TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 66, Issue Special II, October, 2023

IMPLEMENTATION PROJECT MANAGEMENT OF A ROBOTIC MANUFACTURING CELL USING THE CRITICAL PATH METHOD

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Abstract: *This paper proposes the application of the critical path method in the development and implementation of a new manufacturing process using Microsoft Project. For the analysis of the implementation management of the new manufacturing structure, a concrete case was taken from a car parts manufacturing company in Oradea. The first step was to identify all the activities necessary for the implementation of the project. For each activity the dependency relationships (predecessors of each activity) were established. All the human and material resources needed to implement the project were identified with the help of the project manager and the technical team. For each resource, costs (fixed and variable, as appropriate) were established. These data were entered into Microsoft Project software. The use of Microsoft Project highlighted future problems that may arise in the implementation of the project (shortage of resources, critical activities, implementation time, ...). The use of this program leads to the optimization of the implementation project by concrete identification of the critical path, reduction of implementation time, visualization of costs. This paper proposes a method to optimize the implementation design of the new manufacturing system structure. This approach helps production managers to change/implement a new manufacturing structure, track implementation milestones and visualize costs. This method is an effective tool for project implementation. The paper presents the advantages of using these motions (critical path) in the modernization/change of manufacturing structure using Microsoft Project.*
Key words: *management, robotic manufacturing cell, critical path method, Microsoft Project.*

1. INTRODUCTION

In today's market economy, the uptake of new products is an important challenge for any company. The assimilation process needs to take place in the shortest possible time and at the lowest possible cost. These goals can be achieved through the most efficient procedures [1], [2]. A procedure based on the critical path method has been used for the assimilation of the *Disk limiting* product [3], [4]. *Microsoft Project* [5], [6] is an application that helped project managers to plan and track projects, allocate resources, track progress, manage costs and resources (human resources and equipment).
This application is used to provide a wide range of graphical information. Information from *Microsoft Project* can also be exported to other applications for processing [7], [8], [9], [10], [11], [12].

2. CONTRIBUTIONS ON THE IDENTIFICATION OF ACTIVITIES TO BE CARRIED OUT FOR THE IMPLEMENTATION OF THE MANUFACTURING CELL FOR THE PRODUCTION OF THE DISK LIMITER PRODUCT

The activities being carried out for the assimilation of the *Disk limiting* product have been organized as a project. This project was implemented in *Microsoft Project* software. *Microsoft Project* software is a tool that allows the management of a project using the *critical path method*.
By applying this method, it is possible to identify critical activities within the project. In order to shorten the execution time of the project the execution time of the *critical activities* must be

shortened. The duration of an activity can be shortened by allocating additional resources.
The use of *Microsoft Project* in the case under analysis provides decision-makers with information that allows them to make decisions that lead to a reduction of the time needed to assimilate the *Disk limiting* product.

Project implementation in *Microsoft Project* requires that the following attributes are associated with each activity: duration, predecessors and resources required to complete the activity, **Tab. 1.**

Table 1

Manufacturing cell implementation project activities

Crt. no.	Name of activity	Duration [days]	Predecessors	Resource
1	**Design, realization, testing and validation of the processing of the Disk limiting product under the specific conditions of the adopted manufacturing cell variant**			
1.1	**Design, manufacture and testing of cutting tools**			
1.1.1	Design of new cutting tools	1		CNC Process Engineer
1.1.2	Offer and Order of cutting tools	0.25	1.1.1	Purchasing Agent CNC Process Engineer
1.1.3	Manufacture of combined cutting tools	50	1.1.2	Supplier Cutting Tools
1.1.4	Transport to FMKT	0.38	1.1.3	Courier
1.1.5	Reception of cutting tools	0.13	1.1.4	Procurement Department
1.1.6	Assembly, testing of combined cutting tools	5	1.1.5	CNC Process Engineer
...	**...**			
3	**Software design of the manufacturing cell**			
3.1	CNC Programming and Simulation	10	1; 2	CNC Process Engineer
3.2	Programming and Simulation of Automated Assembly Using Industrial Robots	15	2.2.1; 2.3.1	Automation Engineer
3.3	PLC Process Programming and Simulation	15	3.2	Automation Engineer
...	...	...	...	...
7	**Reception and handover of the robotic manufacturing cell to the production department**	1	1; 18; 36; 40; 45; 50	Automation Engineer CNC Maintenance Engineer Maintenance Engineer CNC Devices CNC Process Engineer Technical Manager

In order to achieve the best version of the implementation process it was necessary to indicate the standard and additional costs of the human resources involved, and the costs of the necessary equipment.

