in other words, the transition cost measuring this effort in C12.

Let us keep in mind that we do not have the production system yet and we are only now trying to define it by determining the products that will be made. We also have to mention that the whole reasoning is dominated by the transition cost, which thus becomes a decisive criterion.

In order to establish witch of the types of products will be made in the system and which ones won't, we could use the mathematical set of rules from the zero-sum math game theory. In short the principles belonging to that part of game theory which we will use, are the following:

1) Game theory is a theory of conflicts in which at least two contradictory interests promoted by two players (partners, rivals) are highlighted. Everything one of them loses, is won by the other.
2) The player who loses is called the minimizer, because he wishes to minimize his loss, and the player who wins is called the maximizer, because he wishes to maximize his gains.
3) The optimal situation, in game theory, between the two players, reflects a level of the gain and of the loss which is acceptable for both of them. This level of gains/losses is called the value of the game.
4) The two players promote their interests through a set of actions called strategies. Hence, we will have the maximizer's and the minimizer's strategies.

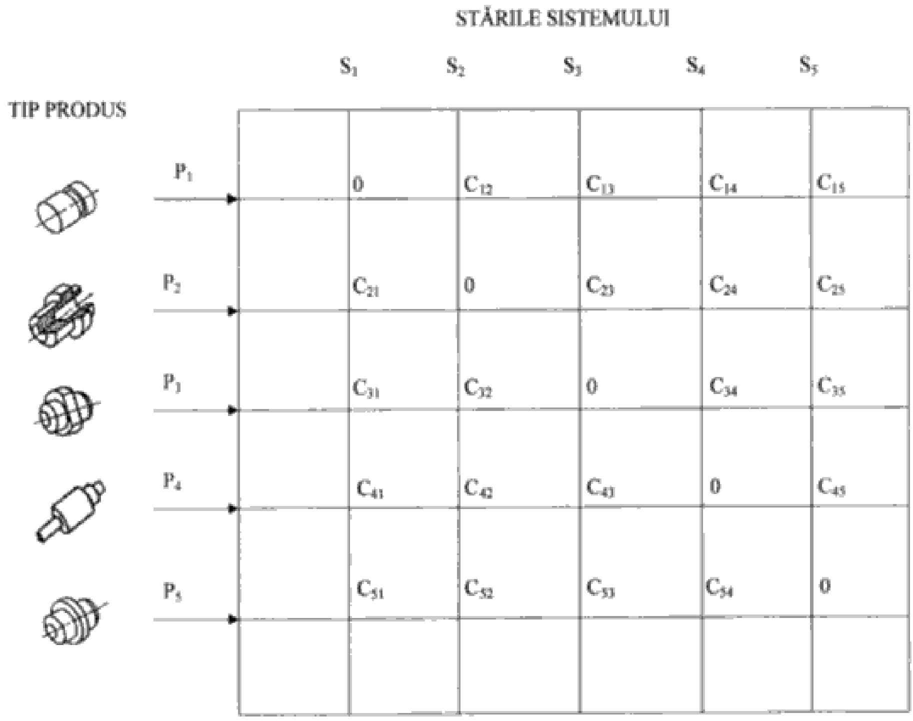

Fig.3.4. The transition costs of the system's states [29]

Let's notice that our problem presents a conflict between the variety of products that have to be made and as civilization evolves, this variety also increases the ability of the production systems to realize this variety in economic conditions.

Within the FMS, this contradiction exists between the diversity of products that should be made in the FMS and the limited production possibilities of the system. Who establishes these possibilities? The effort of the system is definitely an important factor in determining these possibilities. This effort is, "measured" by the transition cost, that is the system's effort, "to glide" among its states, but to also materialize these states. The system "would prefer" this effort to be as small as possible (it is the minimizing player) and the production task (the variety of products supposed to be made in the system) would rather this effort be as big as possible. The production task is the maximizing player. In the terminology of math game theory, this conflict may be interpreted as a "game against nature", "nature that tries to stretch" the possibilities of the system. Just like in the case of a roll-piston (Fig.3.5), on one side we have the typological diversity, and on the other, the abilities of the system. Where will the piston stop? This point represents the optimal solution from game theory, and the competition takes place under the pressure of the system's transition effort (which gives the system's capability)

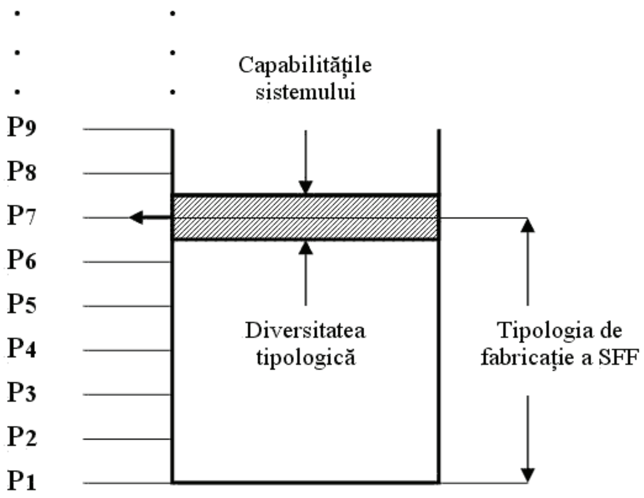

Fig.3.5 The typological diversity vs. the capabilities of the system

According to game theory, the optimal solution contains both the value of the game, or what a player loses and the other one wins, and the strategies or actions with which the two players operate in order to reach this result.

The strategies of the system are its states. The more states a system has, the bigger the effort to "navigate" through these states is. The effort to materialize these states is equally high (meaning extra adjustments, extra equipment or tools and verifying devices-sets)

But this effort was called transition cost, and it represents what the system loses and the production task gains. The strategies of the production task (the maximizing player) are basically the types of products made by the system. This player wishes that the system could produce as many items as possible.

Any math game has a game matrix (of gains and losses, which, in the interpretation of FMS as a math game), is the transition costs matrix itself.

Without using too advanced mathematics, we may conclude that the optimal solution of this game has the following components:

1. The optimal solution for the maximizing player (the production task) consists in the proportions in which the different types of products have to be made so that the transition effort should be as big as possible.
2. The optimal solution of the minimizing player (the production system) consists in the proportions in which the system's states must be exercised so that the transition effort should be as small as possible.
3. The value of the game (what the system loses and what the production task gains) is the average transition cost.

If the maximizer's solution is materialized in the system, then the average transition cost tends towards the value of the game, coming from a higher point than this value. If the minimizer's solution is adopted, then the average transition cost realized in the system tends towards the value of the game, coming from a lower point than this value. The minimizer's solution is better, in view of reducing the average transition cost. Such a solution is presented in Table 3.2, for a FMS that is expected to produce 25 types of parts: P_1, P_2…P_{25}, that generates 25 system states S_1, S_2… S_{25}, with the transition costs matrix presented in Table 3.1.

Table 3.2. Solution for the model from Tab.3.1 [30]

State	**Frequency(Probability)**
S1	
S2	0.1570
S3	
S4	
S5	0.2153
S6	
S7	
S8	
S9	
S10	0.1827
S11	
S12	0.2965
S13	
S14	
S15	
S16	
S17	
S18	
S19	
S20	0.0350
S21	
S22	
S23	0.0750
S24	0.0385
S25	
Value of the game	**52.868**

Table 3.1. Matrix of the game (of transition costs)

0	17	23	31	16	25	44	80	37	4	92	7	50	14	15	21	13	16	18	43	87	23	51	12	13
8	0	45	32	97	78	12	10	58	71	62	1	69	27	36	12	54	23	43	76	71	11	33	44	11
50	11	0	67	67	75	87	92	92	95	73	21	48	56	96	65	87	90	89	54	89	34	67	89	55
8	52	46	0	48	94	73	13	69	52	4	4	61	52	91	12	56	87	90	22	86	45	87	33	45
59	28	58	27	0	38	93	80	12	92	55	34	97	78	55	34	87	33	2	7	54	12	8	56	22
84	71	2	82	60	0	53	68	96	95	8	20	79	3	31	23	2	77	66	98	53	23	21	13	76
10	73	44	20	52	26	0	99	44	89	53	7	57	75	67	23	68	76	44	32	91	23	44	56	11
39	55	97	73	43	76	41	0	77	74	44	11	71	66	87	11	55	76	23	43	12	82	32	64	57
21	76	7	45	83	6	39	40	0	98	52	5	68	71	63	23	65	89	45	21	67	2	5	67	98
59	49	64	89	50	81	90	92	99	0	99	81	76	91	97	89	77	88	94	78	79	79	79	45	62
17	17	72	65	39	55	51	18	44	81	0	17	84	21	90	21	34	87	45	23	11	99	65	34	22
15	1	11	14	12	19	12	13	10	30	18	0	22	17	19	21	27	29	17	55	41	27	20	19	3
91	50	37	54	81	71	9	53	47	79	84	9	0	25	86	33	65	78	98	98	21	33	55	76	78
30	40	57	19	38	64	21	17	63	83	49	10	48	0	10	22	23	4	65	78	91	32	34	65	90
74	49	43	31	53	69	25	82	24	91	13	23	19	89	0	18	16	34	67	13	16	64	87	87	21
21	43	65	76	54	34	27	98	43	27	18	19	20	30	50	0	23	54	87	32	21	87	34	34	23
10	11	12	43	26	27	65	87	92	11	55	76	49	54	23	68	0	9	71	23	43	55	76	76	89
32	65	87	45	67	8	98	3	2	22	66	55	98	34	65	76	4	0	77	32	45	19	57	15	34
14	31	65	23	18	58	87	65	24	45	77	84	76	42	4	44	66	78	0	22	34	67	22	21	87
56	43	97	54	33	66	89	76	54	78	89	68	97	33	55	87	78	87	23	0	56	78	23	75	54
22	34	10	20	54	12	17	43	87	98	34	19	20	40	32	54	7	4	67	23	0	40	32	54	11
22	55	87	90	32	33	56	67	98	43	87	5	34	93	29	39	36	49	33	76	87	0	9	23	11
33	65	78	34	98	55	98	34	23	76	18	19	10	45	11	17	34	16	51	45	20	30	0	12	31
11	16	29	36	28	68	22	56	11	76	23	17	54	12	86	33	21	55	23	24	56	78	17	0	14
14	64	87	5	67	54	89	73	23	67	45	34	23	14	19	34	64	28	57	12	32	76	22	31	0

We can make the following observations on this solution:

The value of the game, assimilated with the average transition cost, is 52.87;

Of all the system's states, only the following 7 will be carried out: S_2, S_5, S_{10}, S_{12}, S_{20}, S_{23} and S_{24}.

In the frequencies column (with the probabilities) were written the proportions of the various states of the system, meaning that for 10 000 transitions : 1570 must lead to S_2, 2153 to S_5, 1827 to S_{10}, 2965 to S_{12}, 350 to S_{20}, 750 to S_{23} and 385 to S_{24}. -so, if these states will have the above frequencies, for 10.000 transitions, the average transition cost will not be higher than

3.1.1. Interpretations and results [11]

1. Using the principles of game theory, we can generate:

a) the family of products that will be made in the system, if the system is not yet constituted. In the case above, the FMS will only produce P_2, P_5, P_{10}, P_{12}, P_{20}, P_{23} and P_{24} out of 25 types supposed to be made in the system.
b) if the system is already constituted for producing the 25 types, then the solution of Table 2 could be a production program that should reduce the average transition cost to its lowest value, in the context in which the system still remains flexible.

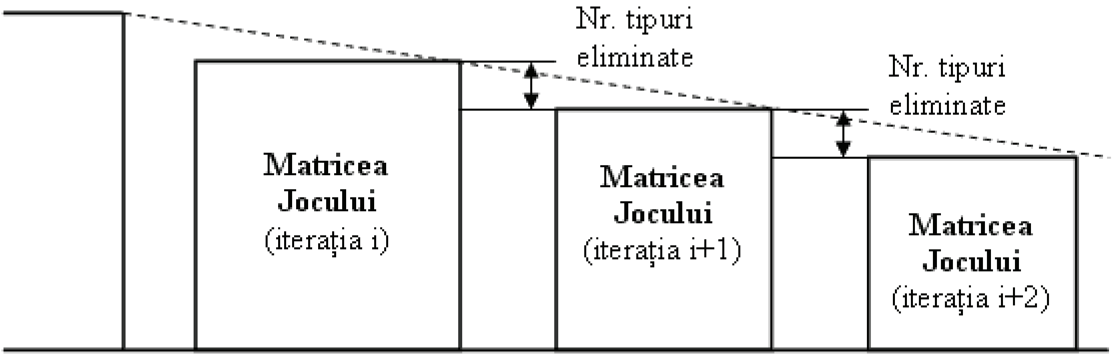

Fig.3.6 The model of game theory successive application

2. The example previously presented shows us (this being a fact in all researched cases), that the application of game theory eliminates some of the types (we reached 7 out of 25)

So, if applied for an initial typology, it may function as a filter for all the types of products that will be made in the system. The selection criterion is the transition cost of the system, which was assimilated with the dimension of the difference/similarity between the analysed products. What would happen to the 7 remaining parts, if they were used in another transition costs matrix and if we applied the principles of game theory once again (see Fig. 3.6)? In this particular case, by applying game theory again, we reached another solution with the remaining parts P_2, P_{10}, P_{20} and P_{23}. But, what if we applied game theory to these 4 types of parts? How far does this successive application of the game theory go? An answer given by research [29] is that the last iteration appears when the value of the game has a level more or less equal to the average of the values in the last transition costs matrix.

3. In the previous reasoning, the value of the game was linked to the average transition cost, as an economic parameter for the functioning of a FMS. We can ask ourselves if this connection is correct. Research has been done regarding the simulation of FMS functioning, in which the input was represented by the types of products resulting from the minimizer's optimal solution and the output was the value of the game. As expected, the more the simulation

frequencies "connected" with the theoretical frequencies, the more the average transition cost complied with the condition of being lower than the theoretical value of the game. In [5], a sensitivity analysis of the FMS was conducted, compared to the theoretical value of the game. Subsequently, we must mention that the more transitions we have in the analysed period of time, the more firmly the practical results confirm the theoretical suppositions.

4. The study regarding the quality of the solutions [7]; [8], shows that in the case of the maximizer's and minimizer's optimal solutions, the difference in the average, transition cost is of almost 18%. It is also remarkable that from the point of view of the average transition cost, it is better to choose any solution that contains only the types from the optimal solution without respecting the frequencies resulting from this solution, than to take other types from outside the optimal solution.

5. The following question could also be asked: "How relevant are these results as compared to the actual functioning of FMS?" Regarding the selection of the product types to be made in the system, the efficiency of the method is not to be questioned. As to the FMS programming, the minimizer's optimal solution may offer an economizing standard, if, according to the market demand, another functioning of the FMS might be imposed. If it takes longer than expected to analysis the functioning of the FMS and if one can rely on the existence of stocks, then the game theory mechanism might generate a periodic adjustment for using the FMS according to economizing principles.

We shall continue by bringing solid arguments for what we have previously presented, arguments resulting from research.

3.2. Analysis of the FMS productions task

3.2.1. The Production Task-Definition

Analyzing the production task represent the first step in programming the FMS. This is a highly important stage because the morphological characteristics of the selected products represent the initial processing typology and will determine the future structure, as well as the abilities of the production system.

By production task, we understand all the products, goods or components to be produced within the same production unit (department, manufactory, enterprise). In the stage of production task analysis, two major objectives must be pursued:[28]

- establishing a typological group, which should be able to transfer its morphological characteristics onto the abilities of the future FMS.
- ensuring the future reasonable use of the FMS, taking into account the initial investment in technical equipment that should absorb its acquisition costs and the costs that appear during the production time in about 10 to 15 years . Hence, we must take into account the future tendencies and the evolution of the market over a period of time of at least 10 years.

Due to the fact that anticipating what the future system is going to produce is fairly uncertain, the analysis user as a starting point either the product typology already existent in the company, or it creates a list of products with similar characteristics which should satisfy the future market demand.

A model of the initial production task analysis may have as a starting point the criteria presented in the following image:

[28] Abrudan, I., *Sisteme Flexibile de Fabricaţie. Concepte de proiectare şi management*, Editura Dacia, Cluj-Napoca, 1996, pag. 47;

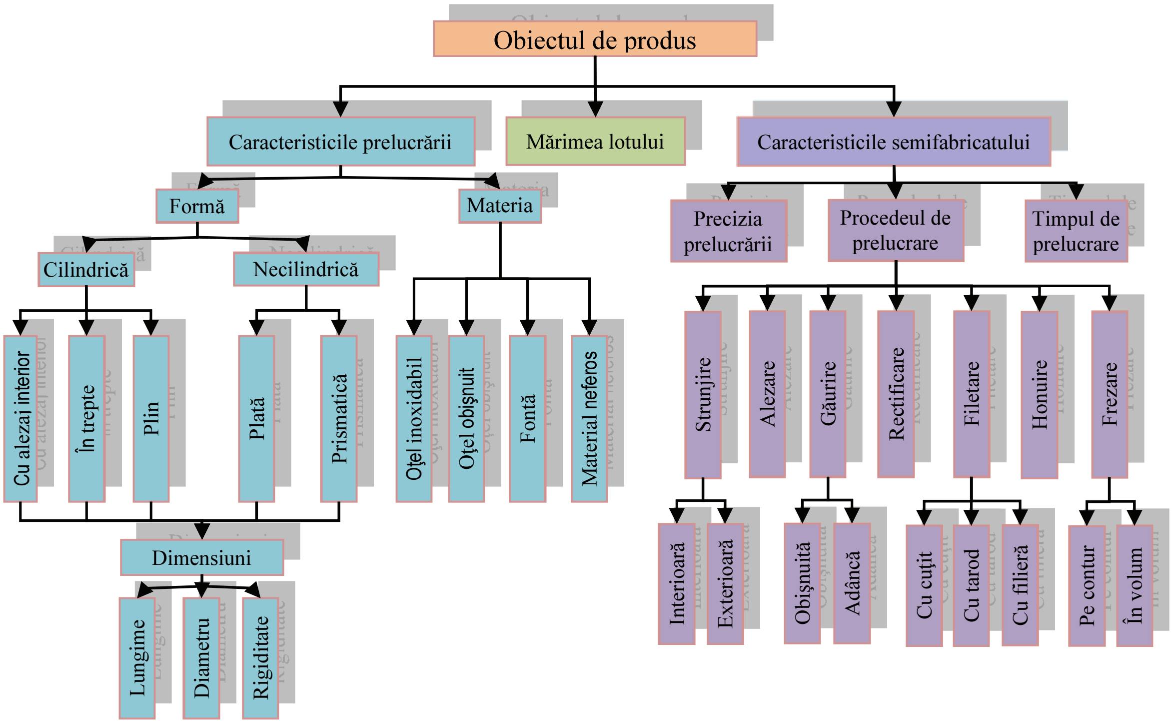

Fig. 3.7 Criteria for the description of production-task typology[29]

Within the analysis of the production task, we may distinguish two intermediary, but extremely important working stages[30]:

- *the stage of typological concentration*. This stage presents the creation of selection of the diverse products included very consistent and stable typological core is determined. By using this core/nucleus as a starting point for the programming of the FMS, the technological and constructive particularities of the products will be transferred to the abilities of the future system. Thus, the future system will successfully generate the components included in the typological core.
- *the stage of typological rise* - a stage when the system is already shaped. This stage represents the attempts to cover the system with as many tasks as possible, so that all the abilities of the system should be economically justified in production. The goal is that for as many types of compatible parts to be brought into the system which will thus have a stable configuration.

