COMPUTER AIDED DESIGN AND MANUFACTURING OPTIMIZATION PROCESS FOR A SET OF SPUR GEARS OF A GEARBOX

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Abstract: In their effort to deliver products on schedule and with a given budget, today's projects teams will face with rapidly changing environments. Microsoft Project is a software tool to help the user to consider projects composed by individual parts, identify potential overloads in their production process and generate information to keep the project under control. Using this software tools in the framework of manufacturing projects is a good way to solve many problems which can appear in the production process. The key points considered in this article are: defining the deliverables, planning activities, defining calendars, scheduling project tasks, managing resources, adding resources to the projects, finalizing project plan, updating a project and recordering progress for a spur gear of a gearbox.

Keywords: optimization manufacturing projects, computer aided design and 3D modeling, operation management, spur gears, tooth profile, CATIA, AutoCAD, Critical Path Method, Precedence Diagram Method.

1. INTRODUCTION

In any production systems, subassemblies, components and final products are conceived, designed, manufactured and assembled. Components are converted into subassemblies and more of them are converted into final products. In order to meet external demand for final products and spare parts, the amounts needed for components must be determined by calcul. For this, it is necessary to describe and analyze the inter-relationship between all items of the product and the production capacity of the company because it is necessary to deliver the products in schedule, at the lowest costs and with a reduction of the resources involved.

The article describes a methodology for a manufacturing optimization process of four spur gears from a gearbox. These spur gears have different shapes and technical production processes, but they are manufactured using the same resources. With this methodology, the project manager can determine the best production time using his company limited resources, identify their potential bottlenecks and find different solutions to eliminate or diminuate them.

Generally, the benefits of project management using Microsoft Project are: success in lowering costs, increase productivity, bringing projects in schedule and improving quality is achieved through the proper utilization of project management methodologies.

Many experts in project management offer capable solutions in the areas of project management, scheduling, estimating, risk analysis, project management, process development and analysis and integration of management information systems.

2. THE FUNDAMENTAL ELEMENTS OF PROJECT MANAGEMENT

A project can be defined as a temporary endeavor undertaken to create a unique product or service. A manufacturing project is usually a one-time activity with a well-defined set of objectives and results. It can be divided into sub-tasks that must be accomplished in order to achieve the project goals. The project is complex enough that the sub-tasks require careful coordination and control in terms of timing, precedence, cost and performance.

The project manager is authorized to direct activities, spend money (usually within preset limitation), request material resources and personnel and start the project on its way. The process of developing the project plan varies from organization to organization, but any project plan should contain the following elements:

- Overview – a short summary of objectives and scope of the project;
- Objectives – contain a more detail statement of the general goals noted in the overview section;
- General approach – describes the both managerial and technical approaches to the work. The technical approaches describes the relationship of the project to available technologies and the managerial approach takes note of any deviation from routine procedures, for example, the use of subcontractors for some parts of the work;
- Contractual aspects – includes a complete list and description of all reporting requirements, customer-supplied resources, liaison arrangements, advisory committees, project review and cancellation procedures, proprietary requirements, any specific procedure for changing any of them;
- Schedules – various schedules and a list of all milestone events;
- Resources – in this part appear two aspects. The first is the budget, both capital and expense requirements are detailed by task project budget. The second aspect is the cost monitoring and procedures which must be designed to cover special resource requirements for the project, such as special machines, test equipment, laboratory usage, logistics, field facilities and special materials;
- Personnel – represents a list with the personnel required for the project;
- Evaluation methods – any project must be evaluated by standards and methods established at the project's start;
- Potential problems.

These are the elements that constitute the project plan and are the basis for the more detailed planning of the budgets, schedules, work plan and management of manufacturing projects.

3. DESIGNING THE GEARBOX AND SCHEDULING THE PROJECT PLAN

The considered mechanism transmits the movement in two steps between the input (primary) shaft and the exit (secondary) shaft. In the design phase, for an accurate calculus, there were also involved the values for the power and the rotation speed for both shafts.

