CONSIDERATIONS ABOUT SCHEDULING METHODS USED IN THE DESIGN BY NONCONVENTIONAL TECHNOLOGIES ORGANIZATION

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Abstract
In the current environment there is a growing need for rapid development of advanced manufacturing technologies. The complexity of such projects requires the integration of work from various technical specialties. If the new product is an incremental development of existing technology, the previous plans could be adapted to the new project. In the absence of pre-existing schedule templates, managers must develop the work breakdown using their best knowledge. Once the activities are identified, the order in which they are to be performed will form the project's schedule. Axiomatic Design theory is a method that breaks down customer needs into functional requirements and design parameters which become the project deliverables and can help in developing the most comprehensive work breakdowns. This article investigates the application of Axiomatic Design in the development of a project schedule for the development of nonconventional technology which utilizes computer programs, automated tools, and laser beam for material removal. The results of the study prove that the method is beneficial for developing better product designs due to the application of the theory's axioms but also for developing better plans. This method is quick and easy to apply in many industries either for designing products or processes.

Keywords: *project management, scheduling, axiomatic design, case study*

Clasificare JEL : *M40, M41*

1. Introduction

Unlike traditional technologies which rely on mechanical forces, nonconventional technologies (NCT) rely on increased energy available to work (Slatineanu et al, 2014) as seen in electric discharge machining (EDM), electrochemical machining (ECM), ultrasonic machining (USM), or laser beam machining (LBM). Since 1770, when EDM was introduced by Joseph Priestly, NCTs have been widely used to manufacture complex, high-quality parts. Consequently, the design of new nonconventional technologies has also increased.

In the development of new technologies, hard and soft based technologies are regularly employed for improved performance. When a set of activities are undertaken in order to obtain a clear and unique result, such as a product or a service, within a specified time frame, it is known as a project as defined by the Project Management Institute (PMI) (Project Management Institute, 2017). According to PMI, a project lifecycle includes initiation, planning, execution, monitoring, and closure phases that are defined by a set of processes which are integrated into a project plan for the successful achievement of project goals.

According to (Kerzner, 2009), (Baccarini, 1999), (Prabhakar, 2008), (Varajão et al, 2014) a project is successful if it meets the expected deadline, budget, quality as well as customer approval. Success is achieved when all activities are managed, such tasks being identified, resources assigned, activities sequenced, and all work monitored. Therefore, the organization and management of resources in order to achieve a pre-determined goal, is the responsibility of the project manager.

2. Project management approaches

With an increased use of project management in all economic sectors, several frameworks have emerged. There are three approaches to project management such as traditional, agile and hybrid, and each is associated with several methodologies/guidelines that facilitate project management (Hua et al, 2023). Traditional methodologies are characterized by completing work definition and planning before beginning the execution. The methodologies are Waterfall, Critical Path Method (CPM), Critical Chain Project Management (CCPM), PMBOK (Project Management Body of Knowledge), V-model (German government), RBPM (Risk Based Project Management - HSBC), SDLC (System Development Life Cycle) and PRINCE2 (Projects IN Controlled Environments) (Cruz et al, 2020). In 1976, the PMI created the PMBOK to define processes, techniques, and methods for the knowledge areas such as scope, time, cost, quality, human resources, communications, risk, procurement, and integration management.

Agile methodologies are adaptable to frequent changes by planning the work one iteration at a time, as seen in SCRUM, XP (Extreme Programming), Kanban, DSDM (Dynamic System Development Model) and MSF (Microsoft Solutions Framework) (Cesarotti, 2019). Hybrid methodologies combine elements of both traditional and agile approaches, such as detailed planning of work for one iteration until the next one begins.

Regardless of whether the methodology is traditional or agile, numerous project management tools, such as Microsoft Project or Primavera software, emerged to improve project performance, but many organizations don't know what the best tool for their business is. None of the existing tools provide all the desired features but what they have in common are task scheduling, resource management, collaboration, cost tracking and document management (Cicibas et al, 2010).

Primavera P6, developed by Oracle, is a popular software for managing large project portfolios and offers collaboration, control, project, and product management features, such as Gantt chart, activity status and relationship reports (Rayabharapu et al, 2024).

Microsoft Project 2016, developed by Microsoft, is a popular software for small to large projects. It supports collaboration, communication, task management, information access, portfolio management, and document management (Wali and Othman, 2019).

The visual embodiment of a schedule is reflected into a Gantt chart. This chart includes deliverables, schedule and resources (Wilson, 2003). Sometimes the organizations undertake similar projects, and previous plans can be reused and adapted to the new requirements. Sometimes, the project is so different from past projects that breaking down of the work can be challenging.

A work breakdown structure (WBS) partitions projects into stages, deliverables, and work packages (Siami-Irdemoosa et al, 2015). A typical WBS approach begins with determining the main deliverables for the project, which will subsequently be broken down into smaller chunks of work.