The figure 3.8 is a draft of the process of transition for the components of the initial tasks: the stage of typological concentration and the stage of typological rise.

[29] Abrudan, I., *Sisteme Flexibile de Fabricaţie. Concepte de proiectare şi management*, Editura Dacia, Cluj-Napoca, 1996, pag. 47;

[30] Abrudan, I., *Sisteme Flexibile de Fabricaţie. Concepte de proiectare şi management*, Editura Dacia, Cluj-Napoca, 1996, pag. 48;

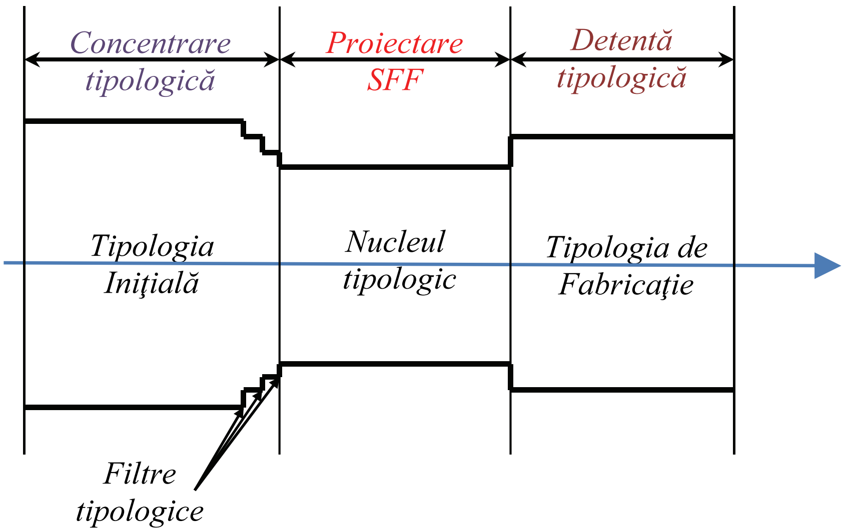

Fig.3.8 Stages in the analysis of the production task[31]

As mentioned before, the two distinct stages of the production task analysis are of utmost importance for the future configuration of the system, We consider that the first stage-of typological concentration-significantly influence the future structure of the FMS, by determining the typological nucleus that represents the starting point of the typological nucleus that represents the starting point of the FMS programming. In this stage, certain typological filters are applied onto the initial set of products, in order to select those parts that generate a consistent stable nucleus.

A very important fact to be mentioned is that the filters that are about to be applied must take into account both the physical characteristics of the parts (length, diameter, weight) and those established by the consumers (the annual series, price, quality level). Besides these two factors that ensure a technical filtering of the initial task, as well as of the market, we could also include in this stage filters that should allow the selection of those products that follow environmental guidelines, thus ensuring a “healthy development” of the system.

Another large class that could be considered restriction-generating to the initial task, is the human resource class. By human resource we understand the level of professional education of the person contributing to the making of the product, as well as the wages he claims. Regarding the wages, we must mention the fact that it is closely linked to the development of the area and to the legislation of the country where the production system is set.

In order to quantify every restriction, we will statistically analysis the production task. This analysis establishes the way to quantify the characteristics of the products for every chosen criterion. Actually, this statistics consists in analyzing the available data in order to point out the frequency of every variation interval of the studied characteristics. In the specialized literature, the following formulas are used to determine the length of the distribution (grouping in sets) interval.[32]

$$l = \frac{x_{\max} - x_{\min}}{1 + 3{,}322 * \log n} \qquad (3.1)$$

[31] Abrudan, I., *Sisteme Flexibile de Fabricaţie.Concepte de proiectare şi management*, Editura Dacia, Cluj-Napoca, 1996, pag. 48;

[32] Popescu, I., *Optimizarea proceselor de aşchiere, Editura Scrisul Românesc*, Craiova, 1987.

$$k = 4 * \left[0{,}75 * (n-1)^2\right]^{\frac{1}{5}};\qquad(3.2)$$

where:

l – the length of the interval of distinct sets;
x_{max}, x_{min} – the maximal/minimal values of the desired characteristics;
n – the number of the statistical observations;
k – the number of sets;

In the second stage, of the typological rise, those parts that were excluded by the typological filters, to ensure an acceptable charging level for the new system, will be introduced in the typological nucleus. By the introduction of the initially excluded parts, the ability of the system to absorb new products with different characteristics from those included in the typological nucleus can also be tested.

The successive following of the two stages, ensures a degree of reasonable flexibility to the system. This means the processing of the parts that rationally generate the lowest costs, according to the criteria imposed by typological filters. It also means the flexibility of the typological nucleus, by introducing the initially excluded parts in the stage of typological rise, in order to analyze the behavior of the system.

3.2.2 Ways to determine a typological nucleus

The Pareto-analysis method

In the ABC, or Pareto analysis, thus named after the inventor, is a simple and efficient selection method of the 20% of causes that produce 80% of the effects. It may be applied to most issues existing around us, giving satisfactory results. In our case, the Pareto analysis will indicate those stable and consistent parts in our family of products that the producer intends to make.

By stability we mean recurrence. The highly stable elements of the production task are the types that appear in production most frequently. An indicator of stability is the annual production task. As to consistency, those elements of the production task are taken into consideration, which take up the most of the ability of the production system (the processing time required by the production system). Generally speaking, the ABC method is satisfactory, though maybe too general, because it does not take into consideration other production criteria that determine production and which may be more important.

The ABC analysis has a very important part in the analysis of the production task. The ABC analysis is actually derived from the application of the Pareto law in the study of the customer's behavior. He studied the tax-distribution in the USA and noticed that a small proportion of the tax-payers (about 20%) was covering the largest amount of taxes entering the state budget (80%)[33].

The existence of a similar law was highlighted in various domains, such as the statistics of traffic-accidents, the amount of articles in stock as compared to the investment, as well as the amount of parts within a production task.

The analysis of the distribution of products, according to the 20-80 law, represents a fundamental element in defining the best adaptation strategy to the demands of the market and to the contextual restrictions of a company. According to this method, we might consider that a company has a balanced commercial activity if 20% of the products ensure the coverage of 80% of the company's ability to produce.

[33] Sankar S.S., S.G. Ponnambalm, V.Rathinavel, M. Gurumarimuthu, *A Pareto based multi-objective genetic algorithm for scheduling of FMS*, Cybernetics and intelligent systems International Conference, 2004, pp. 700-705;

The analysis of the 20-80 law means the following stages[34]:

- the stabilization of the parameters under study;
- identifying the nature of the products;
- defining the criteria that will allow the making of the classification: physical parameters (length, diameter, weight), economic parameters(annual series, price, quality level), as well as environmental parameters(the quantity of the material used, the recyclability of the product);
- the downward ordering of the products according to the analysis indicator(for instance, the descending ordering according to the points obtained);
- devising the concentration curve according to the percentual relative accumulated frequencies;
- interpreting the results.

In production, Pareto's observations generated the analysis of product distribution according to their presence in the list of goods. Thus, in every enterprise we have 3 groups of products offered by the specialized literature in the following percentage [35]:

Table 3.3. Class formation limits

Class	The technological component	The value component
A Class	5-15%	50-60%
B Class	20-30%	25-40%
C Class	55-75%	5-15%

The application of the Pareto law in the case of the initial production task offers important information about its structure according to the selection criteria chosen for the making of the classification. However, starting from this classification, we may conclude about the contents of the typological nucleus and about the percentage of every part within the respective family of products.

Starting with the technological data and the information about every part, we will perform an ABC analysis on 20 products in downward order. This order was established according to the points obtained as a result of the specific usefulness to the 6 criteria, and taking into account the importance coefficients, which are relevant to each criterion, thus resulting 13 different cases.

Following this hierarchy, the 20 products were ordered according to the chosen criteria, in 3 large classes[36]:

- A Class (0% - 40%) – made of the products with the highest points according to the chosen criteria.
- B Class (40% - 90%) – made of the products of average points
- C Class (90% - 100%) – made of the products with the lowest points according to the chosen criteria.

[34]http://www.contabilizat.ro/file/cursuri_de_perfectionare/informatica_economica/Sisteme%20informatice%20in%20comert/cap9.pdf

[35] Cândea, D., Abrudan, I., *Organizarea şi conducerea întreprinderilor industriale*, Litografia institutului Politehnic, Cluj-Napoca, 1984

[36] Chiş, I., Lungu, F., *Analiză comparativă între metode de determinare a nucleului tipologic,* Revista de Inginerie şi Management nr.3, Cluj-Napoca, 2010;

The Electre method for ranking products

Having in view that establishing the similaries/differences between the products has a great influence on the typological nucleus, we consider that this stage must be experimented by several methods in order to analyse the results. Thus, one of the solutions corresponding to these methods might be chosen and the others – rejected.

One of the methods used to validate these results is the ELECTRE method. It is used to compare products P_1, P_2 … Pn according to criteria C_1, C_2 … C_n. The application of the ELECTRE method relies on 2 groups of parameters: correspondence indicators (Cc) and discord indicators (Cd) [the importance coefficients/ the veto thresholds].

A product of the French Management School, the ELECTRE method was discovered in 1968; it may be used in complex decision – making problems, with many alternatives, criteria and consequences of decisional options.[37] The optimal variant is that which outranks the others and may be applied when the preferences about the criteria are known.

The Onicescu Method

Starting with the idea that establishing the similarities/differences between the products of the system has a great influence on the typological nucleus, we consider that this stage has to be experimented by several methods in order to analyse the results. Besides the Pareto and the Electre methods, we will also present a new method, used for the first time in determining the typological nucleus, which starts from the "informational energy" algorythm, which was developed by the Romanian mathematician Octav Onicescu.

The Onicescu method is used in ranking the products P_1,P_2…P_n, according to the criteria C_1,C_2…C_n. The Onicescu method may be used in decision making problems, complex from the point of view of the alternatives, criteria and consequences of decisional variants. The optimal variant is that which outranks the others and may be applied when the preferences about the criteria are known[38].

Game Theory

The algorythms and the stages that must be followed in order to determine the typological nucleus, are presented in the second chapter.

Below is an example [17] for to comparasise the many methods for to determine the tipological nucleus with advantages and dis-advantages of every methods.

A systems adapting capacity to a variety of existing production loads defines the concept of a flexible manufacturing system. This flexibility involves the "movement" of the system in different states, movements called transitions, each state determined by the manufacturing stage of a certain type of product. Starting from the fact that the system is in a continuous transition we can deduct that the effort of flexibility of the system is directly proportional to the resemblance/distinction between types of products.

To determine which of production loads components are representative, we will use three methods to determine the typological nucleus, namely the ABC analysis, the Mathematical Games Theory and the ELECTRE method.

In the case of ABC analysis, the products to be processed are selected according to certain characteristics being chosen those which are representative in terms of established criteria. In the case of the Mathematical Game Theory, however, starting from the affinity

[37] Bernard, G., Besson, M.L., *Douze methodes d'analise multicritere*, Revue francaise d'automatique, informatique et recherche operationelle, V3,1971, pp. 19-66;

[38] Bhatia P.K., *On measures of informational energy*, International Sciences, Vol 97, Iss 3-4, 1997, pp 233-240

coefficients and using the mathematical algorithm for solving max / min problems implemented in a program, we determine the types of products significant for the production load. The ELECTRE method implies achieving a hierarchy of products that form the initial production load. We establish criteria that describe the initial production load and these criteria are associated with an importance coefficient. Starting from the initial production load description and using a method specific algorithm, the concordance and discordance coefficients matrix is built, finally achieving a hierarchy of products that form the initial production load.

In the present study the aim is to achieve a comparative study regarding these three methods of typological filter, listed above, to see which one best meets the feature of flexibility specific to the processing system. We will seek to show both theoretical issues and implementation of typological filtering algorithms in examples. Finally we will interpret the obtained solution and we will determine the overall conclusions of this research.

The initial production task description

The analysis of the production task has as objective to select from the product family, planned to be completed in FMS, a few products that are representative for the entire production load. They form the “typological nucleus”. They must have attributes of stability (to appear frequently in manufacturing) and consistency (to have a considerable processing time compared to the total processing time of the system).

Through stability we mean, here, repeatability. The elements with maximum stability in the production load are the types that occur most frequent in the process. An indicator of the stability is the annual production load.

Regarding the consistency, the elements of the production load that are taken into account are those which occupy as much as possible of the systems production capacity (the processing time required by the manufacturing system).

Establishing evaluation criteria and physical characteristics of products

Choosing the filters to be applied to the initial production load will take into account both the physical characteristics of products (e.g. length, diameter, weight) and those which are determined by consumers (annual series, price, quality level). Besides these two categories of factors, which provide an initial filtering of the production load from a technical and market point of view, we could enter at this stage filters allowing selection of those products that meet environmental requirements ensuring a healthy development of the system in this regard.

The following figure presents a way of approaching the sources from which may come the restrictions. The figure represents a triangle whose corners are listed as the three major areas from which may come the restrictions of a typological nucleus selection.

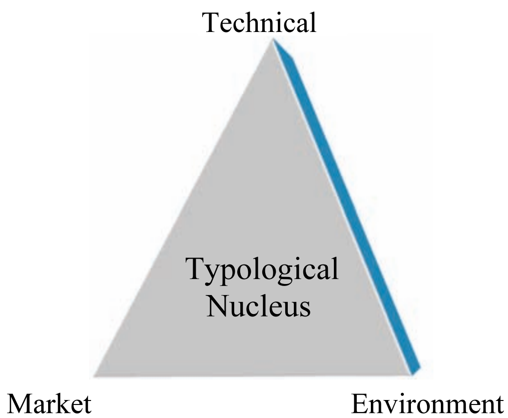

Figure 3.9. Sources of the restrictions

In this case study we considered to be representative to describe the production load the following six criteria, each criterion being assigned a significance coefficient established aprioristically:

- Raw material quantity [gram/piece] $K_1=0.13$;
- Number of processing operations $K_2=0.15$;
- Economic benefit [lei/piece] $K_3=0.22$;
- Production annual series[piece/year] $K_4=0.22$;
- Actual execution time [min/piece] $K_5=0.15$;
- Energy consumption [lei/piece] $K_6=0.13$.

The following table shows, for all the 20 items composing the initial production load, the criteria in which basis we will make the analysis and the values for each item in the considered criterion:

Table 3.4. Entry data associated to the initial production load

No.	*Product name*	*Raw material quantity* [gram/buc]	*Number of operations*	*Economic benefits* [lei/buc]	*Annual series* [buc/an]	*Actual execution time* [min/buc]	*Energy consumption* [lei/buc]
1	Artic. taler / *Head valve*	13	10	0,183	270000	0,249	0,01679
2	CamCamă / *Cam*	42	10	0,279	30000	0,326	0,02082
3	Colier / *Clamp*	132	17	0,728	380000	1,02	0,04529
4	Supapă / *Cone valve*	471	13	2,268	10000	1,322	0,22788
5	Flanşă / *Flange*	47	13	0,298	840000	0,372	0,04243
6	Limitator / *Catcher*	50	16	0,599	350000	1,58	0,15251
7	Opritor tija / *Arrester*	23	14	0,332	270000	0,973	0,04141
8	Pinion D / *Pinion D*	237	15	1,113	60000	1,301	0,08139
9	Pinion V / *Pinion V*	358	16	1,775	380000	1,731	0,08296
10	Pinion Z / *Pinion Z*	90	13	1,012	380000	1,407	0,12521
11	Piston P / *Piston P*	644	13	3,253	5000	2,71	0,16213
12	Piston S / *Piston S*	139	14	1,421	120000	2,438	0,30819
13	Placa dis. / *Gear cam*	82	10	0,734	480000	0,66	0,15015
14	Placa ext. / *Ext.Plate*	89	10	0,695	480000	0,654	0,15018
15	Roata curea / *Gear C*	13	10	0,147	60000	0,39	0,01046
16	Roata lanţ / *Spud*	25	11	0,218	120000	0,259	0,03295
17	Rotor / *Impeller*	96	11	0,485	240000	0,431	0,07717
18	Suport N / *Carrier N*	193	10	1,204	650000	0,826	0,10415
19	Suport V / *Carrier V*	148	14	0,641	360000	0,961	0,0628
20	Zăvor / *Lock*	31	15	0,649	12000	0,855	0,03174

Utility matrix calculation

The main objective in establishing the typological nucleus consists from including within it the major types of products significant in terms of selected criteria. To bring all six criteria outlined above to a common denominator we will replace the values of the table with "utilities", which will be calculated using the formula:

$$u_k = \frac{a_k - \min}{\max - \min}; \qquad (3.3)$$

$$u_k = \frac{\max - a_k}{\max - \min}; \qquad (3.4)$$

where: - u_k represents the calculated utility within the criterion for the benchmark „k";
- a_k represents the value of the considered criterion for the benchmark „k";
- max/min represents the maximum / minimum value from the criterion

In the utility theory it is given the utility 1 for the most favorable situation within each criterion (in our case the limit values) and utility 0 for the least favorable situation. The intermediate values will be marked with utilities included in (0, 1) calculated through linear interpolation according to one of the formulas shown above. Based on these considerations the utility matrix is obtained.

Table 3.5. Utilities calculation

No	*Product name*	*Utility of raw material quantity*	*Utility of operations no*	*Utility of economic benefits*	*Annual series utility*	*Utility of actual ex. time*	*Utility of energy consumption*
1	Artic. taler / *Head valve*	1	1	0,012	0,683	1	0,979
2	CamCamă / *Cam*	0,954	1	0,042	0,970	0,969	0,965
3	Colier / *Clamp*	0,811	0	0,187	0,551	0,687	0,883
4	Supapă / *Cone valve*	0,274	0,571	0,683	0,994	0,564	0,270
5	Flanșă / *Flange*	0,946	0,571	0,049	0	0,950	0,893
6	Limitator / *Catcher*	0,941	0,143	0,146	0,587	0,459	0,523
7	Opritor tija / *Arrester*	0,984	0,429	0,060	0,683	0,706	0,896
8	Pinion D / *Pinion D*	0,645	0,286	0,311	0,934	0,573	0,762
9	Pinion V / *Pinion V*	0,453	0,143	0,524	0,551	0,398	0,756
10	Pinion Z / *Pinion Z*	0,878	0,571	0,278	0,551	0,529	0,615
11	Piston P / *Piston P*	0	0,571	1	1	0	0,491
12	Piston S / *Piston S*	0,800	0,429	0,410	0,862	0,111	0
13	Placa dis. / *Gear cam*	0,891	1	0,189	0,431	0,833	0,531
14	Placa ext. / *Ext.Plate*	0,880	1	0,176	0,431	0,835	0,531
15	Roata curea / *Gear C*	1	1	0	0,934	0,943	1
16	Roata lanț / *Spud*	0,981	0,857	0,023	0,862	0,996	0,924
17	Rotor / *Impeller*	0,868	0,857	0,109	0,719	0,926	0,776
18	Suport N / *Carrier N*	0,715	1	0,340	0,228	0,766	0,685
19	Suport V / *Carrier V*	0,786	0,429	0,159	0,575	0,711	0,824
20	Zăvor / *Lock*	0,971	0,286	0,162	0,992	0,754	0,929

ABC Analysis

Within the ABC Analysis we perform a hierarchy of the products on 3 classes based on the scores sum obtained in the utility matrix, as follows:

- A class (0-40%) – includes those products which obtained the highest score as the sum of utilities assigned within the criteria;

- B class (40-90%) – includes those products which obtained an average percentage score as the sum of utilities assigned within the criteria;
- C class (90-100%) – includes those products which obtained the lowest score as the sum of utilities assigned within the criteria.