In order to establish the coordinates of points defining the tooth profile, a C++ program was elaborated, based on the parametric equations of the involute flank profile, cinematically generated by rolling on the pitch circle.

The tooth profile was generated using this C++ program and AutoCAD 2000 and saved under the DWG file format on the hard disk. This format, as well as the DXF format are recognized and imported by CATIA V5. Thus, the profile and flank lines are represented in a parametric CAD environment, the tooth profile is extruded along the flank line and the tooth is generated as 3D model. Then, the four spur gears are differently generated based on their

functional role. AutoCAD was used to generate the complex tooth profile according to specified technical dimensions and CATIA to parametrically model the tooth, the spur gears and, alongside the other components, the gearbox.

In figure 1 are shown some elements of the gearbox in two isometric views. These elements are: the four spur gears, a splined shaft, a cylindrical shaft and four ball-bearings.
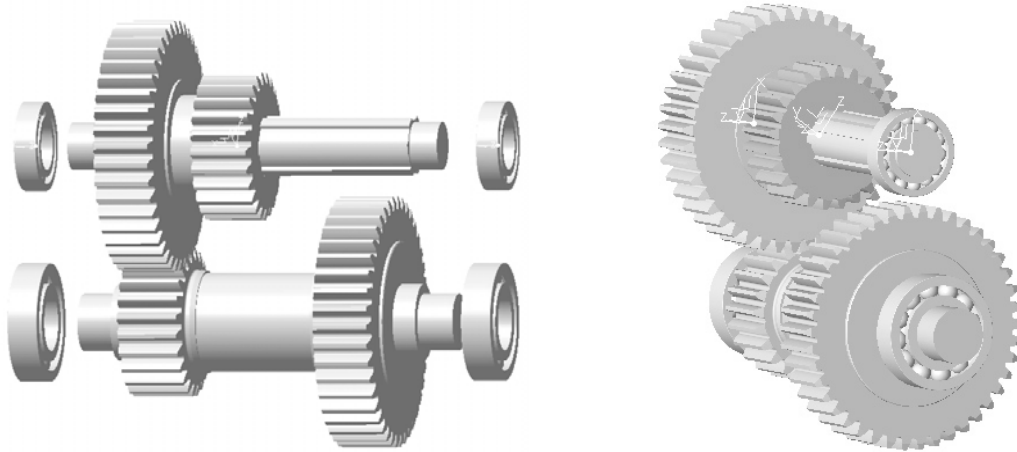

Fig.1. Elements of the gearbox

In figure 1 the gearbox elements are presented in a functional assembly. The case study considered in this article concern only the manufacturing optimization process of the four spur gears, so they are presented in 3D models in figure 2, with their module and tooth number.
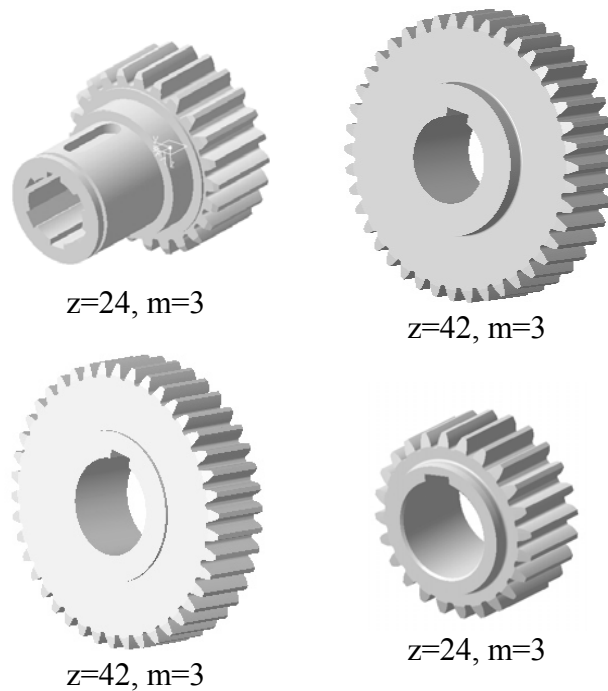

z=24, m=3

z=42, m=3

z=42, m=3

z=24, m=3

Fig. 2. The 3D models of the four spur gears

To manufacture these spur gears, the project manager should consider the following machine-tools, called, from now on, resources: one circular saw, two centre lathes, one milling machine, one slotting machine, one broaching machine, two gear-cutting machines, one border-cutting machine for gears, one installation for heat treatment, two gear-grinding machines, two gear-grinding machines with abrasive blade and some control instruments.