3. Axiomatic Design approach

In 2001, Axiomatic Design (AD) theory was introduced by N.P. Suh (Suh, 2000), to streamline the product design process. This approach relies on four domains such as customer, functional, physical, and process domains that include customer needs, product functional requirements, product design parameters and process variables. Each functional requirement has one or more corresponding design parameters. Each design parameter has a corresponding process variable. This is done until last unit cannot be broken down anymore. This process is called mapping of one domain's requirements to the parameters within the adjacent domain.

The mapping of customer and functional domains is known as the concept design matrix, the mapping of functional and physical domains is known as the product design matrix, and the mapping of physical and process domains is known as the process design matrix. These can be express by the eq. (1) and eq. (2):

$$\{FR\} = [A]\ \{DP\} \quad (1)$$

Where:

{FR} is the vector of functional requirements.

{DP} is the vector of the design parameters.

[A] is the design matrix.

$$\{DP\} = [B]\ \{PV\} \quad (2)$$

Where:

{PV} is the vector of the process variables.

Axiom 1, known as the independence axiom, requires functional requirements to be independent, while Axiom 2, known as the information axiom, requires the design to minimize the information content. The best solution is obtained when both axioms are satisfied. If functional requirements are not independent, the design is called coupled, when there are less DPs than FRs, or redundant, when there are more DPs and FRs (Nordlund et al, 2016). The design needs to be adjusted so that for each function or decision there is only one physical module.

As the design parameters form the physical domain, they can be used for defining project deliverables. This will make it easy to begin planning activities in the development of an unknown or nonconventional product.

4. Case study

In the case of developing a machinery that utilizes computer programs and automated tools to remove material from a piece using laser beam while performing the work fast, precise, and consistently.

First level functional requirements address the basic objectives of the system to remove material according to program. The desire is to have one physical module per one function.

FR1 = to remove material

DP1 = machine tool assembly

FR2 = to control machining

DP2= control panel module

These functions can be decomposed further so that the machine laser tool assembly is broken down into the movable components that allow for the removal of material, while the controlling of these actions is further broken down into the modules that allow human machine communication and data transfer.

FR1.1 = to provide laser beam power

DP1.1 = laser source

FR1.2 = to provide laser beam

DP1.2 = laser head

FR1.3 = to move laser head

DP1.3 = laser head driving system

FR1.4 = to hold workpiece vertically

DP1.4 = workpiece bed module

FR1.5 = to hold workpiece horizontally

DP1.5 = positioning module

FR2.1 = to input machining program

DP2.1 = input module

FR2.2 = to communicate to user

DP2.2 = visual display

FR2.3 = to control the system

DP2.3 = machine control unit

The designer will be determining if additional decomposition is necessary, if these modules don't exist, as is the case in this study

FR1.1.1 = to produce light

DP1.1.1 = diode laser

FR1.1.2 = to amplify light

DP1.1.2 = resonant cavity

In producing the laser beam, the design will focus on concentrating the laser beam, in a cooled environment, at a controlled distance from the workpiece, while ensuring that molten material is removed from the workpiece.

FR1.2.1 = to concentrate laser beam

DP1.2.1 = focusing lenses

FR1.2.2 = to provide cooling

DP1.2.2 = cooling system

FR1.2.3 = to control beam location

DP1.2.3 = tracking system

FR1.2.4 = to remove molten material

DP1.2.4 = assisting gas system

These modules are again evaluated for further decomposition.

In moving the laser head, there are certain requirements that are desirable such as the ones shown below.

FR1.3.1 = to provide power system

DP1.3.1 = servo motor unit

FR1.3.2 = to provide power transfer

DP1.3.2 = ball screw assembly

FR1.3.3 = to provide power transfer support

DP1.3.3 = linear guide

In regard to holding the workpiece either in the horizontal or vertical way, further decomposition is necessary, as the design will focus on providing clamping and positioning.

FR1.4.1 = to affix workpiece

DP1.4.1 = clamping system

FR1.5.1 = to hold workpiece in x and y direction

DP1.5.1 = fixture module

The control of machining is done by converting data into actions. The design will focus on providing for manual input, upload of data, storage of data, and manual control of the system

FR2.1.1 = to manually input machining program

DP2.1.1 = keyboard module

FR2.1.2 = to upload input machining program

DP2.1.2 = wireless module

FR2.1.3 = to store machining program

DP2.1.3 = memory card module

FR2.3.1 = to manually control the system

DP2.3.1 = button actuator unit

A simplified presentation of functional to design decomposition is shown in (table no. 1). This shows the main components of the system, a type of information typically provided by the engineering subject matter expert to the project manager building the plans.

Every one of these systems need further decomposition if some modules are to be reused from previous projects. Otherwise, even if they need to be slightly modified, they are to be decomposed into smaller units for make or buy decisions.

If the decision is to make them, each of these modules will be undergoing a typical process of design, manufacture, and testing to prove the achievement of individual requirements. Final testing is to be performed to demonstrate, the system achieves the customer requirements that form the bases of this project.

A project plan will be focusing on additional information that needs to be addressed in order to accomplish the development of these modules and the system.