To calculate the utilities sum we also take into account the importance coefficients for each criterion, resulting the following table:

Table 3.6 ABC Analysis

	K1=0,13	K2=0,15	K3=0,22	K4=0,22	K5=0,15	K6=0,13				
Product type	*Utility of raw material quantity*	*Utility of operations no*	*Utility of economic benefits*	*Annual series utility*	*Utility of actual ex. time*	*Utility of energy consumption*	*Utility sum*	*Cumulative utility*[%]	*Total cumulative utility*[%]	*Class*
2	0,954	1,000	0,042	0,970	0,969	0,965	0,768	6,490	6,490	A
15	1,000	1,000	0,000	0,934	0,943	1,000	0,757	6,400	12,891	A
16	0,981	0,857	0,023	0,862	0,996	0,924	0,720	6,092	18,982	A
1	1,000	1,000	0,012	0,683	1,000	0,979	0,710	6,003	24,986	A
17	0,868	0,857	0,109	0,719	0,926	0,776	0,663	5,609	30,594	A
20	0,971	0,286	0,162	0,992	0,754	0,929	0,657	5,552	36,146	A
4	0,274	0,571	0,683	0,994	0,564	0,270	0,610	5,157	41,304	B
13	0,891	1,000	0,189	0,431	0,833	0,531	0,596	5,041	46,345	B
14	0,880	1,000	0,176	0,431	0,835	0,531	0,592	5,008	51,353	B
11	0,000	0,571	1,000	1,000	0,000	0,491	0,589	4,985	56,338	B
8	0,645	0,286	0,311	0,934	0,573	0,762	0,586	4,951	61,289	B
7	0,984	0,429	0,060	0,683	0,706	0,896	0,578	4,886	66,176	B
18	0,715	1,000	0,340	0,228	0,766	0,685	0,572	4,835	71,010	B
19	0,786	0,429	0,159	0,575	0,711	0,824	0,542	4,580	75,591	B
10	0,878	0,571	0,278	0,551	0,529	0,615	0,542	4,580	80,171	B
3	0,811	0,000	0,187	0,551	0,687	0,883	0,486	4,106	84,277	B
5	0,946	0,571	0,049	0,000	0,950	0,893	0,478	4,041	88,318	B
9	0,453	0,143	0,524	0,551	0,398	0,756	0,475	4,015	92,334	C
12	0,800	0,429	0,410	0,862	0,111	0,000	0,465	3,931	96,264	C
6	0,941	0,143	0,146	0,587	0,459	0,523	0,442	3,736	100	C

Game Theory

To apply the algorithms from the Game Theory we use data from the utility matrix to determine the correlation coefficients matrix. Using this matrix we determine the affinity coefficients matrix, whose coefficients will be used to solve the max / min problems from the Mathematical Game Theory.

Concordance coefficient matrix calculation

Multiplying the utilities obtained for each criterion with the importance coefficient corresponding to the criterion, and summing the products obtained from each type of benchmark, we obtain a "grade" associated to the benchmark. The difference between the "grades" of two products is the "concordance coefficient", which can be calculated with formula:

$$C_{(g,h)} = \sum_{j=1}^{6} K_j \cdot (u_{gj} - u_{hj}) \qquad (3.5)$$

where : - g, h represents the indices of the product types between which the concordance is established;
- j represents the index of the criterion describing the production load;
- k_j represents the importance coefficient of the criterion j;
- u_{gi}, u_{hj} represents the calculated utilities for the P_g and P_h products within the criterion j.

Table 3.7. Concordance coefficients matrix

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P1	***0***	0,069	0,224	0,237	0,232	0,268	0,132	0,235	0,235	0,168	0,260	0,324	0,114	0,118	0,069	0,069	0,062	0,138	0,168	0,189
P2	0,069	***0***	0,282	0,168	0,290	0,326	0,198	0,182	0,293	0,226	0,191	0,303	0,171	0,175	0,032	0,062	0,104	0,196	0,226	0,125
P3	0,224	0,282	***0***	0,242	0,296	0,136	0,148	0,154	0,054	0,133	0,265	0,286	0,254	0,256	0,354	0,307	0,240	0,238	0,090	0,182
P4	0,237	0,168	0,242	***0***	0,584	0,407	0,422	0,251	0,308	0,315	0,080	0,282	0,451	0,453	0,474	0,459	0,427	0,450	0,390	0,363
P5	0,232	0,290	0,296	0,584	***0***	0,294	0,211	0,303	0,245	0,179	0,328	0,393	0,200	0,204	0,303	0,254	0,217	0,135	0,189	0,274
P6	0,268	0,326	0,136	0,407	0,294	***0***	0,174	0,148	0,028	0,074	0,163	0,184	0,217	0,222	0,379	0,333	0,257	0,261	0,140	0,208
P7	0,132	0,198	0,148	0,422	0,211	0,174	***0***	0,103	0,103	0,079	0,171	0,192	0,191	0,196	0,205	0,160	0,125	0,195	0,038	0,080
P8	0,235	0,182	0,154	0,251	0,303	0,148	0,103	***0***	0,111	0,190	0,111	0,204	0,346	0,347	0,308	0,293	0,262	0,304	0,181	0,137
P9	0,235	0,293	0,054	0,308	0,245	0,028	0,103	0,111	***0***	0,212	0,212	0,323	0,380	0,382	0,513	0,466	0,371	0,339	0,227	0,341
P10	0,168	0,226	0,133	0,315	0,179	0,074	0,079	0,190	0,212	***0***	0,150	0,214	0,168	0,170	0,338	0,291	0,199	0,188	0,119	0,252
P11	0,260	0,191	0,265	0,080	0,328	0,163	0,171	0,111	0,212	0,150	***0***	0,366	0,614	0,615	0,636	0,621	0,590	0,612	0,552	0,525
P12	0,324	0,303	0,286	0,282	0,393	0,184	0,192	0,204	0,323	0,214	0,366	***0***	0,418	0,420	0,473	0,426	0,394	0,439	0,318	0,344
P13	0,114	0,171	0,254	0,451	0,200	0,217	0,191	0,346	0,380	0,168	0,614	0,418	***0***	0,109	0,345	0,340	0,253	0,150	0,264	0,393
P14	0,118	0,175	0,256	0,453	0,204	0,222	0,196	0,347	0,382	0,170	0,615	0,420	0,109	***0***	0,344	0,339	0,249	0,146	0,261	0,392
P15	0,069	0,032	0,354	0,474	0,303	0,379	0,205	0,308	0,513	0,338	0,636	0,473	0,345	0,344	***0***	0,185	0,222	0,267	0,281	0,204
P16	0,069	0,062	0,307	0,459	0,254	0,333	0,160	0,293	0,466	0,291	0,621	0,426	0,340	0,339	0,185	***0***	0,185	0,271	0,242	0,198
P17	0,062	0,104	0,240	0,427	0,217	0,257	0,125	0,262	0,371	0,199	0,590	0,394	0,253	0,249	0,222	0,185	***0***	0,217	0,201	0,272
P18	0,138	0,196	0,238	0,450	0,135	0,261	0,195	0,304	0,339	0,188	0,612	0,439	0,150	0,146	0,267	0,271	0,217	***0***	0,311	0,466
P19	0,168	0,226	0,090	0,390	0,189	0,140	0,038	0,181	0,227	0,119	0,552	0,318	0,264	0,261	0,281	0,242	0,201	0,311	***0***	0,231
P20	0,189	0,125	0,182	0,363	0,274	0,208	0,080	0,137	0,341	0,252	0,525	0,344	0,393	0,392	0,204	0,198	0,272	0,466	0,231	***0***

Affinity coefficients matrix

We observe that the flexibility effort expressed through the concordance coefficients is symmetrical, which is not true in reality. Therefore we rely on so called “affinity coefficients”, according to which the system will prefer one or another benchmark on the principle of minimum effort.

To eliminate the symmetry, the concordance coefficients values from each line are replaced with an index indicating their ascending order. This index is called “affinity coefficient” and it is the result of establishing the ascending order relationship within the concordance coefficients. With these new elements we obtained the “Affinity coefficients matrix” shown in Table 3.8.

Table 3.8. Affinity coefficients matrix

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P1	***0***	2	12	16	13	18	7	14	15	9	17	19	5	6	3	4	1	8	10	11
P2	3	***0***	15	6	16	19	12	9	17	13	10	18	7	8	1	2	4	11	14	5
P3	8	15	***0***	11	17	4	5	6	1	3	14	16	12	13	19	18	10	9	2	7
P4	3	2	4	***0***	19	11	12	5	7	8	1	6	15	16	18	17	13	14	10	9
P5	8	12	14	19	***0***	13	6	15	9	2	17	18	4	5	16	10	7	1	3	11
P6	14	16	3	19	15	***0***	7	5	1	2	6	8	10	11	18	17	12	13	4	9
P7	7	16	8	19	18	11	***0***	4	5	2	10	13	12	15	17	9	6	14	1	3
P8	11	8	6	12	15	5	1	***0***	2	9	3	10	18	19	17	14	13	16	7	4
P9	8	10	2	11	9	1	3	4	***0***	5	6	12	16	17	19	18	15	13	7	14

P10	6	15	4	18	9	1	2	11	13	***0***	5	14	7	8	19	17	12	10	3	16
P11	8	6	9	1	10	4	5	2	7	3	***0***	11	16	17	19	18	14	15	13	12
P12	10	7	6	5	13	1	2	3	9	4	12	***0***	15	16	19	17	14	18	8	11
P13	2	5	10	18	7	8	6	14	15	4	19	17	***0***	1	13	12	9	3	11	16
P14	2	5	10	18	7	8	6	14	15	4	19	17	1	***0***	13	12	9	3	11	16
P15	2	1	14	17	9	15	5	10	18	11	19	16	13	12	***0***	3	6	7	8	4
P16	2	1	12	17	8	13	3	11	18	10	19	16	15	14	4	***0***	5	9	7	6
P17	1	2	10	18	7	13	3	14	16	5	19	17	12	11	9	4	***0***	8	6	15
P18	2	7	9	17	1	10	6	13	15	5	19	16	4	3	11	12	8	***0***	14	18
P19	5	9	2	18	7	4	1	6	10	3	19	17	14	13	15	12	8	16	***0***	11
P20	5	2	4	15	12	8	1	3	13	10	19	14	17	16	7	6	11	18	9	***0***

FMS modelling using Game Theory

FMS operation can be modeled according to mathematical game theory with zero-sum. The solution thus obtained will determine the types of products to be processed in the FMS and the frequency with which they must appear in the system. In addition to this feature, the Game Theory has also a strong focus effect on the initial production load, selecting only those products that are "significant" for the initial load.

To achieve these results we start from the affinity coefficients matrix and construct the following system of inequalities:

$$\left\{\begin{array}{l}
0X_1+2X_2+12X_3+16X_4+13X_5+18X_6+7X_7+14X_8+15X_9+9X_{10}+17X_{11}+19X_{12}+5X_{13}+6X_{14}+3X_{15}+4X_{16}+1X_{17}+8X_{18}+10X_{19}+11X_{20}\geq 1\\
3X_1+0X_2+15X_3+6X_4+16X_5+19X_6+12X_7+9X_8+17X_9+13X_{10}+10X_{11}+18X_{12}+7X_{13}+8X_{14}+1X_{15}+2X_{16}+4X_{17}+11X_{18}+14X_{19}+5X_{20}\geq 1\\
8X_1+15X_2+0X_3+11X_4+17X_5+4X_6+5X_7+6X_8+1X_9+3X_{10}+14X_{11}+16X_{12}+12X_{13}+13X_{14}+19X_{15}+18X_{16}+10X_{17}+9X_{18}+2X_{19}+7X_{20}\geq 1\\
3X_1+2X_2+4X_3+0X_4+19X_5+11X_6+12X_7+5X_8+7X_9+8X_{10}+1X_{11}+6X_{12}+15X_{13}+16X_{14}+18X_{15}+17X_{16}+13X_{17}+14X_{18}+10X_{19}+9X_{20}\geq 1\\
8X_1+12X_2+14X_3+19X_4+0X_5+13X_6+6X_7+15X_8+9X_9+2X_{10}+17X_{11}+18X_{12}+4X_{13}+5X_{14}+16X_{15}+10X_{16}+7X_{17}+1X_{18}+3X_{19}+11X_{20}\geq 1\\
14X_1+16X_2+3X_3+19X_4+15X_5+0X_6+7X_7+5X_8+1X_9+2X_{10}+6X_{11}+8X_{12}+10X_{13}+11X_{14}+18X_{15}+17X_{16}+12X_{17}+13X_{18}+4X_{19}+9X_{20}\geq 1\\
7X_1+16X_2+8X_3+19X_4+18X_5+11X_6+0X_7+4X_8+5X_9+2X_{10}+10X_{11}+13X_{12}+12X_{13}+15X_{14}+17X_{15}+9X_{16}+6X_{17}+14X_{18}+1X_{19}+3X_{20}\geq 1\\
11X_1+8X_2+6X_3+12X_4+15X_5+5X_6+1X_7+0X_8+2X_9+9X_{10}+3X_{11}+10X_{12}+18X_{13}+19X_{14}+17X_{15}+14X_{16}+13X_{17}+16X_{18}+7X_{19}+4X_{20}\geq 1\\
8X_1+10X_2+2X_3+11X_4+9X_5+1X_6+3X_7+4X_8+0X_9+5X_{10}+6X_{11}+12X_{12}+16X_{13}+17X_{14}+19X_{15}+18X_{16}+15X_{17}+13X_{18}+7X_{19}+14X_{20}\geq 1\\
6X_1+15X_2+4X_3+18X_4+9X_5+1X_6+2X_7+11X_8+13X_9+0X_{10}+5X_{11}+14X_{12}+7X_{13}+8X_{14}+19X_{15}+17X_{16}+12X_{17}+10X_{18}+3X_{19}+16X_{20}\geq 1\\
8X_1+6X_2+9X_3+1X_4+10X_5+4X_6+5X_7+2X_8+7X_9+3X_{10}+0X_{11}+11X_{12}+16X_{13}+17X_{14}+19X_{15}+18X_{16}+14X_{17}+15X_{18}+13X_{19}+12X_{20}\geq 1\\
10X_1+7X_2+6X_3+5X_4+13X_5+1X_6+2X_7+3X_8+9X_9+4X_{10}+12X_{11}+0X_{12}+15X_{13}+16X_{14}+19X_{15}+17X_{16}+14X_{17}+18X_{18}+8X_{19}+11X_{20}\geq 1\\
2X_1+5X_2+10X_3+18X_4+7X_5+8X_6+6X_7+14X_8+15X_9+4X_{10}+19X_{11}+17X_{12}+0X_{13}+1X_{14}+13X_{15}+12X_{16}+9X_{17}+3X_{18}+11X_{19}+16X_{20}\geq 1\\
2X_1+5X_2+10X_3+18X_4+7X_5+8X_6+6X_7+14X_8+15X_9+4X_{10}+19X_{11}+17X_{12}+1X_{13}+0X_{14}+13X_{15}+12X_{16}+9X_{17}+3X_{18}+11X_{19}+16X_{20}\geq 1\\
2X_1+1X_2+14X_3+17X_4+9X_5+15X_6+5X_7+10X_8+18X_9+11X_{10}+19X_{11}+16X_{12}+13X_{13}+12X_{14}+0X_{15}+3X_{16}+6X_{17}+7X_{18}+8X_{19}+4X_{20}\geq 1\\
2X_1+1X_2+12X_3+17X_4+8X_5+13X_6+3X_7+11X_8+18X_9+10X_{10}+19X_{11}+16X_{12}+15X_{13}+14X_{14}+4X_{15}+0X_{16}+5X_{17}+9X_{18}+7X_{19}+6X_{20}\geq 1\\
1X_1+2X_2+10X_3+18X_4+7X_5+13X_6+3X_7+14X_8+16X_9+5X_{10}+19X_{11}+17X_{12}+12X_{13}+11X_{14}+9X_{15}+4X_{16}+0X_{17}+8X_{18}+6X_{19}+15X_{20}\geq 1\\
2X_1+7X_2+9X_3+17X_4+1X_5+10X_6+6X_7+13X_8+15X_9+5X_{10}+19X_{11}+16X_{12}+4X_{13}+3X_{14}+11X_{15}+12X_{16}+8X_{17}+0X_{18}+14X_{19}+18X_{20}\geq 1\\
5X_1+9X_2+2X_3+18X_4+7X_5+4X_6+1X_7+6X_8+10X_9+3X_{10}+19X_{11}+17X_{12}+14X_{13}+13X_{14}+15X_{15}+12X_{16}+8X_{17}+16X_{18}+0X_{19}+11X_{20}\geq 1\\
5X_1+2X_2+4X_3+15X_4+12X_5+8X_6+1X_7+3X_8+13X_9+10X_{10}+19X_{11}+14X_{12}+17X_{13}+16X_{14}+7X_{15}+6X_{16}+11X_{17}+18X_{18}+9X_{19}+0X_{20}\geq 1
\end{array}\right.$$

Figure 3.10. Inequalities system

where: - $X_1 \ldots X_{15}$ are the frequencies with which should occur in the system the products P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20.

The condition is imposed that the efficiency function (objective function) to be Min Z $= \sum_i X_i$. According to Neumann's theory (who laid the foundations of Game Theory), any matrix game admits at least one equilibrium point in mixed strategies. These points are the optimal strategies of the two players.

To establish the optimal strategy, in the inequalities system we operate the following change of variable: $x_i = \frac{1}{v} \cdot \bar{x}_i, i = 1, \ldots, m$, and we solve the new system using Storm software. The results obtained from running the program are:

Table 3.9 Game Theory Results

Benchmark type	Simulated value	Probability of occurance	Game value
P1	0	0	11,174
P2	0	0	
P3	0	0	
P4	0	0	
P5	0,0176	0,197	
P6	0	0	
P7	0	0	
P8	0	0	
P9	0,00752	0,084	
P10	0	0	
P11	0,0140	0,156	
P12	0,0198	0,221	
P13	0	0	
P14	0,00747	0,083	
P15	0,0118	0,132	
P16	0,0113	0,126	
P17	0	0	
P18	0	0	
P19	0	0	
P20	0	0	

As a result of the computer simulation of the mathematical model we obtained the results shown in the above tables and to determine the game value and the probability that products appear in the mathematical model a variable change is operated V = 1 / Z.

The solution of the mathematical model consists in the type of products selected for an economic operation of the system and they are ***P_5, P_9, P_{11}, P_{12}, P_{14}, P_{15}, P_{16}***. The obtained objective function value was Z = 0.08949, and the games value was obtained by applying the change of variable.

ELECTRE method

ELECTRE method is a product of the French management school, discovered in 1968, that can be used to solve complex decision problems in number of options, criteria and consequences of decision alternatives. The optimal variant is the one that outperforms the other variants and can be applied when the criteria preferences are known.