To make effective decisions and take related actions, it is necessary that the project manager and the members of the team have a high level of competency in planning, scheduling

and control and these functions are directly connected. An important part of a project manager's responsibility is the coordination of a variety of related activities, which constitute the project scope. Determining the content, sequence and inter-relationship of such activities will assist him in creating a project plan.

Planning can be defined as making decisions now with the objective of influencing the future. Planning can also be seen as the desk study of what is anticipated will happen in the future. To ensure that will be no unpleasant surprises that have not been anticipated, planning needs to be an important preoccupation in any company.

One of the most important responsibilities in a project is the planning of activities, analyzing and integrating their effects and executing the resulting project plans. Because of the relatively short duration and prioritized control that exists in many projects, there is a requirement for formalized detailed planning. This is done through the development of a project scheduled plan. The first version of this plan is developed during the conception phase.

A view in the activities diagram looking for inter-relationship may reveal where resources can be shifted or rescheduled to enable a significant reduction in the overall time for project completion. A diagram of sequences and inter-relationships will aid much in coordinating inputs and activities and reducing confusion and delays. Activity diagrams models have a special significance because they have certain mathematical characteristics that enhance their value in finding optimal solutions for complex problems. Initiating a project or each phase of a project requires the following procedures: stating the problems, identifying the goals, listing the objectives, preliminary determination of constraints, identification of assumptions and risks.

The five steps in the detailed procedures of the planning process are:

a. identifying the activities;

b. determining the sequence of activities;

c. estimating the time durations of each activity;

d. identifying the critical activities;

e. modeling the allocation of resources.

Scheduling is the determination of the timing of activities and it follows logically from the planning process. The scheduled plan is a tool to determine the activities necessary to complete a project, the sequence and the timeframe within which activities must be completed.

The Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) were developed in the same period by separated groups for performing the planning and control functions in the management of project.

The original PERT and CPM models differed in the way they treat time and cost factors. PERT considered only the time variable. Precedence Diagram Method (PDM) is a most complex version of Critical Path Method (CPM). The complexity arises through the greater number of dependences between activities and events.

In PDM are four logical relationships between activities as follows in figure 3:

finish to start (FS)

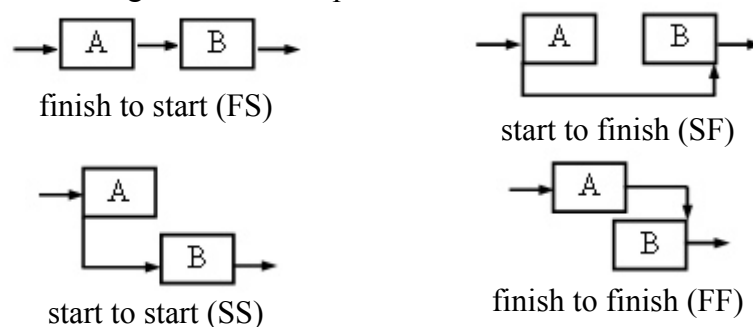start to finish (SF)

start to start (SS)

finish to finish (FF)

Fig. 3. Four dependencies used in PDM

The identified project activities are grouped into a system which is broken down into subsystems and elements. The work breakdown structure (WBS) is the break down of the project

into all activities and task needed to design, procure, implement and complete the project (the spur gears production).

The WBS is a mean of displaying the physical subsystems to be developed or produced. The first step in creating a WBS is to divide the total project into major work sub-projects. These sub-projects are then subdivided into units which are subdivided and so on.

This level-by-level breakdown continues so that the scope and complexity of work elements is reduced with each level of breakdown. This analysis will reduce the project into elements that can be thoroughly and accurately defined, budgeted, scheduled and controlled.

