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CONSIDERATIONS ABOUT COST ESTIMATES IN PRODUCT DESIGN OF A CUTTING TOOL

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Abstract: *In the project management of new product development, the cost estimates of a project are directly influenced by the scope of the project. In product development, the scope of a project is the finished product. Unless the new product is a combination of existing sub-components for which the costs are known, a decomposition of an unknown product is necessary in order to form the estimates. A quick and easy method for cost estimation will be investigated involving the use of Axiomatic Design method applied to a custom design milling machine. The results confirm the utility of the method in cost estimation of a new product.*

Keywords: *project management, cost estimates, axiomatic design, product design, cutting tool.*

1. INTRODUCTION

In the development of a new product, a set of activities are performed in order to achieve a unique result, within a set time frame.

According to the Project Management Institute (PMI) [1], these activities are defined as a project. PMI also defines a project lifecycle as to include phases such as initiation, planning, execution, monitoring, and closure phases. These phases include various processes which form a project plan in order to achieve the project goals.

Many authors [2, 3, 4, 5] consider that a successful project meets the customer approval within the expected deadline, budget, and quality. Therefore, success is achieved when all tasks are identified, resources are costed and assigned, activities are sequenced, all work is rigorously monitored and objectives are achieved within the agreed budget. It is the responsibility of a project manager to ensure the successful management of all project resources in order to achieve its goals.

The cost estimation is a procedure which examines a specific scope of work and forecasts the cost of work to be completed [6].

In any project cost estimation is very important because regardless of know-how,

financial strength, or management's competence inaccurate cost estimation will lead to a loss [7].

The topic of cost estimation has been previously studied and several methods have been developed for a specific application, such as software or construction projects, or for a more general approach, such as work breakdown structure (WBS). Some of them are manually applied while others have their own software.

According to [8] in software development there are parametric models, such as SLIM, COCOMO, SEER-SEM, Checkpoint, ESTIMACS, PRICE-S, and COSYSMO. There are also Expertise based models such as Delphi technique, Work Breakdown Structure (WBS), Rule-based Systems, Top-Down, and Bottom-Up. There are also Evolutionary computing models such as Case-based Reasoning, Neural Networks, Genetic Algorithms, and Genetic Programming. In the Regression-based techniques class are included "Standard" regression and "Robust" regression, while in Size-based estimation techniques are included Function Points and Use Case Points. Other techniques include System dynamics approach, Fuzzy Systems, Bayesian approach, Price-to-win, and Proxy-Based Estimating.

Axiomatic Design is a method that improves upon existing methods, such as WBS, and it can be used in all applications that are suitable to

WBS. A literature review reveals that [9] considered AD for analyzing cost changes. In that study, the focus is on presenting the framework and less on applying it to a case study. Therefore, it is beneficial to study the application of AD to cost estimation of a product.

2. PROJECT MANAGEMENT

In project management, cost estimates are performed after tasks and resources are identified. Planning of activities and their resources could follow either a traditional, agile or hybrid framework, each being associated with several methodologies that facilitate project management [10].

Traditionally, work definition and planning are completed before beginning the execution. Some popular methodologies using the traditional include Waterfall, Critical Path Method (CPM), PMBOK (Project Management Body of Knowledge), V-model (German government), and PRINCE2 (Projects IN Controlled Environments) [11].

The Agile methodologies adapt to frequent changes by planning the work for one iteration at a time, such as SCRUM or Kanban [12]. A combination of both traditional and agile approaches are called Hybrid methodologies. This approach focuses on planning the work for one iteration until the next iteration begins.

Some popular project management tools, such as Microsoft Project or Primavera software, are used for task scheduling, resource management, collaboration, cost tracking and document management [13, 14, 15]. The schedule is presented as a Gantt chart, which includes deliverables, schedule and resources [16]. The chart follows the development of a WBS which partitions projects into stages, deliverables, and work packages [17]. A typical WBS determines the main deliverables for the project and their smaller chunks of work [18].

3. AXIOMATIC DESIGN

Axiomatic Design (AD) theory was introduced by N.P. Suh [19], in order to streamline the product design process. A combination of customer, functional, physical,

and process domains that address the customer needs, product functional requirements, product design parameters and process variables, respectively. In an ideal design, for each functional requirement there is one or more corresponding design parameters, and for each design parameter there is only one corresponding process variable. This mapping of one domain's requirements to the parameters within the adjacent domain is done until it reaches the smallest unit.