Concordance/ discordance coefficients calculation

Comparing two of the products, Pg and Ph, the concordance index highlight favorable aspects of the product Pg to product Ph, and the discordance indicators highlights discrepancies of variant Ph to Pg. Based on this reasoning we will calculate two indicators Cc – concordance indicator and Cd – discordance indicator which will highlight the degree of distance / proximity between products.

To calculate the two index, in SEMA version, we will use the following specific formulas:

$$C_C(P_g, P_h) = \sum_{i=1}^{6} k_i, \text{where } k_i = \begin{cases} k_i, u_{gi} \geq u_{hi} \\ 0, u_{gi} < u_{hi} \end{cases}; \quad (3.5)$$

$$C_d(P_g, P_h) = Max(x_i), \text{where } x_i = \begin{cases} u_{gi} - u_{hi}, u_{gi} \leq u_{hi} \\ 0, u_{gi} > u_{hi} \end{cases} \quad (3.6)$$

where: P_g, P_h – the products between which the concordance/discordance coefficient is calculated;

k_i – significance coefficient specific to benchmark i;

u_{gi}, u_{hi} – the utility of the products g and h within the benchmark i;

x_i – discordance coefficient value.

After covering the utilities matrix and the calculation of all concordance/discordance indexes, we will construct the concordance/discordance matrix. The two matrices are listed below in the following tables:

Table 3.10. Concordance coefficients matrix

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P1	*1*	0,56	0,78	0,56	0,78	0,78	0,78	0,56	0,78	0,78	0,56	0,56	0,78	0,78	0,65	0,56	0,56	0,78	0,78	0,56
P2	0,59	*1*	0,78	0,56	0,78	0,78	0,65	0,78	0,78	0,78	0,56	0,78	0,78	0,78	0,74	0,72	0,78	0,78	0,78	0,43
P3	0,22	0,22	*1*	0,41	0,44	0,5	0,22	0,41	0,63	0,5	0,41	0,41	0,35	0,57	0,22	0,22	0,35	0,48	0,48	0,22
P4	0,44	0,44	0,41	*1*	0,59	0,74	0,59	0,59	0,52	0,74	0,43	0,82	0,44	0,44	0,44	0,44	0,44	0,44	0,59	0,59
P5	0,22	0,22	0,56	0,56	*1*	0,56	0,3	0,56	0,56	0,56	0,56	0,56	0,41	0,41	0,37	0,22	0,41	0,41	0,56	0,3
P6	0,22	0,22	0,5	0,26	0,44	*1*	0,22	0,13	0,65	0,35	0,41	0,41	0,35	0,35	0,22	0,22	0,35	0,35	0,35	0
P7	0,44	0,22	0,78	0,41	0,7	0,78	*1*	0,56	0,78	0,63	0,41	0,56	0,48	0,48	0,22	0,35	0,26	0,35	0,63	0,28
P8	0,44	0,22	0,59	0,41	0,44	0,72	0,44	*1*	0,78	0,72	0,41	0,5	0,57	0,57	0,44	0,44	0,44	0,35	0,44	0,35
P9	0,22	0,22	0,37	0,26	0,44	0,5	0,22	0,22	*1*	0,57	0,41	0,5	0,57	0,57	0,44	0,22	0,22	0,57	0,22	0,22
P10	0,22	0,22	0,72	0,41	0,59	0,65	0,37	0,28	0,65	*1*	0,56	0,56	0,57	0,57	0,22	0,22	0,35	0,35	0,5	0,37
P11	0,44	0,44	0,59	0,72	0,59	0,59	0,59	0,59	0,59	0,59	*1*	0,72	0,44	0,44	0,44	0,44	0,44	0,44	0,59	0,59
P12	0,44	0,22	0,59	0,13	0,44	0,59	0,59	0,5	0,5	0,44	0,28	*1*	0,44	0,44	0,22	0,44	0,44	0,44	0,72	0,35
P13	0,37	0,37	0,65	0,56	0,59	0,65	0,52	0,43	0,43	0,43	0,56	0,56	*1*	0,85	0,37	0,37	0,5	0,65	0,65	0,52
P14	0,37	0,37	0,28	0,56	0,59	0,65	0,52	0,43	0,43	0,43	0,56	0,56	0,65	*1*	0,37	0,37	0,5	0,65	0,65	0,52
P15	0,63	0,41	0,78	0,56	0,63	0,78	0,78	0,78	0,78	0,78	0,56	0,78	0,78	0,78	*1*	0,63	0,78	0,78	0,78	0,56
P16	0,44	0,28	0,78	0,56	0,78	0,78	0,65	0,56	0,78	0,78	0,56	0,78	0,63	0,63	0,5	*1*	0,78	0,63	0,78	0,43
P17	0,44	0,22	0,5	0,56	0,59	0,65	0,74	0,56	0,78	0,65	0,56	0,56	0,5	0,5	0,22	0,37	*1*	0,63	0,65	0,3
P18	0,37	0,37	0,52	0,56	0,44	0,65	0,52	0,65	0,43	0,65	0,56	0,43	0,5	0,5	0,37	0,37	0,37	*1*	0,52	0,52
P19	0,22	0,22	0,52	0,41	0,44	0,65	0,52	0,43	0,78	0,5	0,28	0,43	0,35	0,35	0,22	0,22	0,35	0,35	*1*	0,15
P20	0,44	0,57	0,78	0,41	0,57	1	0,72	0,78	0,78	0,63	0,41	0,63	0,48	0,48	0,44	0,57	0,7	0,48	0,85	*1*

Table 3.11. Discordance coefficients matrix

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P1	***0***	0,287	0,175	0,671	0,037	0,134	0,048	0,299	0,512	0,266	0,988	0,398	0,177	0,164	0,251	0,179	0,097	0,328	0,147	0,309
P2	0,046	***0***	0,145	0,641	0,007	0,104	0,030	0,269	0,482	0,236	0,958	0,368	0,147	0,134	0,046	0,027	0,067	0,298	0,117	0,120
P3	1	1	***0***	0,571	0,571	0,143	0,429	0,383	0,337	0,571	0,813	0,429	1	1	1	0,857	0,857	1	0,429	0,441
P4	0,726	0,695	0,613	***0***	0,672	0,667	0,710	0,492	0,486	0,604	0,317	0,526	0,617	0,606	0,730	0,707	0,594	0,441	0,554	0,697
P5	0,683	0,970	0,551	0,994	***0***	0,587	0,683	0,934	0,551	0,551	1	0,862	0,431	0,431	0,934	0,862	0,719	0,429	0,575	0,992
P6	0,857	0,857	0,360	0,537	0,491	***0***	0,373	0,347	0,378	0,428	0,854	0,286	0,857	0,857	0,857	0,714	0,714	0,857	0,301	0,406
P7	0,571	0,571	0,127	0,623	0,244	0,086	***0***	0,251	0,464	0,218	0,940	0,350	0,571	0,571	0,571	0,428	0,428	0,571	0,099	0,309
P8	0,714	0,714	0,166	0,372	0,377	0,296	0,339	***0***	0,213	0,285	0,689	0,155	0,714	0,714	0,714	0,571	0,571	0,714	0,143	0,326
P9	0,857	0,857	0,358	0,443	0,552	0,488	0,531	0,383	***0***	0,428	0,476	0,347	0,857	0,857	0,857	0,714	0,714	0,857	0,333	0,518
P10	0,471	0,440	0,268	0,443	0,421	0,063	0,281	0,383	0,246	***0***	0,722	0,311	0,429	0,429	0,429	0,467	0,397	0,429	0,209	0,441
P11	1	0,969	0,811	0,564	0,950	0,941	0,984	0,645	0,453	0,878	***0***	0,800	0,891	0,880	1	0,996	0,926	0,766	0,786	0,971
P12	0,979	0,965	0,883	0,453	0,893	0,523	0,896	0,762	0,756	0,615	0,590	***0***	0,722	0,724	1	0,924	0,815	0,685	0,824	0,929
P13	0,448	0,539	0,352	0,563	0,362	0,156	0,365	0,503	0,335	0,120	0,811	0,431	***0***	0,002	0,503	0,431	0,288	0,154	0,293	0,561
P14	0,448	0,539	0,352	0,563	0,362	0,156	0,365	0,503	0,348	0,120	0,824	0,431	0,013	***0***	0,503	0,431	0,288	0,164	0,293	0,561
P15	0,057	0,042	0,187	0,683	0,049	0,146	0,060	0,311	0,524	0,278	1	0,410	0,189	0,176	***0***	0,053	0,109	0,340	0,159	0,162
P16	0,143	0,143	0,164	0,660	0,026	0,123	0,037	0,288	0,501	0,255	0,977	0,387	0,166	0,153	0,143	***0***	0,086	0,317	0,136	0,139
P17	0,203	0,251	0,107	0,574	0,117	0,073	0,120	0,215	0,415	0,169	0,891	0,301	0,143	0,143	0,224	0,148	***0***	0,231	0,050	0,273
P18	0,455	0,742	0,323	0,766	0,231	0,359	0,455	0,706	0,323	0,323	0,772	0,634	0,203	0,203	0,706	0,634	0,491	***0***	0,347	0,764
P19	0,571	0,571	0,059	0,524	0,239	0,155	0,198	0,359	0,365	0,142	0,841	0,287	0,571	0,571	0,571	0,428	0,428	0,571	***0***	0,417
P20	0,714	0,714	0,025	0,521	0,285	0	0,143	0,149	0,362	0,285	0,838	0,248	0,714	0,714	0,714	0,571	0,571	0,714	0,143	***0***

Differences matrix and dominance matrix

Having determined the composition of the two matrices, we calculate, based on these, the differences matrix presented in the following table:

Table 3.12. Differences matrix

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
P1	1	0,27	0,61	-0,11	0,74	0,65	0,73	0,26	0,27	0,51	-0,43	0,16	0,60	0,62	0,40	0,38	0,46	0,45	0,63	0,25
P2	0,54	1	0,64	-0,08	0,77	0,68	0,62	0,51	0,30	0,54	-0,40	0,41	0,63	0,65	0,69	0,69	0,71	0,48	0,66	0,31
P3	-0,78	-0,78	1	-0,16	-0,13	0,36	-0,21	0,03	0,29	-0,07	-0,40	-0,02	-0,65	-0,43	-0,78	-0,64	-0,51	-0,52	0,05	-0,22
P4	-0,29	-0,25	-0,20	1	-0,08	0,07	-0,12	0,10	0,03	0,14	0,11	0,29	-0,18	-0,17	-0,29	-0,27	-0,15	0	0,04	-0,11
P5	-0,46	-0,75	0,01	-0,43	1	-0,03	-0,38	-0,37	0,01	0,01	-0,44	-0,30	-0,02	-0,02	-0,56	-0,64	-0,31	-0,02	-0,02	-0,69
P6	-0,64	-0,64	0,14	-0,28	-0,05	1	-0,15	-0,22	0,27	-0,08	-0,44	0,12	-0,51	-0,51	-0,64	-0,49	-0,36	-0,51	0,05	-0,41
P7	-0,13	-0,35	0,65	-0,21	0,46	0,69	1	0,31	0,32	0,42	-0,53	0,21	-0,09	-0,09	-0,35	-0,08	-0,17	-0,22	0,53	-0,03
P8	-0,27	-0,49	0,42	0,04	0,06	0,52	0,10	1	0,57	0,43	-0,28	0,35	-0,14	-0,14	-0,27	-0,13	-0,13	-0,36	0,30	0,02
P9	-0,64	-0,64	0,01	-0,18	-0,11	0,01	-0,31	-0,16	1	0,14	-0,07	0,15	-0,29	-0,29	-0,42	-0,49	-0,49	-0,29	-0,11	-0,30
P10	-0,25	-0,22	0,46	-0,03	0,17	0,59	0,09	-0,10	0,40	1	-0,16	0,25	0,14	0,14	-0,21	-0,25	-0,05	-0,08	0,29	-0,07
P11	-0,56	-0,53	-0,22	0,16	-0,36	-0,35	-0,39	-0,06	0,14	-0,29	1	-0,08	-0,45	-0,44	-0,56	-0,56	-0,49	-0,33	-0,20	-0,38
P12	-0,54	-0,75	-0,29	-0,32	-0,45	0,07	-0,31	-0,26	-0,26	-0,17	-0,31	1	-0,28	-0,28	-0,78	-0,48	-0,38	-0,25	-0,10	-0,58
P13	-0,08	-0,17	0,30	0,00	0,23	0,49	0,16	-0,07	0,10	0,31	-0,25	0,13	1	0,85	-0,13	-0,06	0,21	0,50	0,36	-0,04
P14	-0,08	-0,17	-0,07	0,00	0,23	0,49	0,16	-0,07	0,08	0,31	-0,26	0,13	0,64	1	-0,13	-0,06	0,21	0,49	0,36	-0,04
P15	0,58	0,37	0,59	-0,12	0,58	0,63	0,72	0,47	0,26	0,50	-0,44	0,37	0,59	0,60	1	0,58	0,67	0,44	0,62	0,40
P16	0,3	0,14	0,62	-0,10	0,75	0,66	0,61	0,27	0,28	0,52	-0,42	0,39	0,46	0,48	0,36	1	0,69	0,31	0,64	0,29
P17	0,24	-0,03	0,39	-0,01	0,47	0,58	0,62	0,35	0,37	0,48	-0,33	0,26	0,36	0,36	0,00	0,22	1	0,40	0,60	0,03
P18	-0,08	-0,37	0,20	-0,21	0,21	0,29	0,07	-0,06	0,11	0,33	-0,21	-0,20	0,30	0,30	-0,34	-0,26	-0,12	1	0,17	-0,24
P19	-0,35	-0,35	0,46	-0,11	0,20	0,50	0,32	0,07	0,42	0,36	-0,56	0,14	-0,22	-0,22	-0,35	-0,21	-0,08	-0,22	1	-0,27
P20	-0,27	-0,14	0,76	-0,11	0,29	1,00	0,58	0,63	0,42	0,34	-0,43	0,38	-0,23	-0,23	-0,27	0	0,13	-0,23	0,71	1

Starting from the *differences matrix* we calculate the dominance matrix by comparing the values from the dominance matrix (Rj, Ri) with (Ri, Rj). Instead of the elements of equal value or greater we given the grade 1 in the dominance matrix, and instead of items with a lower value we grade 0, the diagonal will be the value 1 and when items have equal values than both positions will be awarded the grade 1. The dominance matrix is presented in the following table:

Table 3.13. Dominance matrix

	P1	***P2***	***P3***	***P4***	***P5***	***P6***	***P7***	***P8***	***P9***	***P10***	***P11***	***P12***	***P13***	***P14***	***P15***	***P16***	***P17***	***P18***	***P19***	***P20***
P1	***1***	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
P2	1	***1***	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P3	0	0	***1***	1	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
P4	0	0	0	***1***	1	1	1	1	1	1	0	1	0	0	0	0	0	1	1	1
P5	0	0	1	0	***1***	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
P6	0	0	0	0	0	***1***	0	0	1	0	0	1	0	0	0	0	0	0	0	0
P7	0	0	1	0	1	1	***1***	1	1	1	0	1	0	0	0	0	0	0	1	0
P8	0	0	1	0	1	1	0	***1***	1	1	0	1	0	0	0	0	0	0	1	0
P9	0	0	0	0	0	0	0	0	***1***	0	0	1	0	0	0	0	0	0	0	0
P10	0	0	1	0	1	1	0	0	1	***1***	1	1	0	0	0	0	0	0	0	0
P11	0	0	1	1	1	1	1	1	1	0	***1***	1	0	0	0	0	0	0	1	1
P12	0	0	0	0	0	0	0	0	0	0	0	***1***	0	0	0	0	0	0	0	0
P13	0	0	1	1	1	1	1	1	1	1	1	1	***1***	1	0	0	0	1	1	1
P14	0	0	1	1	1	1	1	1	1	1	1	1	0	***1***	0	0	0	1	1	1
P15	1	0	1	1	1	1	1	1	1	1	1	1	1	1	***1***	1	1	1	1	1
P16	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	***1***	1	1	1	1
P17	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	***1***	1	1	0
P18	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0	0	0	***1***	1	0
P19	0	0	1	0	1	1	0	0	1	1	0	1	0	0	0	0	0	0	***1***	0
P20	0	0	1	0	1	1	1	1	1	1	0	1	0	0	0	0	1	1	1	***1***

Summing all the grades on a line, obtained by a benchmark from the dominance matrix, we obtain a value that characterizes the benchmark in comparison with other products. The difference between the final grade of a benchmark and the final grade of another benchmark is actually measuring the gap between the two products relative to the considered criteria.

Thus applying the calculation methodology specific for ELECTRE method on an initial production load consisting of 20 products, and considering the chosen criteria and the significance coefficients specific for the criteria we established the following hierarchy of products:

Table 3.14. ELECTRE results

Nr. Crt.	Denumire produs	Metoda ELECTRE	Poziţia ocupată	Nr. Crt.	Denumire produs	Metoda ELECTRE	Poziţia ocupată
1	Artic. taler	18	3	*11*	Piston	11	10
2	Camă	20	1	*12*	Piston strj.	1	20
3	Colier	5	16	*13*	Placa dis.	15	5
4	Supapă	11	9	*14*	Placa ext.	14	7
5	Flanşă	5	17	*15*	Roata curea	19	2
6	Limitator	3	18	*16*	Roata lanţ	17	4
7	Opritor tija	9	12	*17*	Rotor	15	6
8	Pinion dis.	8	13	*18*	Suport N	11	11
9	Pinion vib.	2	19	*19*	Suport V	7	15
10	Pinion z19	7	14	*20*	Zăvor	12	8

Final conclusions and results interpretation

After applying on the initial production load of specific algorithms and calculation methodology specific to the three methods used, namely the ABC analysis, Game Theory, ELECTRE method, the results obtained in each method are centralized in the following table:

Table 3.15. Results centralization

Nr. Crt	Denumire produs	Analiza ABC	Poziția ocupată	Teoria Jocurilor	Poziția ocupată	Metoda ELECTRE	Poziția ocupată
1	Artic. taler	6,003	4	0	0	18	3
2	Camă	6,49	1	0	0	20	1
3	Colier	4,106	16	0	0	5	16
4	Supapă	5,157	7	0	0	11	9
5	Flanșă	4,041	17	0,197	2	5	17
6	Limitator	3,736	20	0	0	3	18
7	Opritor tija	4,886	12	0	0	9	12
8	Pinion dis.	4,951	11	0	0	8	13
9	Pinion vib.	4,015	18	0,084	6	2	19
10	Pinion z19	4,58	14	0	0	7	14
11	Piston	4,985	10	0,156	3	11	10
12	Piston strj.	3,931	19	0,221	1	1	20
13	Placa dis.	5,041	8	0	0	15	5
14	Placa ext.	5,008	9	0,083	7	14	7
15	Roata curea	6,4	2	0,132	4	19	2
16	Roata lanț	6,092	3	0,126	5	17	4
17	Rotor	5,609	5	0	0	15	6
18	Suport N	4,835	13	0	0	11	11
19	Suport V	4,58	15	0	0	7	15
20	Zăvor	5,552	6	0	0	12	8

In conclusion we can say that the three methods used to determine the typological nucleus solutions do not provide strictly the same products, that is the three methods solutions coincide only partially.