As each activity and task is identified, so the work associated with each element is further elaborated and more clearly specified. During this process, the questions that the team needs to ask include "What else is needed?" and "What has been missed?" By the time, the WBS is completed, all work on the project has been completely defined.

The project objective is to manufacture 100 pieces of each spur gear for 100 gearboxes using the company limited resources, at the lowest costs and in the shortest time, without the requisition for other resources and/or overtime work. For each spur gear there were calculated all the technological times, in minutes, and were established the allocated resources (R1…R15).

The operations structure for the considered project is shown in Table 1.

Table 1. Work breakdown structure

Spur gear	Operation	Operation code	Duration (minutes)	Predecessor	Resource	Resource code
Gear 1 $z=24$, $m=3$	Cutting from ingot	A11	4	-	Circular saw	R1
	Lathing 1	A12	12	A11	Centre lathe 1	R2
	Lathing 2	A13	5	A12	Centre lathe 2	R3
	Finishing lathe	A14	5	A13	Centre lathe	R2
	Key groove milling	A15	4	A14	Milling machine	R4
	Broaching	A16	6	A15	Broaching machine	R6
	Gear-cutting	A17	30	A16	Gear-cutting machine 1	R7
	Border-cutting	A18	16	A17	Border-cutting machine for gears	R9
	Heat treatment	A19	6	A18	Installation for heat treatment	R10
	Internal grinding	A110	9	A19	Gear-grinding machine 1	R11
	External grinding	A111	8	A110	Gear-grinding machine 1	R11
	Spline grinding	A112	25	A111	Gear-grinding machine 2	R12
	Gear grinding	A113	25	A112	Gear-grinding machine with abrasive blade 1	R13
	Control	A114	7	A113	Control instruments	R15
Gear 2 $z=42$, $m=3$	Cutting from ingot	A21	7	-	Circular saw	R1
	Lathing 1	A22	5	A21	Centre lathe 1	R3
	Lathing 2	A23	8,3	A22	Centre lathe 2	R2
	Finishing lathe	A24	4	A23	Centre lathe	R3
	Key groove sloting	A25	5	A24	Slotting machine	R5
	Gear-cutting	A26	35	A25	Gear-cutting machine 2	R8
	Border-cutting	A27	16	A26	Border-cutting machine for gears	R9
	Heat treatment	A28	4,5	A27	Installation for heat treatment	R10
	Internal grinding	A29	5	A28	Gear-grinding machine 1	R11
	External grinding	A210	3	A29	Gear-grinding machine 1	R11
	Gear grinding	A211	30	A210	Gear-grinding machine with abrasive blade 2	R14
	Control	A212	4,5	A211	Control instruments	R15
	Cutting from ingot	A31	7	-	Circular saw	R1
	Lathing 1	A32	6	A31	Centre lathe 1	R3

	Lathing 2	A33	8,5	A32	Centre lathe 2	R2
	Finishing lathe	A34	4,5	A33	Centre lathe	R3
	Key groove sloting	A35	5,5	A34	Slotting machine	R5
	Gear-cutting	A36	35	A35	Gear-cutting machine 2	R8
Gear 3 z=42, m=3	Border-cutting	A37	25	A36	Border-cutting machine for gears	R9
	Heat treatment	A38	4,5	A37	Installation for heat treatment	R10
	Internal grinding	A39	6	A38	Gear-grinding machine 1	R11
	External grinding	A310	3	A39	Gear-grinding machine 1	R11
	Gear grinding	A311	30	A310	Gear-grinding machine with abrasive blade 2	R14
	Control	A312	4,5	A311	Control instruments	R15
	Cutting from ingot	A41	4	-	Circular saw	R1
	Lathing 1	A42	4,5	A41	Centre lathe 1	R2
	Lathing 2	A43	6	A42	Centre lathe 2	R3
	Finishing lathe	A44	2,5	A43	Centre lathe	R2
	Key groove sloting	A45	5	A44	Slotting machine	R5
	Gear-cutting	A46	30	A45	Gear-cutting machine 1	R7
Gear 4 z=24, m=3	Border-cutting	A47	16	A46	Border-cutting machine for gears	R9
	Heat treatment	A48	4	A47	Installation for heat treatment	R10
	Internal grinding	A49	6	A48	Gear-grinding machine 1	R11
	External grinding	A410	2	A49	Gear-grinding machine 1	R11
	Gear grinding	A411	25	A410	Gear-grinding machine with abrasive blade 1	R13
	Control	A412	4,5	A411	Control instruments	R15