2.1 PROJECT IMPLEMENTATION IN MICROSOFT PROJECT

Entering the data into the *Microsoft Project* program resulted in Version I of the manufacturing cell implementation project.

2.1.1 Variant I project implementation

Fig. 1 shows the activities required to build the robotic manufacturing cell and the *Gantt* chart. Also highlighted are the critical activities (those coloured in red) and the activities that are in short supply.
The *Microsoft Project* program highlighted that in Version I of the robotic manufacturing cell implementation project there are activities that have a higher resource requirement than available, Fig. 1.
This indicates that the project cannot be implemented. To solve this problem, we will use the *Resource-Level All* facility of the program, it allows to shift the activities in such a way that they can be accomplished / implemented with the available resources.

2.1.2 Variant II project implementation

After the levelling of resources, the result is the second version of the implementation project. In this variant no resource shortage is reported, but a significant increase in the implementation time of the robotic manufacturing cell is observed. The duration of the robotic manufacturing cell implementation project is *124.76 days* and the total cost is *101 494.24€.*

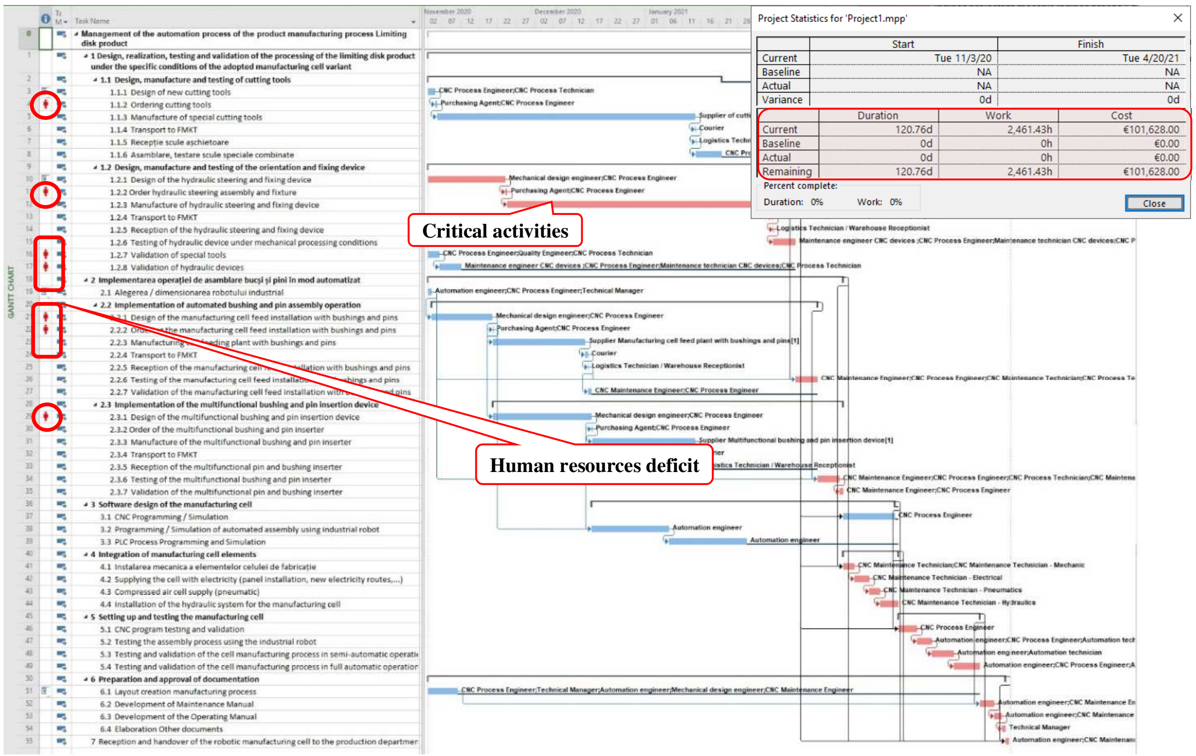

Fig.1 Variant I of the robotic manufacturing cell implementation project

2.1.3 Variant III project implementation

As *Microsoft Project* identifies critical activities (*Critical Path*), in order to shorten the project implementation duration, the execution times of the main critical activities will be shortened.

In a first phase, the following critical activities have been identified, corresponding to the 2nd version of the manufacturing cell implementation project: *Design of the hydraulic orientation and fixing device (1.2.1); Design of the manufacturing cell feeding installation with bushings and pins (2.2.1); Design of the multifunctional bushing and pin insertion device (2.3.1).*

In order to shorten the duration of these activities, the Mechanical Design Engineer resource has been increased by one unit. Under these circumstances, the result of the implementation project, version III.