The selected products by means of calculation provided by “Game Theory” can be found in part among the products which form the typological nucleus resulted from the ABC analysis and ELECTRE method. We observe that from the first five products that ABC analysis has selected to be part of the typological nucleus, two solutions are found in the solutions of Game Theory. It is the product P15 and P16. Analyzing the solutions offered by ABC analysis and ELECTRE method we observe that from the five products from the initial production load, four of them, namely P1, P2, P15, P16, were selected to participate in typological nucleus in both cases. We thus conclude that from the three methods used to determine the typological nucleus, the two methods, ABC analysis and ELECTRE method, offer very similar solutions because they do a strictly technological filtering.

We observe that, with ABC analysis and ELECTRIC method, the interpretation of the FMS as a mathematical game forms a selection method which greatly narrows the types of products classification, because it has a strong concentration of the initial production load. We also notice that using “ABC analysis” from the 20 types of products which formed the initial production 6 products were selected (those that form class A) to form the typological nucleus. With the “Game Theory”, from the 20 products constituting the initial production load, have been selected to be part of the typological nucleus seven products.

The three methods presented can be used to filter the initial production load to determine the typological nucleus of a flexible manufacturing system. Using one method is left to the manager, this being done according to the strategic objectives. Each of these methods, through the algorithms they use, aim to reduce the initial production load in terms of specific considered criteria and the significance coefficients related to each criterion.

3.3. Research upon FMS programming

3.3.1. The costs within the FMS

Being used to a normal, competition based market as a context for the present-day economy, any enterprise wishes competitive advantages, meaning quality products, at the lowest prices possible. It is useless to think about implementing a FMS in a situation in which the system does not offer economic advantages. The investments in flexible systems can reach such amounts that could not be immediately justified.

The decision of implementing such a system should, however aim further, having in view the fact that the investment could be covered in a longer period of time. The acquisition of flexible cells with no particular efficiency, that do not justify their productive investment, is probably permitted only in research, in view of bringing innovations to the field.

As an argument in favour of using the FMS, are the studies that prove that 8-10% of the overall processing time is the operative time necessary for obtaining a piece, of which only 30% is the actual time in which changes occur, as highlighted in the previous chapter.

A FMS has the advantage of automation and computer optimization, which helps the optimal use of time and the increase of productivity. Operations such as loading, unloading, handling, adjustment, programming, will take much less time, due to the absence of manpower, which can lead to mild errors. The robot is however programmed, so that it should substantially reduce the time necessary to preparations, handling, adjustment, and the control should be conducted in real time, coordinated by sensors and assisted by the computer.

The specialized literature points out series of advantages and disadvantages which are the basis of that decision which related to implementing a FMS. If we were to make a synthesis, the main advantages from the point of view of the costs would be[39]:

- reducing the personnel and the insurance - related costs (the luminosity or the controlled temperature of the area in which the robot-assisted production takes place, not being an issue anymore)
- the precision with which the system operates
- the absence of breaks
- non-stop production.

All this leads to arguments in favour of using robots in production.

After the acquisition and implementation stage of the FMS, the stress lays on optimizing its functioning, which means the reduction of **transition costs**. These costs appear because if the system's effort to pass from one state to another, from making one type of product to making another. Some might consider these costs related to the programming costs of the system, meaning that a better programmed system would operate more efficiently, with lower transition costs. Others think that the degree of automation and fitting of the machines and of the system are the causes of transition costs.

Surely, both points of view are correct, because they express factors that influence these costs.

[39] Abrudan, I., *Sisteme flexibile de fabricaţie. Concepte de proiectare şi management*, Editura Dacia, 1996.

Due to the fact that the demand of the market is aleatory and the storage costs represents immobilised values, the system would better produce smaller quantities of goods, satisfying the market instantly at the same time, offering the requested products in the requested quantity in order to get profit. When following certain frequencies in production, the maintaining of competitive costs could be reached, as well as the satisfaction of the market demands.

The average transition cost is the average of all transition costs that appear over a given period of time in the functioning of the FMS. The costs may be divided into 2 categories[40]:

- general costs: which ensure the conditions necessary for a production task.
- special costs: which ensure the conditions necessary for a distinct requirement within the production task.

The special costs are actually those analysed by the present research, because they represent the money needed for the system's effort when another product is introduced and the production and the production task changes.

Table 3.16 – General and special costs of a FMS[41]

General costs	Special costs
General preparation costs; **Fixed expenses:** ✓ Reduction in value; ✓ Interests; ✓ Taxes; ✓ Insurance. **Utilities:** ✓ Premises; ✓ Energy etc.	**Variable expenses;** **Resulting from the production task:** ✓ Further equipment of the machineries; ✓ Devices; ✓ Programs. **Resulting from the production series:** ✓ Replacement of tools and their adjustment; ✓ Supplementary equipment; ✓ Adjustment of work parameters.

In the case of flexible system, with little transition time, these costs would significantly diminish. So, the costs are defined by automation and could be compared to the preparation-ending costs of the classical, serial factory, generated by the issue of a production batch. The larger the batch is, the lower the preparation-ending costs are. The more diverse the products are, the higher the transition costs are, because of the adjustment process of the system to the processing of a new product. In Fig.3.11, Co represents the optimal cost, meaning the point in which the size of the batch balances variety at the lowest possible cost.

[40] Lungu, F., *Cercetări şi contribuţii privind managementul sistemelor flexibile de fabricaţie*, Teză de doctorat, Universitatea Tehnică din Cluj-Napoca, 2005, p. 15.
[41] Adaptat după Abrudan, I., *Cercetări şi contribuţii privind optimizarea tehnologică a sistemelor flexibile de fabricaţie*, Teză de doctorat, 1991, p. 26.

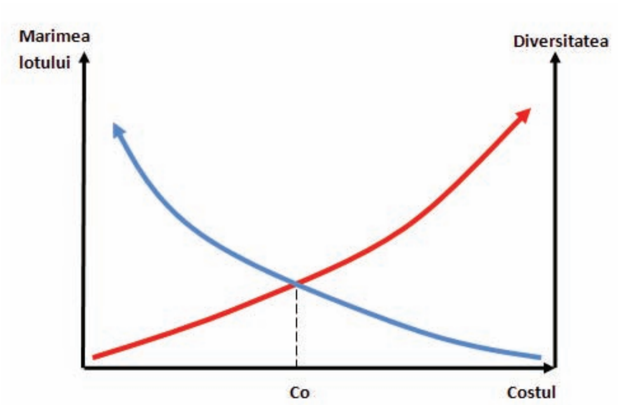

Fig. 3.11. The variation of cost according to the size of the batch and the diversity of the products

Fig.3.12 represents an example for the processing of certain products for which the system needs to adapt. There are 5 states given by 5 types of processing or 5 special tools. Horizontally, we may see the pieces that differ in form/characteristics, hence being processed with different technologies.

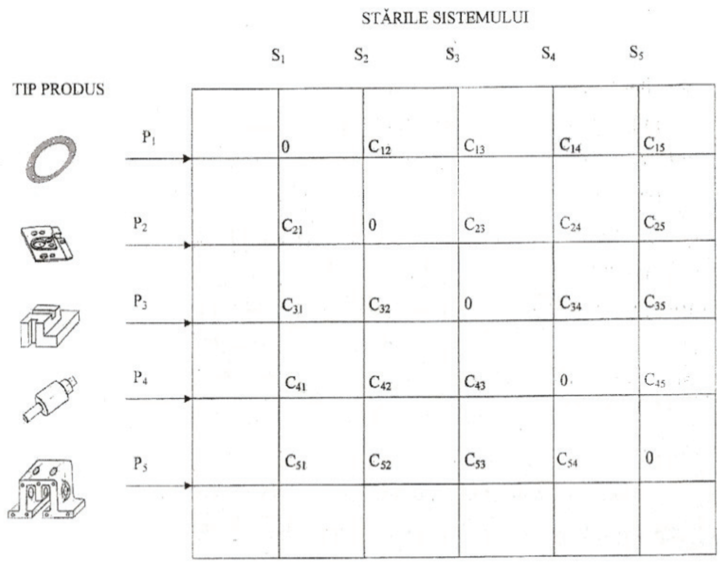

Fig.3.12.The transition costs matrix[42]

In the above figure, we have the following notations:

$C_{i,\,i+1}$ - the transition costs from i to i+1.

P - the products

S - the states of the system.

We notice that in these systems, for every state and for every product there is a transition cost that is not equal to the reverse transition. Thus, transition costs are an unconditional sequel of using the FMS.

The present research is based on the criterion of transition cost optimization. This means that we shall look for the best way to launch the products in the system and to find the best processing method in which the costs of the adjustment effort of the system are minimal. In

[42]Lungu, F., *Cercetări și contribuții privind managementul sistemelor flexibile de fabricație*, Teză de doctorat, Universitatea Tehnică din Cluj-Napoca, 2005

other, less technical, words, we shall try to be as comfortable as possible in preparing the system for production. We shall look for the simplest alternative in other to reduce the costs.

3.3.2. The functioning ways of a FMS

In the case of a FMS, the passage of a system from processing one type of product to processing another, is called transition. By transition, we mean here the switching operation of the system from one production technology to another. The necessary cost for this change was called transition cost and it comprises all the costs generated by changing production from one product to another. Determining the succession of the products that enter the system represents the programming of the succession of the system's states.

In the specialized literature, we have two ways in which the products enter the FMS[43].

- when the types of products enter a FMS according to a pre - determined succession. The optimal succession is that which has the lowest transition costs for the making of all types of products in the system. In this situation, the system does not ensure the flexibility expected by the beneficiary, meaning that it doesn`t allow a quick, efficient response to random product demand. This model enters the products in a well - established order, and when all the types of products are ready, the cycle begins again.
- the random introduction of the types of products in the FMS. Here, the products are introduced at random, aiming at controlling the average transition cost from one state to another, at all times.

One of the most important problems following the implementation of a flexible system is its programming. The system must be operated by software, which should generate the optimal production solution at minimal costs. The problem is twofold:

- *The product demand of the market must be satisfied* - The demand is generally random. In order to find solutions in this respect, we must use mathematical analysis that creates historical reports given by the marketing departments of the enterprise. Predictions are made according to the previous market demand, hoping that the future demand should fit between these values .Production is dimensioned according to these results.
- *The system produces at minimum transition costs* – only when it works with an exact quantity, which actually is either too large, or insufficient. This means that if the system is wanted to be economical, the products could be more or fewer than the requested quantity.

The enterprise will generate profit by selling the finite products. Hence, the enterprise will attempt to satisfy the demand and, at the same time, to work at costs as close to the optimal as possible. This is a highly debated issue by specialists all over the world who try to reach a real solution, easy to apply.

The transition costs, as mentioned in the previous chapter, are a consequence of the system`s effort to change according to the production task.

Probably, a logical question would be : "Why aren`t all the pieces of a certain type produced in the requested quantity, in one batch only, in order to reduce the costs related to the next programming of the system ? ".

The answer is given by the market: diversity is requested and the system is either incapable of instantly producing such a large series in order to satisfy the demand, or the storage

[43] Abrudan, I., *Sisteme flexibile de fabricatie. Concepte de proiectare si management*, Editura Dacia, Cluj-Napoca, 1996

costs are too high to produce and await demand. In the last situation, we would not be talking about flexible production.

Programming a FMS in this case consists in determining the succession of product entry and the calculation of the costs related to the passage of the system from a certain state corresponding to a certain product to a state suitable for the production of the next item .We could compare each state of the system with generating a batch of products for which preparation – ending time is needed. In programming,[44] solutions must be given to the following problems:

- Determining the optimal sequences for the product's entry in the system
- The preferences of the system in order to get to minimal transition costs.
- The similarities between the products.
- Solutions for random production or for the request of a product that is not in the established program

This stage may be considered the one giving coherence and substance to a flexible manufacturing system. Without this stage we would not get to a productive optimization, to the recovery of the investment and to a competitive advantage on the market.

The programming has several criteria to take into consideration:

- the reduction of the working time
- the reduction of non-productive time in the system
- reaching a maximum charge
- obtaining minimal stocks and so on.

The present paper will analyse the matter from the point of view of the reduction of transition costs. These costs are the most relevant and illustrative for a flexible system and they represent the main drawback that could lead to inefficiency. Two identical system may have different types of efficiency, according to the programs used.

3.3.3. Types of FMS programming

Programming a FMS aims at finding the optimal solution, meaning the "best" option according to the chosen criterion.

To reach an optimal point we use mathematical simulation that reproduces reality and generates the unexpected elements that could actually occur. After comparing the results, the domain of the most suitable solution is identified. Using the simulation gives satisfactory results but inexact at times, due to the occurrence of unexpected, real events.

The linear mathematical programming is a frequent method in many domains. A Goal Function is defined (relation 3.7), and is transformed in a mathematical function. Maximizing /or minimizing the unknown parameters becomes an objective. Afterwards, restriction are filled in (rel.3.8), restrictions imposed by the factory`s production capacity or by other resources, totally or partially available. The parameter $b_1,b_2......b_m$ in rel.3.8 refers to the available resources. Because any resource is limited, the conditions for the goal function (which includes the objective of the system) are intended to take the system as close to reality as possible. The non-negativity condition is often required, as presented in rel. 3.9.

$$f = c_1x_1 + c_2x_2 + c_nx_n \qquad (3.7.)$$

[44]Abrudan, I., *Sisteme flexibile de fabricaţie. Concepte de proiectare şi management*, Editura Dacia, Cluj-Napoca, 1996.

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \leq b_2 \\ \cdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \leq b_m \end{cases} \quad (3.8.)$$

$$x_1 > 0, x_2 > 0, \ldots, x_n > 0 \quad (3.9.)$$

A solution for this problem, of the conditioned goal function is a classical problem of linear programming, as long as the components are 1st degree functions. This method is also used in programming the classical production, giving the functioning context (head-start, turning speed, depth, etc) in the context of the variation of the functioning parameters between certain values.

According to the type of system entries, the FMS could function and therefore be programmed in different ways[45]:

1. The products of the typological nucleus enter production according to a **pre-determined succession**. In this case, the calculations are easier, analyzing all the possibilities with the help of the computer which will chose the most advantageous an thus, optimal variant. This problem is solved with the graph theory which indicates exactly where the lowest transition costs appear, meaning the shortest Hamiltonian way .This is, surely, the easiest way to program the FMS, but it is not always close to reality, because flexibility is barely visible in this case .The system always produced what he is taught to, not being flexible to the random market demand, which is its main advantage
2. The second method of product-entry is the **random** one. In this case, we have an imitation of how real market works. As long as there is a market demand, the system adapts itself to the new products that have to be made. The control of this system, based on uncertainty and probability, could be achieved with the help of game theory, among others. This is the method used by the present paper to demonstrate how optimization could be achieved. The method offers great potential and could lead to very good results.

So, the research that represents the starting point of this paper, has tried the development of production- programming when the components of the typological nucleus enter the system at random, with no particular known rule (Fig.3.13).

In practice, this represents the real model that is used. The marketing research establishes necessity at exact times, stage followed by the order of the products required by the market. The problem under research refers to researching the lowest possible transition costs for such a system.

The programming of the system is computer-assisted and with the help of CIM-CAD-CAM is transmitted to the system. The simulation of the process may also be useful in this case, by using a function of random parameter entry in the system.

[45] Abrudan, I., *Sisteme flexibile de fabricație. Concepte de proiectare și management*, Editura Dacia, Cluj-Napoca, 1996.

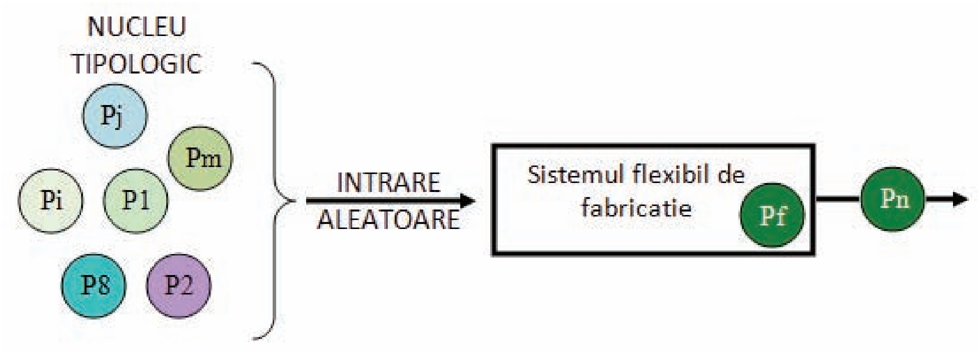

Fig. 3.3.4 Game theory applied in FMS programming[46]

3.3.4. Game theory applied in FMS programming

Game theory represents a powerful instrument for planning and programming the FMS production. In FMS programming two situations may occur. The first situation occurs when the pieces follow a known entry in production, and the second, which is closer to reality, is the one where the normal demand of the market is respected, and pieces enter the system at random.

Due to the fact that a relevant research would mainly refer to the real model, we shall follow the situation in which the pieces enter the system at random, without any precedence or succession whatsoever. In the given situation, a series of factors are not considered by the research, such as: deadlines, loading, or other factors that would only influence the general costs, and not the transition costs. We shall only follow the optimization of transition costs.

The system must produce what is required by the market, at the lowest possible costs. Every order must be seen as a production batch, for which the system needs to adjust. This represents the transition time for the flexible production, or the preparation-ending time of the classical production.

According to other works and by analysing the theory, its' usefulness is justified by the following reasons:

- There is a conflict between two players. We could consider *the market* as being one of the players, which tends to order the system to make varied and diverse products, without taking into account any economic parameter. *The production system* could be the other player, which aims at having as few changes as possible in order to be efficient.
- There is a stake (the payments) meaning the *transition costs* corresponding to each production stage of every product, we shall make the transition-costs matrix.
- Every player has pure strategies, which, combined in the game, constitute the *mixed strategies*
- The strategies are known by both of the players and their choice is based on logical and honest principles .
- The main diagonal is 0, so the game has no saddle point and uses the mathematical matrix game , in which the matrix is always balanced because every product has a stage in its production. The main diagonal is 0, because the stage of a product does not generated costs when the same product is made.
- The desired result is the balance point, namely the *average transition cost*, in which the system produces a diversity of goods corresponding to the acceptable

[46] Adaptat după Abrudan, I., *Sisteme flexibile de fabricaţie. Concepte de proiectare şi management*, Editura Dacia, Cluj-Napoca, 1996.

costs of the system. Every player follows an exact objective: the maximizer's goal is to minimize his loss.

- At the end of the game the used strategies will be accounted for and their *input frequencies* will be created. This will indicate the quantities of products that must enter the system, in order to maintain the optimal production cost.
- The game develops in a succession of matches, in which the two players use their pure strategies for every match.
- The sum of payoffs is constant, meaning that everything a player loses, the other one wins.[47]

After applying the theory our objective will be to obtain the probabilities with which the products enter the system for an optimal and efficient functioning. This information will result from the input of every player`s strategies in the game.

Having in mind these probabilities when entering products into the system or at the different stages of the FMS, the value of the transition costs will definitely not cross a certain limit, equal to the theoretical value of the game, which is also the optimal one. Game theory will also provide us with a considerable part of the typological nucleus, meaning those products that have to be made in order to match the optimal cost given by the game. Having in view the fact that the market demands products at random, no matter the mathematical calculations, we shall try to program the system within optimal parameters, even if restrictions are not imposed.

The given results may be taken into consideration in the decision making process for the FMS functioning, when the products are introduced in the system. They will help the system run efficiently, close to the theoretical value.

The major objective for which game theory is used, is to create a balance between the two contradictory tendencies that appear in the flexible production. The system would rather limit the pieces to being simple an easy to make, but the market demands more and more diverse items.