4. THE SEQUENCE OF ACTIVITIES AND OPTIMISING THE PROJECT DURATION

The next step in planning the manufacturing process is to develop a logic diagram, which can also be called a "sequential activity diagram" or "flow diagram" (figure 4).
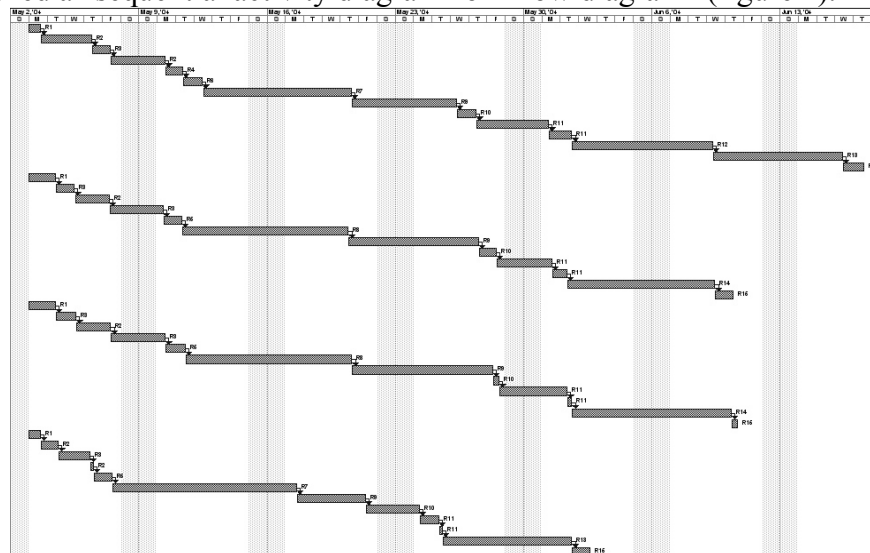

Fig. 4. Sequential activity diagram

In figure 4 is presented the sequential activity diagram for the analyzed project. This diagram is created in Microsoft Project based on the data included in Table 1.

The first step in resource aggregation is to derive a bar chart from the sequential activity diagram that was developed for the project. The completed bar chart is used to unite the resources with the time schedule. This is simply carried out by determining the resources needed for each time unit – hour, day, month – for each activity.

At this moment, each spur gear has a sequence of activities placed in a time scale related to their durations and relations with activities from other spur gears.

Each activity has been associated with a resource. In this case, the resources are represented by machine-tools, but they also can be one of following types: humans, materials, labor, tools etc.

Initially, for every resource, there are provided one or more activities at the same time. Thus, each resource may become over allocated (resource loading is greater than 100%) and the company may need more machine-tools, which are expensive.

Figure 5 presents, as example, the situation for resource R7, over allocated just in some days (the maximum loading value is 200%). For this reason, an extra machine-tool is not necessary and the project manager, using Microsoft Project, will try to eliminate the overload.
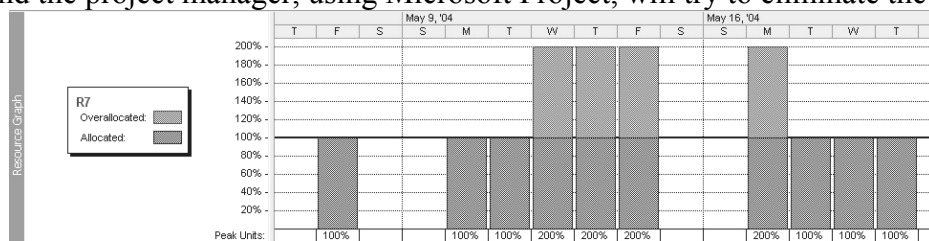

Fig. 5. Loading graph for a resource

Putting together a workable schedule that satisfies all constraints is not an easy task. Shortage of resources can significantly affect the initiation, performance and completion of activities. Limits imposed on resources can be dealt with in several ways. One way is to level the use of resources so that the project completion date can be achieved, respecting all the imposed constraints. This process is known as "resources leveling".