The duration of the robotic manufacturing cell implementation project is 114.26 days and the total implementation cost is 107 954.71€.

2.1.4 Variant IV project implementation

The following critical activity has been identified*: Manufacture hydraulic steering and fixing device (1.2.3).* This activity involves the manufacture by the supplier of two hydraulic devices for orientation and fixing of the limiting disc product. It has been agreed with the supplier that the order will be delayed, i.e. the first device will be delivered to the beneficiary at an earlier delivery date than if the whole order was delivered. This delay also implied a rescheduling of the activities: *Testing of the hydraulic device under mechanical processing conditions (1.2.6); Validation of the hydraulic device (1.4).*

The result of this improvement was the 4th version of the implementation project. The duration of this robotic manufacturing cell implementation project is *108.76 days* and the total implementation cost is *131 525.94€.*

2.1.5 5th implementation variant of the project

Analysing the 4th version of the robotic manufacturing cell implementation project, it was found that the critical activity with the longest lead time is: *Combined chipping tool manufacturing (1.1.3).*

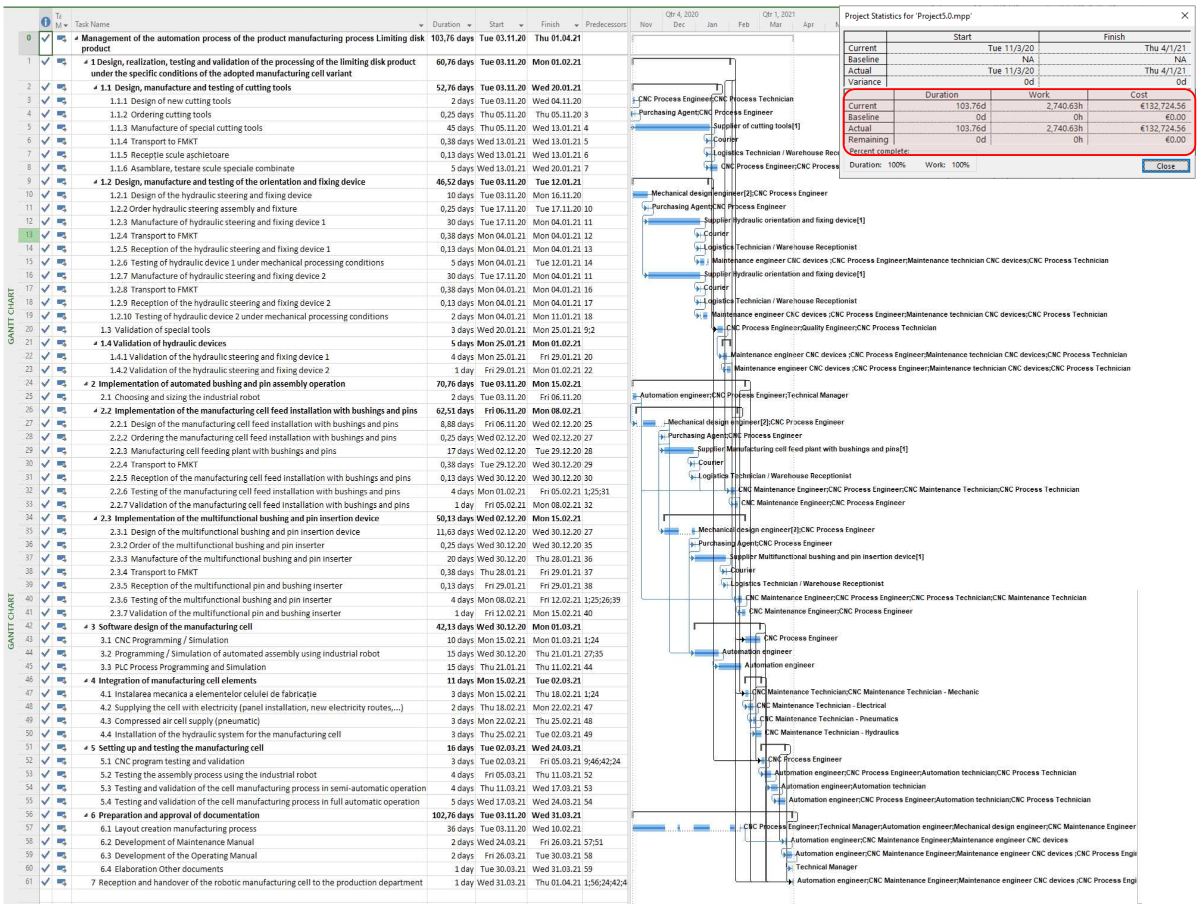

Fig.2 Version V of the robotic manufacturing cell implementation project management