In order to maintain flexibility, the system must not produce one or few products only, but a large variety ,which leads to an economic disaster .The balance point, where the market is satisfied and when the system is subjected to an average effort ,is the optimal point and is located around the result of the game within the math game theory.

The conflict is defined by two hypotheses:

- It is not possible that the making of a product should not generate any cost, and every change in the system will produce a cost.
- If only one product is made, the system is not flexible.

The parameters that have to be known in this game, are the following:

P - the maximizer player, *meaning the market demand to maximize the number of products*, having the pure strategies $P_1, P_2 \ldots. P_n$;
S - the minimizer player, meaning *the flexible manufacturing system that tends towards minimizing the states of the system in order* to produce the P-s, with its pure strategies $S_1, S_2 \ldots.. S_n$;
N - the number of matches, every time a pure strategy is chosen

The stake is represented by the transition cost, around which the program revolves. The transition cost is written c_{ij} and is interpreted as a time transformed in the cost necessary for the adjustment of the system, which is found at state j that wants the production of the item in state i.

[47] Abrudan, I. , *Sisteme flexibile de fabricaţie. Concepte de proiectare şi management*, Ed. Dacia, 1996, p. 105.

For the system, this cost represents a loss, but for the product, it represents a gain, because it undergoes a processing that adds value.

The strategy imposed by one of the two players depends on the opponent's strategy. The actions are predictable, and the decisions are not free.

The components of the game are known and the transition-costs matrix is devised (the effort of the system to adapt from one state to another).The rows of the matrix represent the maximizer's strategies (starting with the first row) and the minimizer's strategies are marked on the column, starting with the first column. The generalized matrix is illustrated as follows:

	S_1	...	S_j	...	S_m
P_1	c_{11}	...	c_{1j}	...	c_{1m}
.	.		.		.
.	.		.		.
.	.		.		.
P_j	c_{i1}	...	c_{ij}	...	c_{im}
.	.		.		.
.	.		.		.
.	.		.		.
P_n	c_{n1}	...	c_{nj}	...	c_{nm}

Fig.3.14. The transition-costs matrix with the strategies of the players

The completion of the transition-costs matrix is according to the data offered by the technology existent in the enterprise, by the programmer of the working processes. After several stages based on the affinity coefficients of the products, meaning the typological differences between the products, the transition cost appears. Fig.3.15 illustrates a draft of the procedure as an example.

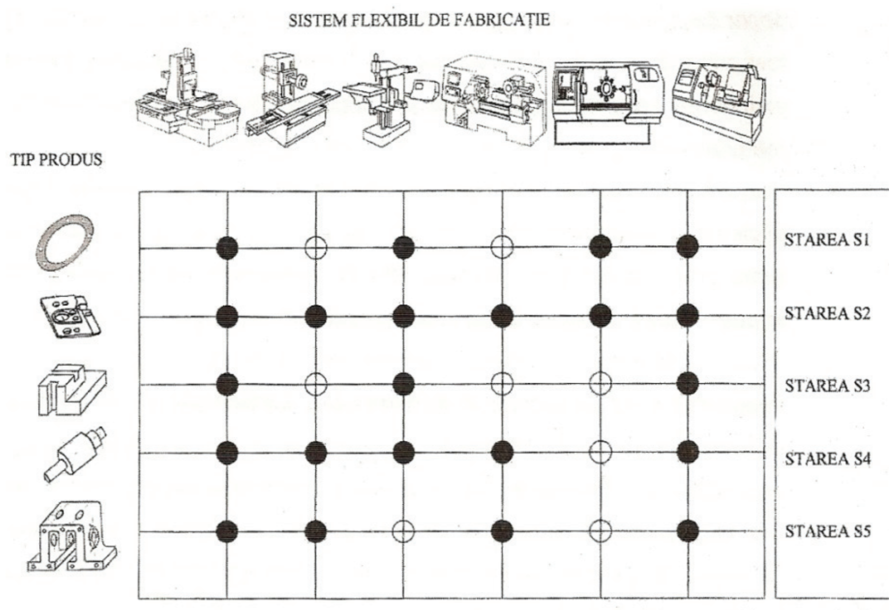

Fig. 3.15 The states of the FMS according to the products

For instance, in order to produce the first piece in this image, the activation of 4 fabrication modules, out of the 6 available ones, is necessary. In order for the four states of the machines to be activated and adjusted for the processing of the respective piece, four transition costs must be supported. These will be centralized in the transition-costs matrix, as the necessary costs for bringing the system to state S_1-the state used for the making of the first product.

This cost will be marked on the line as being the transition cost of the system to generate that particular product

Having the costs matrix, we have the recommendation to solve the game, first of all theoretically, to find the ideal theoretical variant. For this, the SIMPLEX algorithm is used manually, or a specialized computer program. The theoretical value, "V" indicates the balance between the two opponents. For the maximizer, the value of the game represents the minimal of the maximals, and for the minimizer, the value of the game is the maximal of the minimals, according to rel.3.10. Graphically illustrated, this point would be a saddle point if the values were equal. But since in a FMS, the transformation costs matrix always has 0 on the main diagonal, the appearance of a sa point is excluded.

$$v = \max_i \min_j c_{ij} = \min_j \max_i c_{ij} \qquad (3.10)$$

The matches of the game always appear when a new product enters the system and when the system is changed onto a next state. The maximizer follows the highest value on the row, the minimizer follows the lowest value on the column, meaning the smallest loss of that particular match. After the end of the match, we have to take into account the fact that the starting point of the system for the new match represents the latest state of the system which was necessary for the production of the last item. A new item will enter the system, hence a new match will begin.

The mixed strategies appear after the game, with points given for the P and S used strategies. By a simple calculation, we obtain the relative frequencies with which every product enters the system. These frequencies represent the probabilities with which the products must enter the system, in order to get an optimal value.

Some products might not be included in the game, thus resulting 0 value of probability, or under 0,1%. This will be a result of the typological concentration, previously expressed. Thus, the strategy of that product will never be used (or seldom), as compared to the number of matches. This phenomenon might be a sequel of the dominant principle where there were several other more favourable variants which dominated the others. Accounting the results, they can be interpreted as follows.

$$P= x_1P_1+x_2P_2+\ldots+x_nP_n \qquad (3.11)$$

$$S=y_1S_1+y_2S_2+\ldots+y_nS_n \qquad (3.12)$$

$x_1+x_2+\ldots+x_n =1$ și $y_1+y_2+\ldots+y_n=1$ because they are probabilities. (3.13)

The interpretation could be the following: for the efficient functioning of the system, it must make its transitions in the given proportions of x_n , and in order to have diversified products, they must have an entry proportion of y_n in a given period of time. By using computer applications, all the x and y relative frequencies could be obtained, as well as the value of the game, which is the aim of the 2 players. The linear programming could also be done manually, but in the case of the systems with 4-5 restrictions and unknowns, the effort could be very big and the results inexact due to the errors occurring in calculations. Only after a long term-use of this theory was the electronic calculator used.

The research on the FMS programming was started within the Technical University of Cluj-Napoca by prof. Ioan Abrudan's doctorate thesis [4], being followed by a series of other works and studies coordinated by prof. Abrudan, including the candidate's doctorate thesis [1], [18], [29]. These are the starting points of the research in this field.

In order to reach the proposed objectives, a computer program was created [1]. This was created to generate the intended solutions within the FMS programming.

The program provides the relative application frequencies of certain strategies (production), as well as information regarding the optimal value of the game.

The usefulness of the program consists in establishing the proportions in which the pieces will be produced by the enterprise, under the average transition cost.

Knowing the theoretical values of the transition-cost matrix from the previous example, the matrix was adapted as an experimental standpoint for the realised programs. The program can be exploited for a real case transposed in a m x m matrix and for theoretical values of the game corresponding to the respective case.

We will always have a square cost matrix, because:

- the two players are the products and the states of the system.
- any product has a corresponding system state - the number of products/states is equal
- the matrix does not have a saddle point because it has 0 value on the main diagonal.

This objective appears because the system makes no effort to change from its present state to the same state.

The purpose of the program is to apply game theory on the costs matrix, providing the number of strategies chosen in a certain period of time. Those strategies, divided to the overall number of matches, show the entry frequency of the products. If those frequencies are followed in the real programming of the system, this will function efficiently.

The program provides the following information, as output data [1]:

- the display of the results at the end of the game, namely the occurrence of every pure strategy of the players.
- the display of the development of the entire game.
- a graphical illustration with the tendencies of the two players strategies and of their average.

As input data, we use:

- the transition costs matrix
- the theoretical value of the game - known by solving the system of inequities, through methods specific to these systems.
- the number of matches after which the simulation is intended to stop.

The program reads the transition- costs matrix and begins by developing the first match of the game, according to the math game theory. The steps taken by program in order to reach the intended results are the following:

1. In the first match, the highest value of the matrix is chosen and corresponding row represents the first strategy applied by the maximizing player, who has the strategies written on the rows.
2. The reply of the minimizing player comes from identifying and the choice of the smallest number in the row chosen by the maximizer, aiming at the smallest loss. He enters the game with the column that corresponds to this number.
3. Then, the gain of the maximizer an the loss of the minimizer are displayed.
4. The average of the two values is calculated, resulting the value of the games up to that particular match.

5. Next, the highest value of the cumulated values is chosen for the maximizer, starting from the previous strategy. The minimizer will subsequently chose the proper strategy that corresponds to the smallest value of the maximizer's strategy.
6. The average of the losses and gains is calculated, as compared to the number of matches in order to find out the gain/the loss of every player at that point, from the beginning of the game.
7. Step 5 is resumed until the end of the game. The game will end when a value previously indicated will be reached, or when the number of transitions required by the market is reached.
8. The value of the game in a certain match results from the average of the two values v_1/v_2, corresponding to the gains/losses of the players.
9. After reaching the intended objective, according to the planning, the game ends and relative frequencies of every player are calculated, meaning that the strategies chosen by every player are centralized, as compared to the overall number of matches.

After the implementation and the running of the program, the following situations were pointed out:

1. Some strategies might not be used at all. This phenomenon indicates that these products will not be made or those system states will not be favoured, in view of reaching the optimal functioning parameters, with the transition costs as efficiency criterion.
2. It is noticed that the theoretical value of the game may be reached in several matches of the game.
3. Another observation would be related to the fluctuation of the losses and gains, the average of which tends towards the theoretical value of the game.
4. Another important information offered by the program is the number of the match where the optimal was reached first. The interpretation could be the following: the number of products entering the system and the number of transitions performed by the system until they coincided with the optimal. This information indicates the number of chosen strategies that finally constitute the relative frequencies. The match with the optimal indicates the number of chosen strategies that finally constitute the relative frequencies. The match with the optimal indicates the general production volume after which the optimal was reached every time. This may be of help in statistics and analyses.

The program provides a centralization of the above mentioned data, and finally the results come up in a table, as well as the strategies used by every player, and their number in view of obtaining the optimal and annihilating the opponent. It is noticed that after 5000 matches, different figures were obtained with reference to the used strategies. That number, compared to 5000, meaning the overall number of matches, will give the relative frequency of every strategy. For instance, the following results were obtained:

The maximizer P, with his strategies will use 10 out of the 15 strategies, after 5000 matches, namely strategies 2,3,7,8,9,10,11,13,14,15 were 3,8,10,15 could be ignored because their occurrence is under 0,1%. The tendency is towards the making of 6 products.

The minimizer players S, with the j strategies, also uses 10 strategies, namely 1,6,7,8,9,10,11,12,13,15 from which 1,7,11 will be excluded, because they are under 0,1%.

We shall use the frequencies, as follows:

- for strategy 6, 21/5000 = 0,0042 (0,42%)
- for strategy 8, 1332/5000 = 0,2664 (26, 64%)

These results may be very useful in the programming and the choice of products that will be processed, in order to work at the lowest of costs. It is advisable to use the program for as many matches as possible, because this is a calculation of probabilities that function following the rule of large members. The larger the members (the matches performed), the more exact the frequencies.

The number of matches represents the number of products entering the system. This is a dynamic game, in which the strategies are applied successively according to the opponent's choice.

The program will show how many times the theoretical value of the game was reached in the 5000 matches and when it appeared for the 1st time.

In this given case, the program showed the following result: Value 6,752 appeared for the 1st time in the 3248th match, and it appeared 4 times in the 5000 matches performed within the system.

The interpretation and the explanation of the results are the following:

1. As a graphical representation, the two v-s (v_1, v_2) corresponding to the players and to every match, will tend towards the theoretical value V of the game.
2. The value V of the game will be the average of the two v- s (v_1 , v_2)
3. By running the program, we can graphically illustrate the tendency of the two curves (v_1, v_2), but also of the average (v) towards the right, which means the theoretical value of the game.

Strategii Alese

Variabila	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
i	0	1589	2	0	0	0	2346	4	538	2	119	0	124	276	1
j	1	0	0	0	0	21	1	1332	772	1152	1	1273	447	0	1

Fig.3.16. The result given by the program [1]

4. Another interpretation of the results could be that the optimal appeared for the 1st time in game 3248, the system being in the efficiency area.
5. By counting the strategies until that match, we notice the minimal number of products or of states that will enter the system to reach the optimal. This number might not correspond to the market demand, but this is not a parameter for this program alternative.

The program is useful because it provides the frequencies of the products or of the states of the system in view of obtaining a FMS where the products enter at random and which functions at optimal economic parameters.

The result actually shows what products must be made out of the total market demand and s to the system, we could find out how we could improve it and reach a cheaper and a more competitive flexibility. From a technological point of view, the program shows which products do not belong to the production task. The issue is not entirely solved. It is difficult to imagine that the demand will be turned down, because it doesn't include the optimal production quantities of the system.

The market requires diverse products, without taking into account the principles of production programming, or the purpose of the enterprise. These products must be made, no matter the results obtained by the use of game theory, in order to generate profit. Thus, a new idea emerged, namely the idea of the research of the optimal, if the products are required in the minimal quantity. In this case, restrictions are to be applied to the model.

We would like to have information about the size of the production, in the situation in which an exact market demand is required. The objective is to find out how the production should increase in order to satisfy the demand in the necessary quantities. A new program was created [1] for this situation, which studies the FMS behaviour when the market-generated restrictions are followed. The program is presented as follows:

It is supposed that the market requires a minimal quantity of every product. The program that implements math games in the ranking of FMS programming shows the products that can be made and their proportions suitable for the theoretically calculated optimal. In the present program, we have the condition of a minimal production of items, under the form of given restrictions. This means that the products may enter according to the frequencies given by the first program, but according to some minimal imposed quantities. This program shows the size of the production for maintaining the optimal parameters and for producing at the same time what the market requires.

For a correct simulation of the process preformed in the economic context, we consider that the demand is independent of the production capacity, and the systems operate according to the demand. We tried the simulation of a real case of a demand that needed to be answered [1]. Even if all the marketing departments of large enterprises may predict the market demand, according to the previous available data, we notice that the general management tendency of the enterprise is to minimize the size of the stocks and to easily adapt to the demand, by producing "just in time". The arguments in support of this idea are also the world economic contexts that can overturn the situations against the productions, in the case of the stocks that are too large, the lack of cash leading to a crash of the system.

The program operates on the math game theory and the transition costs matrix shows data about the size of the production. The demand being random, can cross a certain limit considered by the first program as being an optimal point. This is why the new program will calculate how many products must be made so that the system should follow the restrictions and reach the optimal again.

The output data are similar to the ones of first program, the only difference being the number of matches, or the number of products that must be made so that the minimal conditions imposed (quantities) should be fulfilled and the production being repositioned on the optimal point.

The table 3.17 shows the centralization of the data resulting from both of the programs.

The first column shows the data given by program M_1, which produced 5000 items. The program showed that item 3248 was the point when the system operated within optimal parameters for the first time.

The values of this column, divided to the total number of matches (5000), will determine the relative entry frequencies for the system. This means that if the system is flexible, but produces at the rate given by the program, it will reach the optimal at a given point. This information is very useful for the planning of production.

The first program also offers information related to the typological nucleus that will be adopted by the system. The products that appear less than 0,1 % of times, will not be made by the system, because they are not competitive or profitable. Of all the 15 products, the game theory selected 6 products.

The second column of the table shows a market demand expressed in minimal values of products that have to be made. We have taken into consideration those products which are relevant, which were given by the first program, with an appearance probability of 0,1%. After the program performed, it stopped when reaching the optimal, or the theoretical value of the game, and when fulfilling all the imposed conditions. The result was of 7139 matches, meaning 7139 products-entries in the system.

Tabel 3.17. Centralization of the data issued by the program [1]

Maximizer player i	Results issued by program 1	Conditions for program2	Rezults issued by program 2	Differences program2/conditions
P1	0	0	0	**0**
P2	1589	1500	2266	**766**
P3	2	0	3	**3**
P4	0	0	0	**0**
P5	0	0	0	**0**
P6	0	0	0	**0**
P7	2346	2600	3388	**788**
P8	4	0	0	**0**
P9	538	600	709	**109**
P10	2	0	0	**0**
P11	119	110	159	**49**
P12	0	0	0	**0**
P13	124	100	245	**145**
P14	276	300	369	**69**
P15	1	0	0	**0**
TOTAL:	**5000**	**5210**	**7138**	**1928**

When comparing the results of the second program and the minimal conditions imposed, we may see that an excess of 1928 items was produced. These items must be placed on the market we can see which was the last product that did not allow the system to stop. This information is, again, very important because those products that are required in excess, taking the system outside economical efficiency, could be externalised. The excess in products appeared as a result of the condition of matching the optimal running parameters, namely the lowest transition costs possible hence the obvious question: "What happens to those items that are produced anyway in order to bring the system to an optimal point and are not requested on the market at that point?" This problem may be solved by enlarging the stocks and by giving new tasks to the marketing and sales departments, in view of promoting those products more efficiently.

The solution to the problem offers an alternative which is optimal only from a technological point of view.

3.4. The analysis of the elasticity of the frequencies entrance of products into a FMS simulated with math games theory [32]

The Flexible Manufacturing System (FMS) is provided with a set of aptitudes that makes the processing of a given products typology possible; therefore it is dedicated to a typological gamma or family of products. The activation of the FMS's aptitude to process a type of product generates a system state and brings in the appropriate technology. The system's passing from processing a product type to another product type, respectively from a state to another is called transition and in fact represents the system's switching from a manufacturing technology to another technology. This system's transition from a state to another (each state corresponding to a product type) supposes a system effort which in minimal way it refers to the adjustment time of the machines, but usually includes and other components. This effort we can call it generically speaking, transition cost.

The transition costs are specific for FMS, measuring the system's flexibility and are linked by the automation degree of the system. With all the progresses from the automation domain these costs can't be eliminated, only reduced. So the transition costs must be linked with the activities that are running in FMS towards its adaptation and preparation when the production task is changing.

Inside a certain period of the system functioning more transitions are achieved and implicitly, a global transition cost is accumulated. If we report this global transition cost to the number of transitions which was achieved, we obtain the average transition cost (CMT).

We consider that for a Flexible Manufacturing System, the size of the average transition cost represents an economic criterion which must have been in view both in the designing of the system and in its functioning.

As in any production system, in the Flexible Manufacturing Systems the problem that interests us is the economical running of the system which is costs as low as possible. The question is if the inputs of the products type in the system are random, can it be found the optimum modality of FMS's running that is a minimum value of the average cost of transition.