Table no 1 Functional requirements and design parameters decomposition

Functional Requirements	**Design Parameters**
FR1 = to remove material	DP1 = machine tool assembly
FR1.1 = to provide laser beam power	DP1.1 = laser source
FR1.1.1 = to produce light	DP1.1.1 = diode laser
FR1.1.2 = to amplify light	DP1.1.2 = resonant cavity
FR1.2 = to provide laser beam	DP1.2 = laser head
FR1.2.1 = to concentrate laser beam	DP1.2.1 = focusing lenses
FR1.2.2 = to provide cooling	DP1.2.2 = cooling system
FR1.2.3 = to control beam location	DP1.2.3 = tracking system
FR1.2.4 = to remove molten material	DP1.2.4 = assisting gas system
FR1.3 = to move laser head	DP1.3 = laser head driving system
FR1.3.1 = to provide power system	DP1.3.1 = servo motor unit
FR1.3.2 = to provide power transfer	DP1.3.2 = ball screw assembly
FR1.3.3 = to provide power transfer support	DP1.3.3 = linear guide
FR1.4 = to hold workpiece vertically	DP1.4 = workpiece bed module
FR1.4.1 = to affix workpiece	DP1.4.1 = clamping system
FR1.5 = to hold workpiece horizontally	DP1.5 = positioning module
FR1.5.1 = to hold workpiece in x and y direction	DP1.5.1 = fixture module
FR2 = to control machining	DP2= control panel module
FR2.1 = to input machining program	DP2.1 = input module
FR2.1.1 = to manually input machining program	DP2.1.1 = keyboard module
FR2.1.2 = to upload input machining program	DP2.1.2 = wireless module
FR2.1.3 = to store machining program	DP2.1.3 = memory card module
FR2.2 = to communicate to user	DP2.2 = visual display
FR2.3 = to control the system	DP2.3 = machine control unit
FR2.3.1 = to manually control the system	DP2.3.1 = button actuator unit

Once these physical components are identified, they become the deliverables in a project plan. Each one of them will have to be designed, manufactured and tested. The benefit of this approach is the early detection of dependencies that if discovered at a later time will be costly to remedy. First level of a WBS is shown in (table no.2) and selective tasks are shown in (table no 3).

Table no. 2 Work breakdown decomposition

WBS 1st level	**WBS 2nd level**	**WBS 3rd level**
1 = machine tool assembly 2= control panel module	1.1 = laser source 1.2 = laser head 1.3 = laser head driving system 1.4 = workpiece bed module 1.5 = positioning module 2.1 = input module 2.2 = visual display 2.3 = machine control unit	1.1.1 = diode laser 1.1.2 = resonant cavity 1.2.1 = focusing lenses 1.2.2 = cooling system 1.2.3 = tracking system 1.2.4 = assisting gas system 1.3.1 = servo motor unit 1.3.2 = ball screw assembly 1.3.3 = linear guide 1.4.1 = clamping system 1.5.1 = fixture module 2.1.1 = keyboard module 2.1.2 = wireless module 2.1.3 = memory card module 2.3.1 = button actuator unit

For the development of a prototype each design parameter will be undergoing design, manufacture, testing, and integration phases.

Table no. 3 Project plan decomposition

Tasks	**Planed activities**
1.1.1 = diode laser Design Manufacture Test Integration 1.1.2 = resonant cavity Design Manufacture Test Integration 1.2.1 = focusing lenses Design Manufacture Test Integration 1.2.2 = cooling system Design Manufacture Test Integration 1.2.3 = tracking system Design Manufacture Test Integration	Design 1.1.1 = diode laser 1.1.2 = resonant cavity 1.2.1 = focusing lenses 1.2.2 = cooling system 1.2.3 = tracking system 1.2.4 = assisting gas system 1.3.1 = servo motor unit 1.3.2 = ball screw assembly 1.3.3 = linear guide 1.4.1 = clamping system 1.5.1 = fixture module 2.1.1 = keyboard module 2.1.2 = wireless module 2.1.3 = memory card module 2.3.1 = button actuator unit Manufacture 1.1.1 = diode laser 1.1.2 = resonant cavity 1.2.1 = focusing lenses … 2.3.1 = button actuator unit Test 1.1.1 = diode laser … Integration 1.1 = laser source …

In this application, all DPs are treated as tasks for scheduling purposes. Any dependencies are identified early in the process. Tasks can be clustered according to skills and phase. A Gantt chart will be generated in which for each task a resource is assigned after which a resource levelling is applied so that no resource is used more than 100%. Time and estimates are defined. Sequencing is affected by resource availability and task priority.

After prototype testing, FRs and DPs are to be reviewed considering what has been discovered before final production.

6. Conclusions

This paper discussed various aspects of utilizing Axiomatic Design in creating a project plan. By decomposing customer needs into first, second, and so on order functional requirements and design parameters, project deliverables are identified which form the foundation of the work breakdown and project schedule.

The Axiomatic Design theory allows for the design of an improved product design as well as project management process by early identifying the functional dependencies according to the theory's axioms 1 and 2 which leads to better resource management.

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