Consequently, an acceleration of the order completion (shortening the delivery time of the combined chipping tools) was negotiated with the supplier. This increased the cost of the associated tools and therefore the total cost (Fig. 2). Accordingly, in this last stage of project improvement implementation, the main characteristics of the project are: project duration is: *103,76 days;* total implementation cost is: *132 724,56 €.*

3. ASSESSMENT OF PROJECT IMPLEMENTATION OPTIONS

The results corresponding to the five project management variants of the robotic manufacturing cell implementation are summarized in Tab 2.

Table 2

Evaluation of the cost-effective implementation options of the robot cell

Project variant	Duration [days]	Total cost [€]	Cost/day [€]	Comments
Variant I- Not implementable	120,76	101 628,0	841,57	Project not implementable
Variant II	124,76	101 494,2	813,51	-
Variant III	114,26	107 954,7	944,81	-
Variant IV	108,76	131 525,9	1 209,32	-
Variant V - Implemented	103,76	132 724,4	1 279,15	Project implemented

The differences between the five variants are highlighted below considering the following indicators: total costs, costs per working day.
Fig. 3 shows, in comparison, the total costs of implementing the robotic manufacturing cell for each of the five project variants analysed. These costs are related to project completion times for each variant.

The graph in Fig. 3 shows the dependence of the total cost on the project duration: the shorter the project duration, the higher the related cost.
Fig. 4 shows the average daily cost for each project variant.

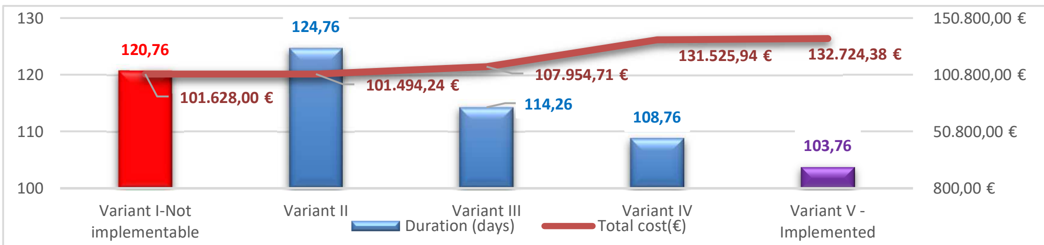

Fig.3 Total costs and implementation times. Project variants

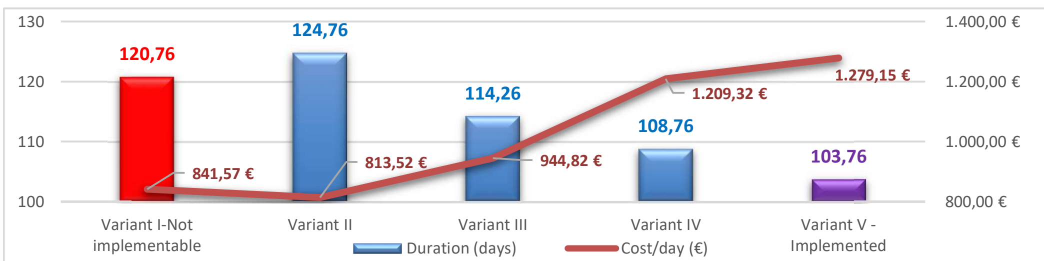

Fig.4 Average costs per implementation day for each project variant

It is found that variant V corresponds to the highest daily cost. The decision-makers have analysed the five project options and concluded that option V corresponds to a balance between duration and cost. Consequently, this option was *implemented.*

4. DETAILED ANALYSIS OF THE IMPLEMENTED VARIANT

In Fig. 5 is presented the total amount (*132 724.56€)* for the 5th variant of the robotic manufacturing cell implementation project.