By showing the loading graph for resources, it is clear where and when the over-demands exceed resource availability. If the resource demands exceed the resource availability during any time period, then either the resources will need to be rescheduled or the schedule of activities will need to be amended.

Usually, the number of resources available is limited and there is no possibility of bringing in additional resources. Using the *Level Resources* option in Microsoft Project, the sequential activity diagram is now leveled and presented in figure 6.
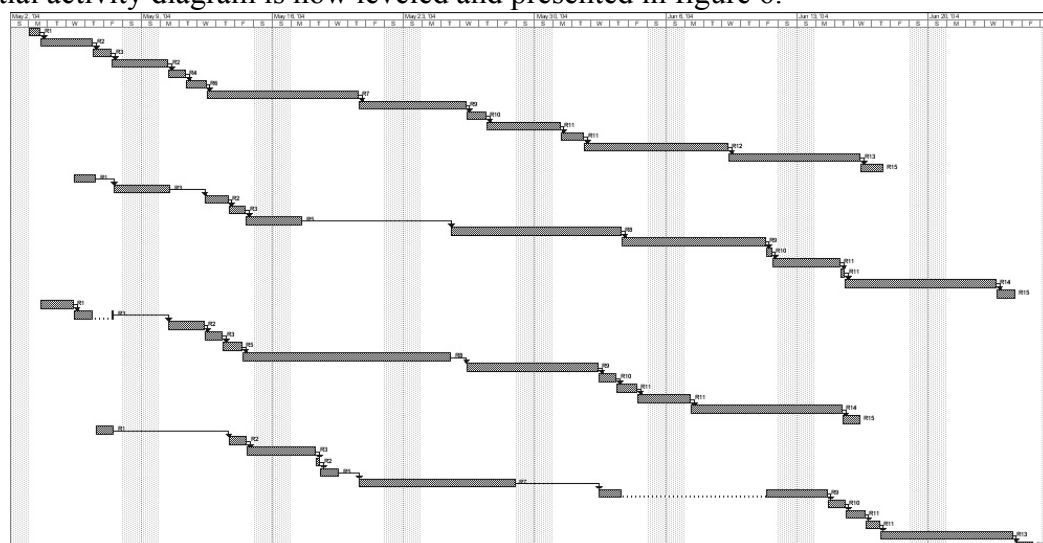

Fig. 6. Sequential activity diagram after leveling

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Resource leveling aims to minimize the period-by-period variation in resource loading by shifting tasks within their slack allowances. The purpose is to create a smoother distribution of resource usage. When resources are leveled, the associated costs also tend to be leveled. If resource usage is increasing as time goes by and if resources are shifted closer to the present by leveling, costs will be shifted in the same way. The project manager must be aware of the cash flows associated with the project and of the means of shifting them in ways that are useful to the company.

Resource leveling is a procedure that can be used for almost all projects, whether or not resources are constrained. If the activities diagram is not too large and there are only a few resources, the leveling process can be done manually. For a larger activities diagram and multiple resources, resource leveling becomes extremely complex and recommended for manual solutions. Thus, computer-aided leveling is not only mandatory, it is also helpful because it allows the project manager to experiment with various patterns of resource usage through simulation.

5. CONCLUSION

Software project management is not always as easy as it looks. Traditional project management techniques are unable to adapt to changes and new risks very well. This makes it harder for the project teams to be flexible and react quickly to changing project issues. However, new techniques such as the presented method can support very complex projects when they are properly implemented.

Through Microsoft Project, a project manager can monitor and schedule projects using any kind of resources. Thus, the project information may be analyzed using Gantt charts, graphs, tables and views to identify better solutions.

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