The mapping of information is presented as a matrix. The concept design matrix is the result of mapping of customer and functional domains, while the product design matrix, eq.1, is the result of mapping the functional and physical domains, and the process design matrix, eq. 2, is the result of mapping of physical and process domains.

The equation 1 and 2 are shown below:

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

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

Where:

$\{FR\}$ is the vector of functional requirements.

$\{DP\}$ is the vector of the design parameters.

$\{PV\}$ is the vector of the process variables.

$[A]$ is the design matrix.

$[B]$ is the process matrix.

The AD theory stresses that the ideal design is achieved when functional requirements are independent, also known as Axiom 1, or the independence axiom. It also requires the design to minimize the information content, known as Axiom 2, or the information axiom. When functional requirements are independent, the design is called uncoupled, but when there are less DPs than FRs, the design is called coupled, while when there are more DPs and FRs, it is called redundant, [20]. The design will be adjusted until for each function there is only one physical module.

In the context of project management, the design parameters, which form the physical domain, become the project deliverables. Once the deliverables are identified, cost estimates can be developed. This will turn budgeting into a quick activity in the development of a new 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 mills cutters while performing the work fast, precise, and consistently, the cost estimates are found after deliverables are identified.

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 = remove material
DP1 = machine tool assembly

FR2 = control machining
DP2 = control panel module

These functions can be decomposed further so that the machine 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 = move cutting tool
DP1.1 = tool driving system

FR1.2 = move workpiece
DP1.2 = workpiece driving system

FR1.3 = hold workpiece vertically
DP1.3 = workpiece bed module

FR1.4 = hold workpiece horizontally
DP1.4 = tailstock module

FR1.5 = check results
DP1.5 = feedback system

FR2.1 = input machining program
DP2.1 = input module
FR2.2 = communicate to user
DP2.2 = visual display

FR2.3 = control the system
DP2.3 = machine control unit

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

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

FR1.1.1 = provide power system
DP1.1.1 = servo motor unit

FR1.1.2 = provide power transfer
DP1.1.2 = ball screw assembly

FR1.1.3 = provide power transfer support
DP1.1.3 = linear guide

These modules are again evaluated for further decomposition, if none exists.

The moving of a workpiece can be achieved by different systems.

FR1.2.1 = provide for workpiece movement
DP1.2.1 = main drive system

FR1.2.2 = provide for transfer movement
DP1.2.2 = bearing system

FR1.2.3 = provide for controlled movement
DP1.2.3 = gearing system

In regard to holding the workpiece either in the horizontal or vertical way, further decomposition is necessary.

FR1.3.1 = hold workpiece in x and y direction
DP1.3.1 = workpiece jig module

FR1.4.1 = hold workpiece in x and y direction
DP1.4.1 = quill module

FR1.4.2 = replace workpiece
DP1.4.2 = release module

The control of machining is done by converting data into actions.

FR2.1.1 = manually input machining program
DP2.1.1 = keyboard module

FR2.1.2 = upload input machining program
DP2.1.2 = wireless module

FR2.1.3 = store machining program

DP2.1.3 = memory card module

FR2.3.1 = manually control the system

DP2.3.1 = button actuator unit

The decomposition aims to find a structure that satisfy the requirements of Axiom 1 and 2 by which the functional requirements must be independent and sufficient. Arranging this information into a matrix format, it should result into an uncoupled design matrix. An example is shown in Table 1.

Table 1.

3rd level product design matrix.

Functional Requirements 3 rd level	Design Parameters of 3 rd level		
	DP1.1.1	DP1.1.2	DP1.1.3
FR1.1.1	X		
FR1.1.2		X	
FR1.1.3			X

Once the decomposition is completed, the design parameters become project deliverables. Each deliverable will undergo a series of processes such as design, fabrication and test. These processes can be financially estimated by aggregating the labor time, labor rate, and acquisition price. A simplified presentation of functional to design decomposition is shown in Table 2.

Table 2

Cost structure.