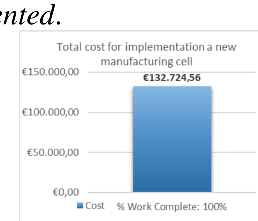

Fig.5 Total cost of implementing the robotic manufacturing cell

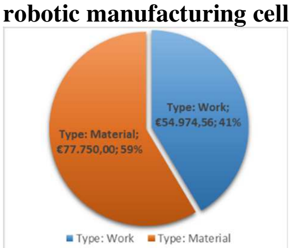

Fig.6 Distribution of robotic manufacturing cell implementation costs

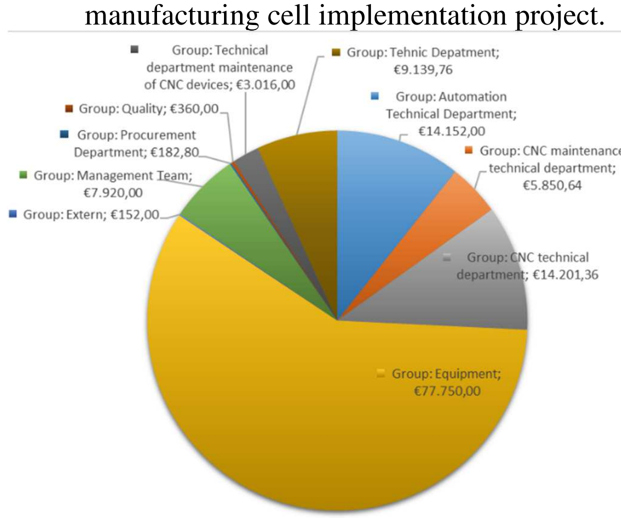

Fig.7 Distribution of costs by resource groups involved in the implementation of the robotic manufacturing cell

The total amount invested, in this case, is composed of: the total cost related to human activities, amounting to *54 974.56 €* (42% of the total project implementation cost) and the total cost of material resources and equipment supplied, amounting to *77 750.00 €* (58%), Fig. 6.

Fig. 7 shows the distribution of costs across the resource groups involved in implementing the robotic manufacturing cell. In this graph it can be seen that the largest share (*58%*) of the total financial effort is represented by costs related to equipment, devices delivered by manufacturers (specialized suppliers).

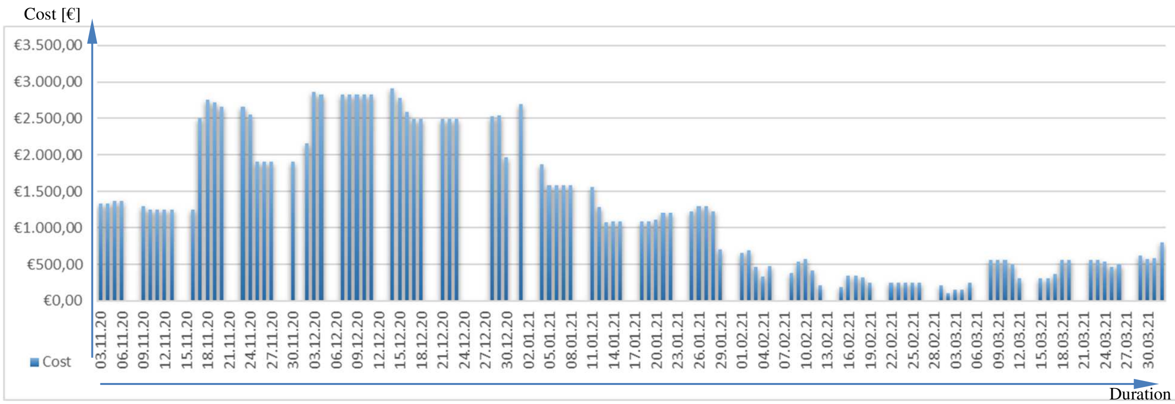

Fig.8 Cash flow during the implementation period of the manufacturing cell project

Fig. 8 shows the cash flow corresponding to the implementation period of the manufacturing cell project. Analysing the cash flow graph, Fig. 8, it can be seen that in the first part of the project implementation the level of cash flow was higher due to the design, implementation, testing and validation activities of the manufacturing process.

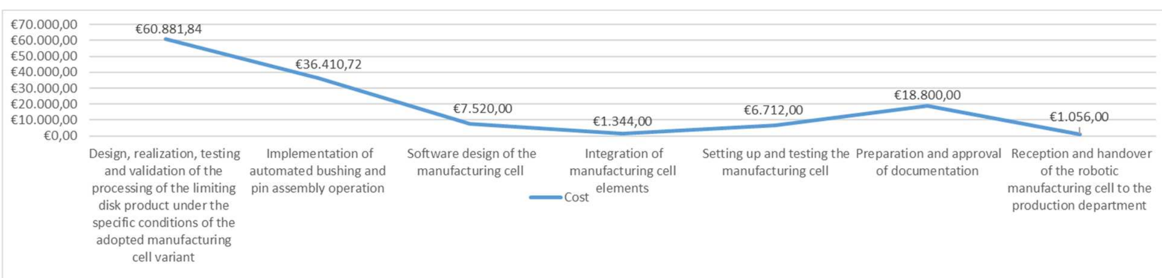

Fig.9 Cost distribution chart for each main activity of the robotic manufacturing cell implementation project