In this chapter we used the mathematical mechanism from the zero-sum game's theory, who gives the solutions in the confliction problems. The principles from that part of the games' theory that we will use it are given below:

1. The games theory is a theory of conflicts where are shown at least two conflicting interests promoted by two players (partners, rivals). What a player loses the other one gains it.
2. The player that loses is called minimizing because he wants to minimize the lost and the player that gains is called maximizing because he wants to maximize the benefit.
3. The optimum situation accordingly with the games theory between the two players shows a level of the bargain respectively of the loss, acceptable for the both players. This level of bargain/loss is called the game value. From the confronting of the two opposite tendencies, it appears an equilibrium situation (game value) which represents the solution of minimizer player and which for the production system determines an "optimal" flexibility (in the respect of mathematical games theory) corresponding to a system which is neither rigid (null flexibility, when it's achieved only one type of product) nor excessive flexible (this situation does not correspond to the economic desideratum).

Before the building of a FMS, it must simulated it's functioning for to discover in the design phase, the problems who can appear and to compute the running costs. The mathematical games theory gives this possibility of FMS simulation.

3.4.1. Interpretation of results

Based on a FMS who process 25 types of parts (the matrix of the game is given in [29], [30]), it was made 170 simulations, in which was increased and decreased with 1% the entering frequencies of the parts and it was studied the variation of average transition cost. It was achieved and used a simulation computer program for each variant of FMS functioning. In the table 3.18 are shown the optimal frequencies of the products obtained as in [29].

Table 3.18. Optimal frequencies according to math games theory

Product	Frequency
R1	0.1765
R2	0.0509
R3	0.0506
R4	0.1137
R7	0.0826
R10	0.075
R11	0.0748
R12	0.0558
R13	0.0221
R16	0.118
R20	0.0344
R21	0.0132
R25	0.1326
Value of the game	10.828

a) It was modified a single frequency

In this case the variation of CTM is directly proportional with increasing or decreasing of the values of modified frequencies. So, in the same time with 1% increasing of the entering frequencies in FMS, we have an increasing of CMT, but under 1%. In every simulation variant we had not an increasing of FMS over the value of the game.

b) They was modified two frequencies

In this case, if the both frequencies increase, CMT decreases and if the frequencies decrease, CMT increases. The negative or positive variation appears to be done by the part who have frequency greater than 0.1. In this case also, CMT is under the value of the game.

c) They was modified three frequencies

If first 3 frequencies increase with 1%, CMT also decreases. If first 3 frequencies decrease, CMT increase, but not too much. So, the conclusion is that the CMT variation is inverse proportionally with the modification of the frequencies. This conclusion is true till the modification of the frequency of the four product, when the variation of CMT become direct proportionally with the modification of frequencies. If 2 frequencies increase/decrease with 1% and other one increases/decreases with 1%, the variation is inverse proportionally. From the simulations made till this point, we obtained an interesting conclusion: into a 3 products combination, the increasing of two frequencies determines the CMT decreasing.

d) They was modified four frequencies

If we modified first 4 frequencies, the CMT variation is inverse proportionally with the modification, true in the case of the combination of the frequencies (two increase, two decrease, three increase, one decrease or inverse).

In this case, the variation of CMT will be done by the products with higher sum of frequencies and will be proportionally with this modify.

e) They was modified five frequencies

If we modified first 5 frequencies, the CMT variation is inverse proportionally with the modification. If we modified 3 into a sense and another 2 in the opposite sense, the variation will be done by the products with higher sum of frequencies and will be proportionally with this modify. The modification of the last 5 frequencies has the same influence like the modification of the first 5.

f) They was modified six frequencies

If first 6 frequencies increase, CMT decreases. If first 6 frequencies decrease, CMT increases.

g) Through the modification of first seven, eight, nine and ten frequencies we observed that the modification of CMT is inverse proportionally with the modification.

h) Modification of all frequencies

The increasing with 1% of all frequencies lead to the increasing of CMT and the decreasing with 1% of all frequencies lead to the decreasing of CMT. If first value increases and the rest decrease, CMT will decreases. If the first value decreases and others increase, CMT will increase. So, we can say that the CMT variation is inverse proportionally with the modification of firsts value of the considered frequencies.

i) Modification in pair

Increasing first and last frequencies with 1%, then first two and last two frequencies and continuing until first six and last six frequencies, we obtained the increasing of CMT. The greatest variation of CMT was for the modification of the pair of six frequencies. The same variation it was achieved if the frequencies was decreased, the maximum variation being already in the case of modify of six frequencies pair.

If first frequency increases and last decreases or first two increase and last two decrease and continuing to first six with last six frequencies, we can observe that the variation of CMT is inverse proportionally with the sense of the frequencies modification of the pair who has the greatest sum of considered frequencies.

Anyway, in all the cases, CMT is under the value of the game.

3.4.2. Conclusions

The most important conclusion of this research is that a modification with 1% of the entrance frequencies of products into a system do not increases the average transition cost over the value of the game. That means the FMS can be design with the help of math game theory and can running in the optimal conditions.

Another conclusion obtained as result of the 170 simulations of FMS is that the product with higher frequency determines the CMT variation. As the same, in the case of many frequencies variation, the CMT variation is determined by the products who have the higher sum of frequencies. The differences consist in fact that in the case of single frequency modification, the variation of CMT is direct proportionally with the sense of frequency modification and in the case of many frequencies modification, this variation is inverse proportionally.

I suppose that this research can open the way to others researches of the variation of the entrance frequencies, so that to can be established a maximum level of variation of the entrance frequencies of products in FMS so that CMT to be under the value of the game. In the same time, using the simulation program of FMS, it can find a correlation between the modification of frequencies and the sensibility of the system. In this way it could be established a maximum level of the frequencies variation for which the sensibility of the system to be close by 100%.

3.5. A proposal method for the programming of the small and unique production series [34]

3.5.1. Production organization

Organization of production refers to all activities, measures, methods, techniques and methods used, established on the basis of studies and technical-economic calculations, taking into account the situation existing technology, to combine the best of the material means of production and human resource , ensuring maximum efficiency from its use.

Organize the production is the main factor in the management attention, because there is a wide variety of specific conditions to be applied for optimal production unit.

Type of production is "a organization state" highlighted by the catalog of products (product list) wich follows to be processed, degree of specialization of the company and how to transfer products from one place between jobs, which are some key features that affect a very large extent, the type of production adopted by an enterprise.

Industrial enterprises can be classified as "state organization" existing at some point in the production unit:

- mass production (flow)
- series production
- unique products(individula)

In the production of small series products we encounter three types of states, depending on volume / quantity of products manufactured in the same range:

- large series production
- midle series production
- small production

The type of an existing production at a time in the company has a decisive influence on how to choose the methods of organization, type of management adopted, the preparation of new products and production methods and production control tracking.

For each type of production, there are, in literature, at least one specific method of organization that is:

- for mass production and mass production unit organization is conducted production lines, which may be continuous or discontinuous flow;
- production of small series and unique, unit organization can be achieved using different methods such as principle homogeneous group of machines, fixed position principle, method of production links, etc.
- mass production using elements of the two methods above in the size batch to batch. The higher volume batch and cycles of the same variety, the more it tends to form a method of organizing production lines
- The batch volume and number of cycles in the same range decreases, the more it tends toward a specific method of organizing production of unique
- Note that, in an industrial features, there is only one type of organization, in most cases there are elements of all three types above, and preferred method of organization (elected) is the weight of elements characteristic is dominant in the existing conditions in the production.

3.5.2. Organisation of production of small and unique series

Organization of small and uniq production is characterized by a broad classification of products and unstable, it required a series of conditions and principles. Machinery, equipment, process equipment must be universal, providing a high flexibility of the manufacturing process and labor must be highly qualified.

The manufacturing organization can be the principle of technology, which involves the performance or operation phases of the process, machine organization is the principle of homogeneous groups of machines and their location is conducted production links;

Another method of organizing production unit can be fixed by the principle of position, this method applies when we made parts / products very large. The method consists in a fixed location marker / product and teams of workers with necessary equipment moving from one part / product to another, the phases or operations required by the technology of product development.

Within the manufacturing machinery and equipment must be universal, able to adapt easily to change the nomenclature of production in a very short time and with a few adjustments.

In this type of production technology using a blanket for the entire range of manufactured products, while the technical details of each part / product to be completed in each workplace where planned.

The organization of production on the principle of technology has some advantage sand disadvantages, of which the most important are:

a) advantages: the use of machinery and equipment with universal, workers with high qualifications, and this production unit ensuring a high degree of flexibility
b) disadvantages:
   - high production cost per unit
   - volume of shipping and handling is very high
   - requires a highly skilled workforce
   - long production cycle
   - very complex production quality control.

3.5.3. Method proposed for management production of small and unique series

The proposed method for managing the production of small series and unique is a combination of two methods known in the literature intake plus authors, Figure 3.17.

Organizing machinery / equipment will be made by the method of production links, which is specific to the production of small series and unique

The location of the transit links in the center of production area is trying to reduce transport distances between homogeneous groups of the transit car. With decreasing distance between groups will reduce the transit time and transportation costs.

The planning process will apply MRP method "Materials Requirements Planning", a method that gives very good results compared with other existing methods. This method allows a description of the product tree on several levels that leads to an accurate analysis of product structure. This analysis starts from the last level, by identifying parts and then determine the exact quantities of raw materials necessary in the manufacturing process. Together with the necessary quantities of materials and operations are set to be subjected to raw materials and materials to be transformed into landmarks.

After identifying the necessary materials to verify their existence pass stock. If they are not found on stock purchasing department buys them from various suppliers. This step is checked the possibility of achieving for a new full product.

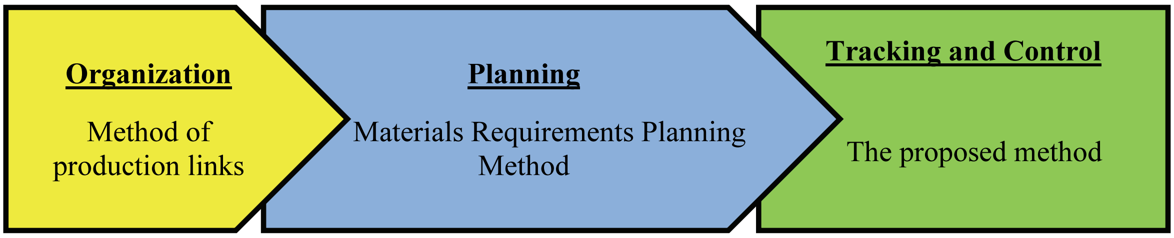

Figure 3.17. The principle of organization, planning, monitoring and control of production of small series and unique

By analyzing a subset of the product structure can be observed the following: the items will feed into the subassembly, as they will assemble parts together, the operation will be used to build sub-assembly of the materials we need to carry out assembly, the machine / machinery /equipment are required in the assembly process. Once identified these activities, they can be scheduled.

Tracking and control method is a method proposed by the authors, this method borrowed elements "Kanban".

Borrowed elements are "labeled" and some information on this “label” The authors propose that the production of small series and unique, the product label to be attached until it is delivered to store or delivered to the beneficiary, while for Kanban method, the label moves only between two successive jobs. Batch sizing and rhythm parts / batch is made with these labels. Between two successive operations there are a limited number of labels, while in this method, sizing and scheduling is done in the planning stage.

For this method proposes an alternative label to accompany and guidemark / product throughout the manufacturing process.

Cod reper/ Part code	**Denumire reper/ Part Name**	**Denumire Produs/ Product Name**	**Material/ Material**	**Data, ora şi min. începerii/ Date, hour and minute to begin**	**Data, ora şi min. finalizare/ Date, hour and minute to finish**
M122	Stâlp/ Pole	Masă/ Table	Lemn/ Wood	24.06.11 – 9’20”	25.06.11 – 10’20”
Itinerar tehnologic/ Engineering roadmap		Debitare – Strunjire – Finisare – Asamblare/ Cutting - Lathe - Finishing - Assembly			
Operaţie/ Operation	Debitare/ Cutting	ok	Operaţie/ Operation	Strunjire/ Lathe	20 min
Durata/ Duration 5 min.	Data, ora şi min. începerii/ Date, hour and minute to begin	Data, ora şi min. finalizare/ Date, hour and minute to finish	Durata/ Duration 30 min.	Data, ora şi min. începerii/ Date, hour and minute to begin	Data, ora şi min. finalizare/ Date, hour and minute to finish
Planificat/ Planned	24.06.11 – 9’20”	24.06.11 – 9’20”	Planificat/ Planned	24.06.11 – 9’40”	24.06.11 – 10’20”
Executat/ Accomplished	ok	ok	Executat/ Accomplished	ok	24.06.11 – 10’40”
Operaţie/ Operation	Finisare/ Finishing		Operaţie/ Operation	Asamblare/ Assembly	

Figure 3.18. Label tracking and control

With this label (Figure 3.18) we can easily track and control all manufacturing process. Information can be gathered from these labels are very important they can be used in decision making.

The most common problems that occur in the production of small series and unique parts are related to planning / operations on machines.

Activity planning is very complex especially when you want to load equipment to achieve optimal production costs as low as possible. An optimum loading of equipment involves accurate planning of operations on machines, which means that the points must be reach at the hour and minute operation planned. The marks often get delayed due to unforeseen factors, difficult to identify in the planning work. For these factors when planning we allocate a safety margin of 10-15% during the implementation of Operation

The following is a problem frequently encountered in a production job (Figure 3.19). The worker must get a job while three types of parts to be processed, two of them arrive late, the type 1 and 3, while type 2 is on schedule. Which operation operator must make?

Case 1. Setting priorities based on a single parameter, namely "time" With these labels, and a few simple calculations, the operator can decide which is the order of processing. If we look at Figure 3, we see that the construction of the first type of play we need 10 minutes to achieve the type we need two 2 * 7 or 14 min and the third type 3 * 5 or 15 min. In the event that there are other factors that influence the decision, the proposal is the operator commences with the type of play that is the total time to achieve the smallest of parts delayed, type 1

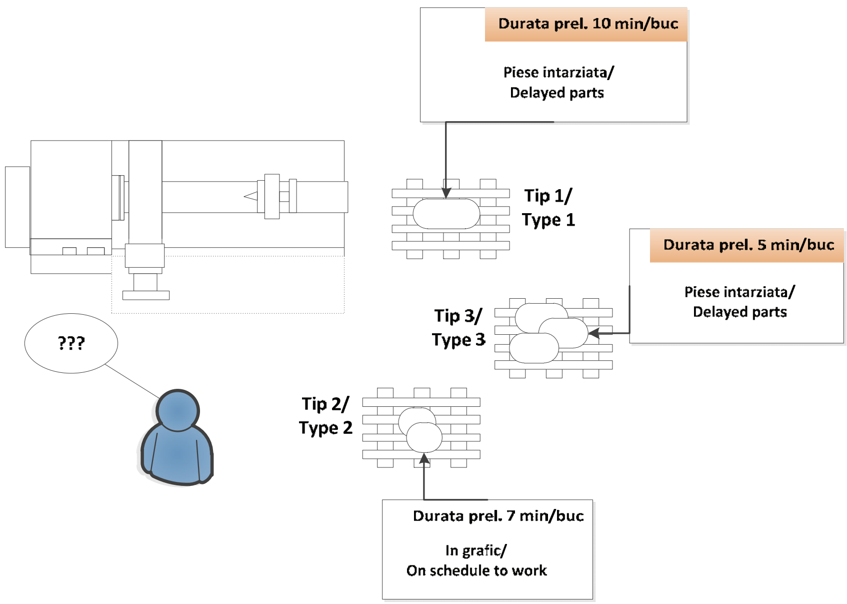

Figure 3.19. Graphical representation of a job

After the song type 1 left, we proceed to analyze the situation. What will be the next type of work piece: Type 2 or 3? The same rule applies - the type of track with the total time to achieve the smallest of parts delayed, processed first. At the time set for the two remaining pieces come together the 10 min that was processed first type. After calculating the time we have the following situation: for parts of type 3will have 10 minutes to existing time delay. he maximum delay for parts of type 2 will be up to 10 minutes. In the planning of operations we allocate additional time, as the safety margin for operations to be conducted safely (in time).

This margin is 10-15% value calculated during the normalization process of the operation. Hence two situations: first case the margin of safety is worth more than 10 min, then the delay is only three such parts, therefore they will be processed the next operator, figure 3.20.

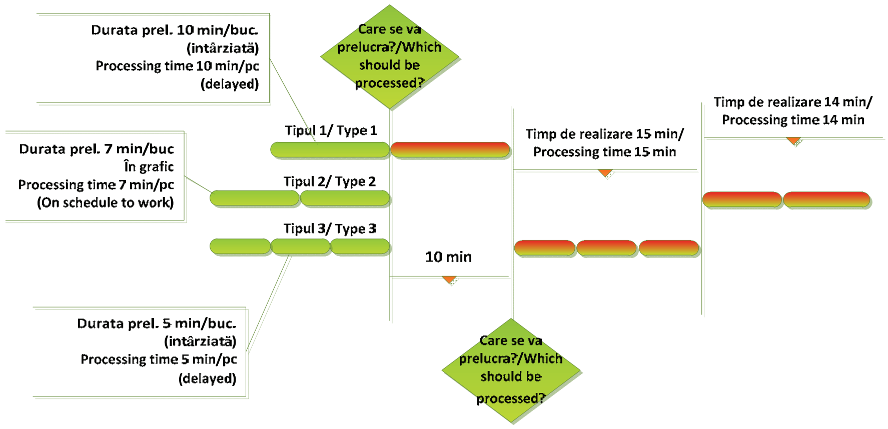

Figure 3.20. Processing decisions when the safety margin is> 10 min

The second situation (Figure 3.21) is the margin of safety is worth less than 10min, then the pieces of type 2 are also in the delay but will have the shortest time to achieve, so the following items will be processed the type 2.

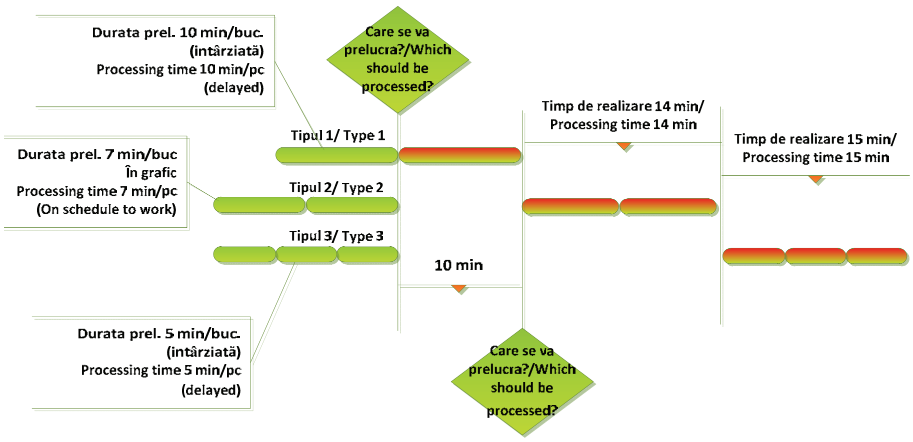

Figure 3.21. Processing decisions when the safety margin is <10 min

Case 2 Setting priorities for when we have several important parameters such as: the value of the part / product, "urgency" to achieve the part / product, parts/ products with very large delays, etc.