Functional requirements	Design parameters	Cost estimated [1000\$]
FR1 = remove material	DP1 = machine tool assembly	146
FR1.1 = move cutting tool	DP1.1 = tool driving system	74
FR1.1.1 = provide power system	DP1.1.1 = servo motor unit	27
FR1.1.2 = provide power transfer	DP1.1.2 = ball screw assembly	32
FR1.1.3 = provide power transfer support	DP1.1.3 = linear guide	15
FR1.2 = move workpiece	DP1.2 = workpiece	37

	driving system	
FR1.2.1 = provide for workpiece movement	DP1.2.1 = main drive system	12
FR1.2.2 = provide for transfer movement	DP1.2.2 = bearing system	20
FR1.2.3 = provide for controlled movement	DP1.2.3 = gearing system	5
FR1.3 = hold workpiece vertically	DP1.3 = workpiece bed module	17
FR1.3.1 = hold workpiece in x and y direction	DP1.3.1 = workpiece jig module	17
FR1.4 = hold workpiece horizontally	DP1.4 = tailstock module	5
FR1.4.1 = hold workpiece in x and y direction	DP1.4.1 = quill module	4
FR1.4.2 = replace workpiece	DP1.4.2 = release module	1
FR1.5 = check results	DP1.5 = feedback system	13
FR2 = control machining	DP2 = control panel module	1
FR2.1 = input machining program	DP2.1 = input module	0.4
FR2.1.1 = manually input machining program	DP2.1.1 = keyboard module	0.1
FR2.1.2 = upload input machining program	DP2.1.2 = wireless module	0.2
FR2.1.3 = store machining program	DP2.1.3 = memory card module	0.1
FR2.2 = communicate to user	DP2.2 = visual display	0.5
FR2.3 = control the system	DP2.3 = machine control unit	0.1
FR2.3.1 = manually control the system	DP2.3.1 = button actuator unit	0.1

Table 2 depicts the main components of the system typically provided by the technical subject matter expert to which the project manager building the plans adds financial data to form the project budget baseline. The values

used in this case are similar to those used in past situations.

The decomposition must reflect the elementary components of the system such as they are to be manufactured and tested for approval. These components can be new, old but modified, or just old and reusable. A typical process for developing these components include design, manufacture, and testing in order to prove the achievement of individual component requirements. Testing is being performed on all subassemblies as well as the main assembly in order to demonstrate, the fulfillment of the customer requirements based on which the project is undertaken.

The detailed decomposition of the system through AD results in the identification of project deliverable for which a financial estimate is needed in order to define project budget. The benefits of this approach include the early detection of functional inconsistencies that if discovered at a later time will be costly to remedy.

5. DISCUSSIONS

Through the application of AD, project tasks and deliverables can be quickly identified in order to define project's schedule and budget. Once tasks are identified they can be clustered according to skills and phase. For each task, a resource is assigned so that no resource is used more than 100%. Task sequencing is directly affected by task priority and resource availability. Each task and resource can then be evaluated in terms of financial value.

After testing is complete, FRs and DPs are to be reviewed in light of what it has been discovered. If some components are to be redesigned, manufactured and tested, the budget can easily be adjusted to reflect these changes.

The limitations of this study include a limited description of a case study, but it is nevertheless able to provide valid solutions. A possible future extension will consist of the other processes of project management.

6. CONCLUSION

This paper discusses the various aspects of utilizing Axiomatic Design in creating a project

budget by decomposing functional requirements of a product into physical sub-assemblies also known as design parameters.

The method was applied to a complex custom design milling machine. The complexity of the product was easily handled through decomposition of the design. The decomposition of customer needs into functional requirements and design parameters, generates the product structure. The best designs are generated when for each functional requirement there is only one design parameter. Early identification of functional dependencies leads to better design structure and cost estimation.

The method provides rapid and traceable results that are easy to adapt to changing requirements. Therefore, it can be applied to many simple or complex designs in various field of industry.

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Considerații privind costurile estimative în proiectarea unei scule tăietoare

În managementul de proiect al dezvoltării de noi produse, estimările de cost ale unui proiect sunt direct influențate de domeniul de aplicare al proiectului. În dezvoltarea unui produs, scopul unui proiect este produsul finit. Cu excepția cazului în care noul produs este o combinație de subcomponente existente pentru care costurile sunt cunoscute, este necesară o descompunere a unui produs necunoscut pentru a forma estimările. Va fi investigată posibilitatea estimării costului, cu ajutorul unei metode relativ simple ce implică utilizarea metodei Axiomatic Design, aplicată pentru o mașină de frezat cu design personalizat. Rezultatele confirmă utilitatea metodei în estimarea costurilor unui produs nou.

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