Fig. 9 provides a visual representation in the form of a cost distribution chart, illustrating the allocation of expenses across the primary activities involved in the implementation of the robotic manufacturing cell project. The diagram shows the main activities and related costs in order of project implementation. It is observed with higher cost for the first two main activities. The highest costs are associated with the main activity: *Design, realization, testing and validation of the process of processing the limiting disc product under the specific conditions of the manufacturing cell variant adopted.*

Fig. 10 displays a comprehensive breakdown of costs, highlighting the distribution across various human resource groups or departments that have been actively engaged in the implementation of the robotic manufacturing cell project.

Upon analysing the graph presented in Fig. 11, it becomes evident that the *Technical-CNC* and *Technical-Automation* departments emerge as the departments incurring the highest costs within the scope of the manufacturing cell implementation.

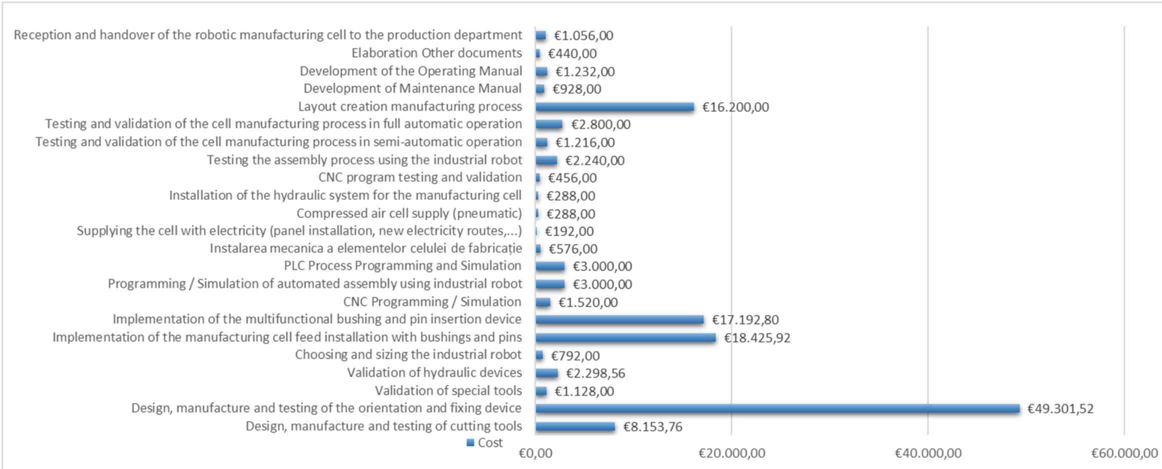

Fig.10 Distribution of costs for activities on the second level of the robotic cell implementation project

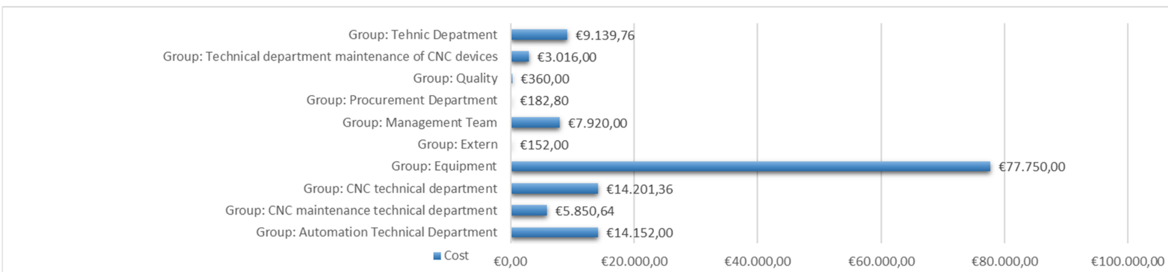

Fig.11 Distribution of costs by human resource groups (departments) involved in the robotic manufacturing cell implementation project

Fig. 12 displays a detailed breakdown, highlighting the cost distribution between new equipment and human resources involved in the implementation of the robotic manufacturing cell project.