If we have several important parameters that must be taken into account in the planning process is proposed the following solution: determining a level of significance for each parameter and a scale drawing of priorities (Figure 3.22).

Stabilirea priorităților în funcție de gradul de prioritate al parametrilor	
Scara culorilor de prioritate	
Grad 0	**Dacă culoarea de fundal a etichetei va fi roșie, înseamnă că se va prelucra imediat ce se eliberează mașlna.**
Grad 1	**Dacă culoarea de fundal a etichetei va fi portocalie, înseamnă că se va prelucra imediat ce se eliberează mașina, cu condiția să nu existe una de culoare roșle.**
Grad 2	**Dacă culoarea de fundal a etichetei va fi galbenă, înseamnă că se va prelucra imediat ce se termină de prelucrat reperul/lotul, cu condiția să nu existe alte etichete de culoare roșie sau portocalie.**
Fără prioritate	**Dacă culoarea de fundal a etichetei va fi albă, înseamnă că se va prelucra după ce se eliberează mașina, cu condiția să nu existe alte etichete de culoare diferită, iar criteriul de prioritate va fi cel mai scurt timp de realizare dintre cele întarziate.**

Figure 3.22. Color priorities settings

Legenda/*Legend:* Stabilirea priorităţilor în funcţie de gradul de prioritate al parametrilor = *Setting priorities considering the importance of parameters*; Scara culorilor de prioritate = *Color scale of priority*; Grad 0 = *Priority 0*; Grad 1 = *Priority 1*; Grad 2 = *Priority 2*; Fără prioritate = *No priority*;

Depending on the priority we attach a color and it will be background labeling (Figure 3.23). If it encounters a situation where we have two labels the same way, the rule will be applied like in case 1.

Cod reper/ Part code	**Denumire reper/ Part Name**	**Denumire Produs/ Product Name**	**Material/ Material**	**Data, ora şi min. începerii/ Date, hour and minute to begin**	**Data, ora şi min. finalizare/ Date, hour and minute to finish**
M122	Stâlp/ Pole	Masă/ Table	Lemn/ Wood	24.06.11 – 9’20”	25.06.11 – 10’20”
Itinerar tehnologic/ Engineering roadmap	Debitare – Strunjire – Finisare – Asamblare/ Cutting - Lathe - Finishing - Assembly				
Operaţie/ Operation	Debitare/ Cutting	ok	Operaţie/ Operation	Strunjire/ Lathe	20 min
Durata/ Duration 5 min.	Data, ora şi min. începerii/ Date, hour and minute to begin	Data, ora şi min. finalizare/ Date, hour and minute to finish	Durata/ Duration 30 min.	Data, ora şi min. începerii/ Date, hour and minute to begin	Data, ora şi min. finalizare/ Date, hour and minute to finish
Planificat/ Planned	24.06.11 – 9’20”	24.06.11 – 9’20”	Planificat/ Planned	24.06.11 – 9’40”	24.06.11 – 10’20”
Executat/ Accomplished	ok	ok	Executat/ Accomplished	ok	24.06.11 – 10’40
Operaţie/ Operation	Finisare/ Finishing		Operaţie/ Operation	Asamblare/ Assembly	

Figure 3.23. Label high priority "0"

3.5.4. Conclusions

One of the main objectives of enterprises carrying out production of small series and unique is to reduce manufacturing costs as much. In most cases reducing the manufacturing cost is optimal loading equipment which requires a lower fixed costs per unit

With the information recorded on these labels can make decisions for future efficient production process that is:

- can easily identify which route each benchmark in manufacturing;
- can identify places where they are strangling the flow of manufacturing;
- can identify worker / operator who has not performed work on time and problems occurring etc.
- can improve their production planning is extremely important for the production of small series and unique to suppress loading of equipment and can ensure transparency of the manufacturing process and better control of resources.

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4. A method for the usage of value analysis in the design of FMS

In the last years, the value analysis method was more and more used in the research and design activities, being one of the most important way for the material costs decreasing, for the increasing of the quality and efficiency of the production and for the labor rationalization.

The value analysis stimulates the creativity for to obtain an optimum ratio between social needs and product quality on the side, and production costs, on the other side.

This method doesn't refer only to the products. The term of product that is used and that materializes the goal of study of the value's analysis is also used for the projection or analysis of the technological processes, labor processes and organizational systems.

The advantages are high, knowing that researches concerning the value's analysis conducted to the conclusion that a significant part from the production costs sometimes passing 50% from their total contributes a little or not at all to the usability value increasing unnecessarily the expenses which must be paid. The value's analysis eliminates these situations showing where exactly must be act on in order to reduce the expenses.

This chapter presents, as an concrete application problem [4], the possibility for to establish the configuration of a Flexible Manufacturing System (FMS) using the value analysis principles. The application starts from a FMS in which 15 types of parts as shafts are processed.

The analysis consists in to determine if it exists a correlation between the value of the module and its utility characterized by the charging degree.

There are correlated the usage time of FMS components with theirs values. It can establish the boundary values for the FMS equipments, and limitations in the flexibility of FMS.

The chapter analyzes the results obtained after using the value's analysis in FMS's configuration in dual mode: on the one hand on the basis of the system's static configuration (barring the fact that the system's inputs are not having an random character) and on the other hand on the basis of the system's dynamic configuration (that respects the mentioned aspect) [1].

Table 1 contains the technological routes for the 15 types of parts, including, also, the duration of each operation. The symbols of the table mean:

C - cutting
S - turning
F - milling
G - boring
R - grinding

The prices for the work units involved in the flexible manufacturing system's frame are:

- centering machine – 9000 RON
- lathe – 9000 RON
- milling machine – 5325 RON
- drilling machine – 42500 RON
- finishing machine – 10500 RON

Table 4.1. Technological routes of the parts [4]

Nr.	Type of part	Operation no. [min/piece]				
		1	2	3	4	5
1	R1	C5	S52	G12	F45	R30
2	R2	C5	S60	F76	G23	R31
3	R3	C5	F54		F63	R22
4	R4	C5	F41	G16	F77	R34
5	R5	C5	S92	F77		R21
6	R6	C5	F72	S72		R33
7	R7	C5	S21	F49	G27	R27
8	R8	C5	S78	F34	S36	R30
9	R9	C5	F78	S94	F38	R21
10	R10	C5	F32		S66	R32
11	R11	C5	F43		F69	R20
12	R12	C5	F76	G17	F61	R25
13	R13	C5	F50		G11	R25
14	R14	C5	S22	F54		R34
15	R15	C5	F72		S34	R37

After the application of the static configuration methodology presented in [1] the following operation modules with the afferent values are obtained [3], [4]:

- the centre drilling module C – 2 machines
  2 · 9000 = 18000 RON
- the turning module S1 – 6 machines
  6 · 9000 = 54000 RON
- the turning module S2 – 6 machines
  6 · 9000 = 54000 RON
- the milling module F1 – 9 machines
  9 · 5325 = 47925 RON
- the milling module F2 – 5 machines
  5 · 5325 = 26625 RON
- the milling module F3 – 6 machines
  6 · 5325 = 31950 RON
- the drilling module G – 2 machines
  2 · 42500 = 85000 RON
- the finishing module R – 8 machines
  8 · 10500 = 84000 RON

In the dynamic configuration [1] the systems parameters were calculated (table 2) and with their help the products' times necessary for passing through FMS.

Table 4.2. Dynamic parameters of FMS [3], [4]

Module Parameter	C	S1	F1	S2	F2	F3	G	R
$\overline{n}$	1.07	0.942	0.953	0.774	0	0.52	1.4	0.182
$\overline{n_f}$	0.46	$7.3\cdot10^{-5}$	$5.4\cdot10^{-8}$	$1.1\cdot10^{-5}$	0	$4.7\cdot10^{-7}$	0.81	$4.2\cdot10^{-14}$
$\overline{n_s}$	0.60	0.941	0.953	0.774	0	0.52	0.58	0.182
$\overline{t_f}$ [ore]	0.03	$1.8\cdot10^{-3}$	$2.8\cdot10^{-4}$	$3.4\cdot10^{-4}$	0	$2.1\cdot10^{-5}$	0.21	$1.6\cdot10^{-10}$
$\overline{t_s}$ [ore]	0.03	0.164	0.111	0.17	0.19	0.163	0.36	0.06
P_0	-	2.124	2.063	1.286	1	1.018	-	1

Admittedly in values' analisys it's working with the notion of function which is considered as a special quality of the goal. In this case of the flexible manufacturing system the functions are represented by the operation modules defined like this: centre drilling, lathe, milling work, drilling, rectification and that compose the flexible manufacturing system. In the values' analisys a very important thing is the ordering, the functions' ranking namely to determine the relative positions and the ponderosity for each function in the usability value of the product. [2,4]

The values' analisys says that the product by itself isn't important but the utility offered by its functions, so in this case it will be discussed about the utility of each module that compounds the flexible manufacturing system.

So the utility of each operation module is perceived through the time fund that must be achieved reported to the total time fund for processing, afferent to the components presumed to be processed.

The utilities are calculated with the next formula, in fact the utilities representing weights:

$$U = \frac{\sum t_m}{\sum t_{tot}} \qquad (4.1),$$

where:

$\sum t_m$ – the sum of the components' processing times that passes through a specific module;

$\sum t_{tot}$ – the total time necessary for the components' passing through all the modules.

After the calculations for all the 8 operation modules for static configuration the results from table 3 were obtained:

Table 4.3. The weights of the processing times for static configuration [4]

Module	Processing times [min/piece]	Weight %
Centre drilling	272330	2.9
Lathe 1	1295490	14.1
Lathe 2	1300848	14.2
Milling work 1	1931292	21.1
Milling work 2	1107464	12.1
Milling work 3	1262399	13.8
Drilling	393671	4.3
Rectification	1564296	17.1

After the weights were calculated as processing time, to be able to make a fine comparison it will also be calculated the weights as values for each module. These weights are calculated in the same way as the weights as processing time are, only that in this situation the value of one module will be reported to the total value of those 8 modules.

The formula is:

$$P = \frac{V_{modul}}{V_{tot}} \quad (4.2),$$

where:

V_{modul} = the value of one module;

V_{tot} = the total value of those 8 modules.

The results were written in table 4.

Table 4.4. The weights as values for static configuration [4]

Module	Value [RON]	Weights %
Centre drilling	18000	4.4
Lathe 1	54000	13.4
Lathe 2	54000	13.4
Milling work 1	47925	11.9
Milling work 2	26625	6.6
Milling work 3	31950	7.9
Drilling	85000	21.1
Rectification	84000	20.9

As it can be observed there is a little discordance between the weights as processing time for the drilling operation module and the value weights of the drilling machine. After some examinations it was attained to the conclusion that the drilling machine's value is overrated.

Because the number of the machines from the static configuration is different we will present a new case where only the machines' value is modified and not the processing time (table 5).

Table 4.5. The new situation [4]

Module	Value [RON]	Weights %
Centre drilling	18000	4.18
Lathe 1	72000	16.73
Lathe 2	54000	12.55
Milling work 1	58575	13.61
Milling work 2	26625	6.18
Milling work 3	31950	7.42
Drilling	85000	19.76
Rectification	84000	19.52

There must be made some assignations concerning the work units: would be wrong to refer to the accuracy of the obtained values from several reasons. One of this is that the prices fluctuate. For example in this flexible manufacturing system the prices of the processing units represent levels of selling as second-hand units.

So the presented calculation modality offers a better orientation and locates us in a certain area of value.

Besides in the special literature it's mentioned with the help of arguments that reduces the rhythm of insertion of these flexible manufacturing systems, exactly the fact that not always can be precisely established the costs of investments, these costs mostly exceed the predictions.

For a practical examination of those identities it is used a regression analysis. The analysis consists of determining the possible concordance between the module's value and its utility characterized through loading degree. The regression curve must pass through the origin of the coordinate axes because it's considered that a function with zero weights must cost zero.

From the regression analysis has resulted [4]:

For static configuration by regression between the weights of processing time and the value weights was obtained the regression curve's equation:

$Y = - 1.51 + 9.72X – 2.06X^2 +0.15X^3 – 0.003X^4$

The coefficient of correlation: 0.8

For static configuration by regression between the degree of the machines' usability and the machines' value was obtained the correlation:

$Y = - 0.96 – 73675.12X + 2682.38X^2 – 31.33X^3 + 0.12X^4$

The coefficient of correlation: 0.94

For dynamic configuration the first graphic (fig.1) presents on X axis the weights of processing time and on Y axis the value weights for operation modules acquiring the equation of regression:

$Y = - 1.34 + 8.77X – 1.81X^2 + 0.13X^3 – 0.003X^4$

The coefficient of correlation: 0.78

The second graphic from dynamic configuration (fig.2) presents on X axis the degree of the machines' usability and on Y axis the machines' value:

$Y = - 19.03 + 4689.33X – 274.46X^2 + 5.014X^3 –0.02X^4$

The coefficient of correlation: 0.76

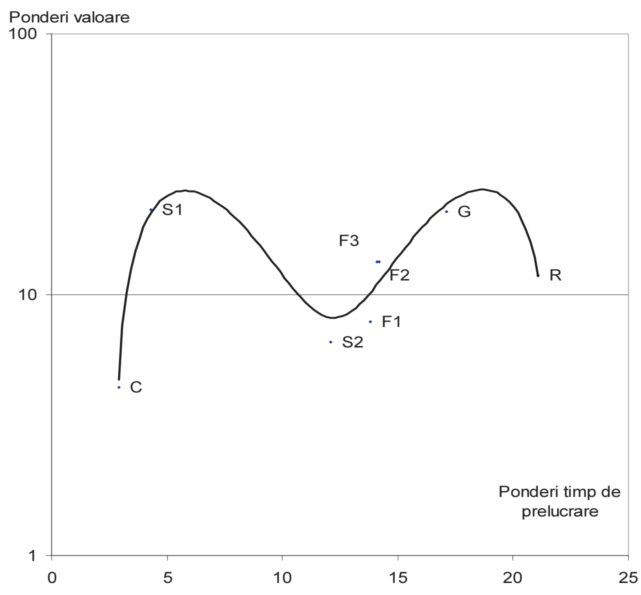

Fig.4.1. [4]

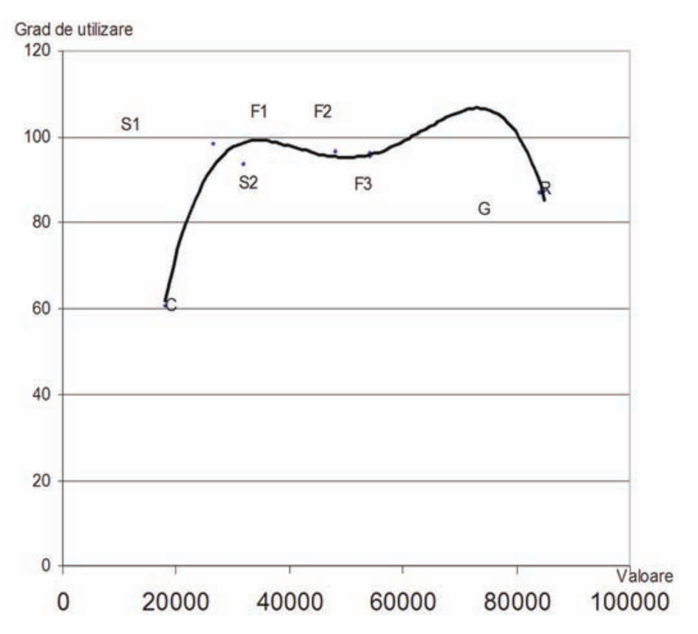

Fig. 4.2. [4]

The coefficients of correlation have good values that lead on the conclusion that there is a link-up between the analyzed data.

In the graphic we observe that some points are positioned over the regression curve and the conclusion is that the modules corresponding to these points are achieved with the costs greater than theirs contribution to the achievement of parts. These modules are oversized.

On the other hand, the modules represented by the points under the regression line are undersized.

These conclusions are very useful because they help very well at the re-designing of the processing modules who was unsatisfied in the analyzed variant.

Having in view the greatest costs need for to set-up of a Flexible Manufacturing Systems, we consider as very necessary the usage of the value analysis as modern method in the designing of FMS.

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5. Scientific, professional and academic future development plan

Growing up an academic is a complex process, due to the huge amount and diversity of the information to be acquired, but mostly to the high-level competences and skills to be developed. If one wants to be successful in gaining an academic position and then progressing in academia, it is important that one gains an understanding of the broader academic context in which she/he will be working. As academic one has to combine teaching and research and develop the capacity to transfer and integrate the new achieved knowledge in the course lectures. This asks for a high-level flexibility and open mind, keeping at the same time a reasonable receptivity and a critical reflection.

Personal and professional evolution of the academic is always sustained by the natural acquisition of new skills and competences. Management and mentoring activities are to be added to the teaching and research ones. As research project manager, the academic needs the capacity to manage human and material resources, and to use efficiently the existing infrastructures, in order to achieve the goals of the project. The coordination of the research team involves not only the distribution of the tasks and the evaluation of the progress, but also mentoring and guiding the young researchers (bachelor, master or PhD students).

In this context, obtaining the habilitation in order to be able to supervise PhD theses is a natural step in the professional development of the candidate. This step will have an important impact on both the candidate teaching and research activity.

The candidate's activity in the future will rely on the experience, the results and the reputation obtained from the activity that lead to the present habilitation thesis.

For the near future, the research activity will be related to the research projects the candidate is involved in.

For the long term, the candidate estimates that his research will be focused on the three basic directions: the simulation of the production systems and the optimization of the production systems and processes; the modeling of managerial processes using math games; researches on the connection between religion and management, but not only these three.

The short-term (3 years) career objectives can be grouped as follows:

- Enrollment of at least 2 PhD students per year;
- Participation as one of the main partners to the preparation of at least two proposals for calls in the frame of Horizon 2020;
- To be an active actor to the modernization of the teaching and research activities in our university and to higher connect them to the ones in European universities and companies;
- Increasing the number of participation of our university as coordinator/partner in national, European and other international research and teaching programs;
- Increasing the attractiveness of the research activity in our university by better promoting our work and by increasing the number of research projects;
- Extending the collaboration with the industry;

Regarding the problems of Flexible Manufacturing Systems programming and simulation, problems approached by this thesis, they are very complex problems, which can get many valences. This thesis investigated systems programming from the organizational point of view for to decrease the transition costs in the time of flexible function. The programming of these types of systems is until a subject what can be developed very much. The approach of this as far as seen of games theory and neuronal networks is an original approach which has been shown not enough explored. Also, the candidate plans to develop other methods to determine the composition of the typological nucleus for the initial production task.

On the other hand, as a full time faculty member, the candidate will also be involved in activities related to teaching and advising. While continuing his lectures on the topics of Operations Management, the candidate hopes to expand his teaching activity with a new and original lecture, related to new methods of production systems modeling, perception and understanding, which can improve the quality of the teaching area.

The candidate will continue to advise diploma and master theses, on subjects related to his research activities. However, if this habilitation will be successful, the candidate will also advise doctoral research, a new challenge implying increased responsibility. The candidate will use his experience to help the PhD students pursue meaningful and fruitful research topics, will work with the students for getting original and publishable results, and will assist them in the publication process. Also, it is the habilitation candidate's opinion that it is the task of the advisor to continuously look for sources of financing for the PhD students he advises, and to help them in the future academic or professional career they choose.