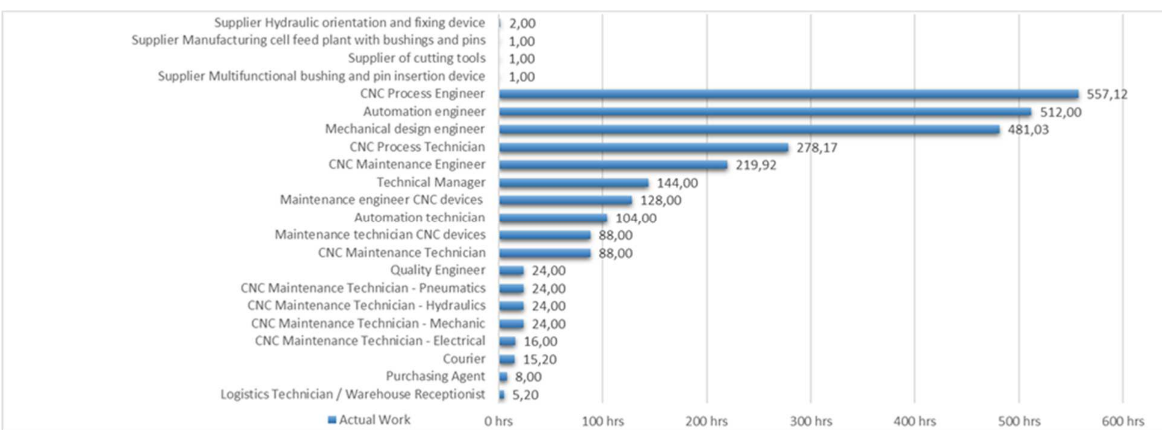

Fig.12 Distribution of costs for new equipment and human resources involved in the robotic manufacturing cell implementation project

In the graph presented in Fig 12, it can be seen that the human resources: *Automation Engineer (12 800 €), CNC Process Engineer (10 585.28 €), Mechanical Design Engineer (9 139.75 €) and Technical Manager (7 920.00 €)* have the most significant weight in terms of financial effort required to implement the robotic manufacturing cell.

The *Microsoft Project* program provides information on the total work time associated with each resource during the project execution.

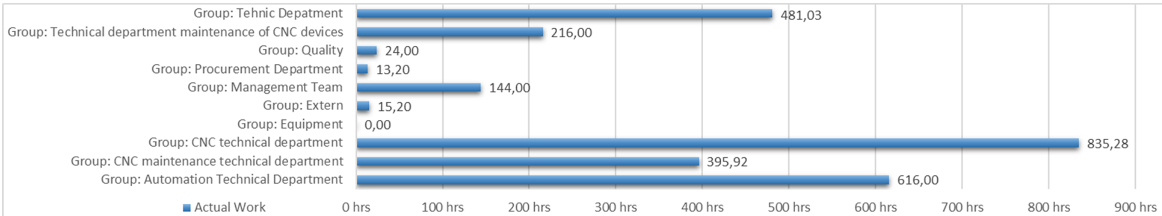

Fig.13 Distribution of working time for each resource group (company departments) during project implementation

Thus, Fig 13 shows the distribution of working time for each resource group (company departments) during project implementation.

Fig 14 shows the distribution of working time for each resource during the project implementation.

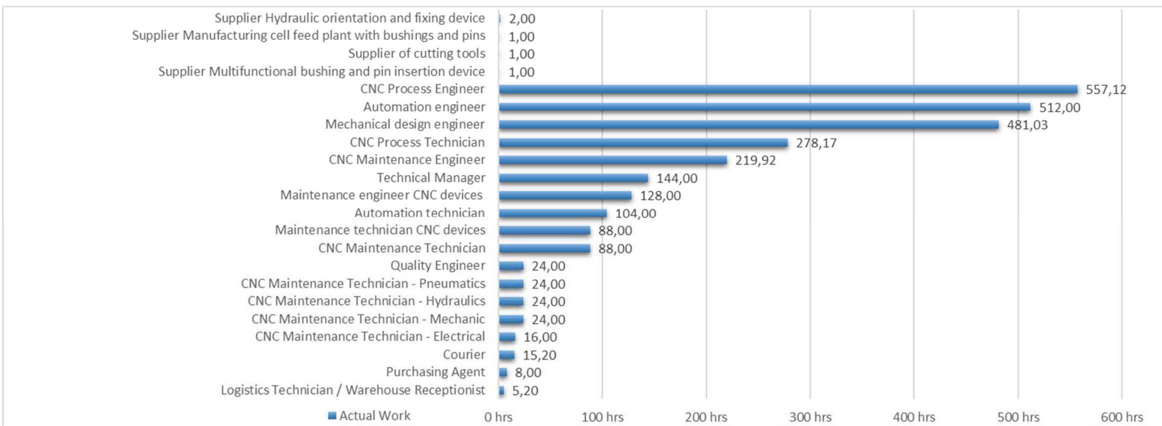

Fig.14 Distribution of working time for each resource required during project implementation

Analysing the time distribution graph for each resource involved in the implementation of the manufacturing cell, **Fig 14**, it can be seen that for the *CNC Process Engineer* resource is allocated the highest cumulative working time *(557 hours)* to perform the assigned tasks.

5. CONCLUSIONS

The implementation of the manufacturing cell, in the version resulting from the decision-making process, was managed as a project.

In the first phase the project activities were defined. These were organised hierarchically on three levels: activities on level I (main); activities on level II (secondary); activities on level III (tertiary). The activities were ordered according to how they were to be carried out over-time, precedence-succession relationships were defined. The duration of each activity was also determined.

The implementation of the implementation project also implied the allocation of human resources, and accordingly the resources related to the project were allocated. These resources are, in fact, specialists within the company's departments. Each resource, each specialist, has been assigned an hourly cost.

The critical path method was used to manage the manufacturing cell implementation project. This was made possible using *Microsoft Project* software.

The information on activities, i.e. resources, was entered into *Microsoft Project* resulting in a first version of the manufacturing cell implementation project. It was found that this variant could not be implemented as the resource requirements exceeded the available resources. Consequently, a feature of *Microsoft Project*, the resource levelling facility, which resulted in the 2nd project variant.

The second project variant was characterised by the fact that the project duration was *124.76 days,* and the related costs were *101 494.24 €.*
In the 2nd project variant, the following critical activities were identified: Design of the hydraulic orientation and fixing device; Design of the bushing and pin manufacturing cell feeding system; Design of the multi-purpose bushing and pin insertion device. For these activities, resources were supplemented, resulting in the third project variant characterised by a duration of *114.26 days* and a total cost of *107 954.71€.*
The fourth implementation project variant resulted from negotiations with the supplier of hydraulic equipment. These negotiations involved splitting the initial order into two independent orders with their own delivery deadlines. This resulted in a project duration of *108.76 days* and a value of *131 525.94€.*
Analysing the fourth project variant, it was found that the activity Manufacturing combined cutting tools is the critical activity with the longest lead time. Consequently, an acceleration of the order completion (shortening the delivery time of the combined cutting tools) was negotiated with the supplier. This resulted in the 5th variant characterised by: the project duration for the implementation of the 5th variant of the robotic manufacturing cell is: *103.76 days*; total implementation cost is: *132 724.56 €.* This project variant has been selected for implementation.
The critical path method proved to be effective in the management of the implementation project. The use of *Microsoft Project* software allowed useful information to be obtained in order to achieve a balance between the implementation time of the manufacturing cell project and the costs associated with this process.

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Managementul proiectului de implementare a unei celule de fabricație robotizata utilizând metoda drumului critic

Această lucrare propune aplicarea metodei drumului critic în dezvoltarea și implementarea unui nou proces de fabricație folosind Microsoft Project. Pentru analiza managementului de implementare a noii structuri de fabricație a fost luat un caz concret de la o companie producătoare de piese auto din Oradea. Primul pas a constat în identificarea tuturor activităților necesare pentru implementarea proiectului. Pentru fiecare activitate au fost stabilite relațiile de dependență (predecesorii fiecărei activități). Cu ajutorul managerului de proiect și al echipei tehnice au fost identificate toate resursele umane și materiale necesare pentru implementarea proiectului. Pentru fiecare resursă, s-au stabilit costurile (fixe și variabile, după caz). Aceste date au fost introduse în programul Microsoft Project. Utilizarea programului Microsoft Project a evidențiat viitoarele probleme care ar putea apărea în implementarea proiectului (lipsa resurselor, activități critice, timp de implementare. Această lucrare propune o metodă de optimizare a proiectului de implementare a noii structuri a sistemului de fabricație. Această metodă îi ajută pe managerii de producție să schimbe/implementeze o nouă structură de fabricație, să urmărească etapele de implementare și să vizualizeze costurile. Această metodă este un instrument eficient pentru implementarea proiectelor. Lucrarea prezintă avantajele utilizării acestor schimbări (drum critic) în modernizarea/schimbarea structurii de fabricație cu ajutorul Microsoft Project.

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