Combined Life-Cycle Including Carbon Footprint for Composite Materials

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Abstract
Cost estimation for a composite material part requires cost driver information from various activities just like any other material part. Every process involved to convert the product from raw material to finished state requires the consumption of certain cost value. The activities that are responsible for these cost changes are termed as cost drivers. Process cycle or life-cycle is a way to represent the processes necessary in a products complete journey. It is important to map different phases in a processes and include them in the life-cycle for proper analysis and management. The present work reviews the importance of different phases in a processes and quantifies the contribution of various processes in the composite material part overall cost. This contribution is represented in a tabular form and then compared to conventional method of life-cycle. The importance of including carbon footprint in the life-cycle is also reviewed and finally a generic process/ project life-cycle for composite material part is defined. This contain processes that are contributing the most to the overall cost of the product and form a basis for process/project analysis, optimization and management.

Keywords
Carbon Footprint, Cost Drivers, Cost Estimation Procedures, Life-Cycle, Process Optimisation and Project Management.

Nomenclature:
ABC: Activity-Based Costing
AFC: Aramid Fiber Composite
CBS: Cost Breakdown Structure
CER: Cost Estimation Relationship
CFRP: Carbon Fiber Reinforced Polymer
CMC: Ceramic Matrix Composite
FRP: Fiber Reinforced Polymer
GFRP: Glass-Fiber Reinforced Polymer
LCCA: Life-Cycle Cost Analysis
MMC: Metal Matrix Composite
PBS: Product Breakdown Structure
RBS: Resource Breakdown Structure
WBS: Work breakdown Structure

I. Introduction

With the advancement in design and requirement of more and more environment friendly machines, advanced materials became the choice for manufacturing of structural as well as non-structural parts. Light weight and higher strength with superior mechanical properties made composite materials a unanimous choice. To make proper use of these materials and to plan the project activities, designers, engineers and project planners needed to make cost estimates related to these materials in advance and with certain degree of acceptability. Developing a perfect CER is challenging keeping in view the complexity involved in the composite material itself and the wide range of manufacturing choices available. Not only this but as every product has to go through a life-cycle, and based upon that, elements contributing to cost are to be mapped, establishing a relationship becomes difficult without actually knowing their importance in the overall life-cycle. These elements also termed as cost drivers need to be properly mapped so as to have a considerable amount of accuracy in the overall estimate of the cost. Process analysis is a capability everyone is looking for, and to achieve that, proper and accurate cost estimates of each and every process parameter is necessary. If these processes and the activities are correctly included in the life-cycle a real time model mapping the activities could be used for the process analysis or in other words process optimization.

This work reviews the importance of cost driver analysis followed by cost estimation procedures and later present the requirement to map phases in a processes for a life-cycle analysis. This is done by analyzing a process flow of a product journey from raw material to the finished product and then calculate the contribution of each phase in a process in relation to the overall cost. This contribution is then represented in a tabular form and compared to the conventional method of life-cycle designing. Another review conducted is in the importance of including carbon footprint as a cost driver early in the life-cycle definition itself, so as to have a proper analysis both financially and environmentally. Finally based on the comparison and a pie distribution, generic project/ process life-cycle for composite material part is defined. Thus by doing this study a proper, elaborate and well defined life-cycle is developed including carbon footprint forming a basis for WBS, CBS and project/process management.

II. Importance of Cost Driver Analysis

Every product has to undergo a life-cycle and thus consume resources while travelling from a raw material to a finished product. Any activity which drives a change in the cost is termed as cost driver. Cost driver selection depends upon a lot of principles. Consumption View, Allocation Base, Activity Base and Traditional approach of Causality being some of the selection methods for cost drivers. The main criteria for the selection depends upon, (i) ease of identification, (ii) existence of relationship, (iii) positive or negative value change, (iv) degree of accuracy and (v) degree of usefulness [1]. A theoretical analysis for choosing cost drivers in ABC in a Chinese well company showed that contributors to cost can be other activities which are otherwise considered unimportant. Data from the company was analyzed against all the processes in operation of the oil well and a number of mathematical analysis were done to find out the cost value for each activity. It was shown that the major cost drivers for ABC would be, (i) number of wells, (ii) distance of wells, (iii) weight, (iv) depth and (v) ton-kilometers. Thus were included as cost drivers in the overall cost analysis of the plant [2]. A study was conducted for the analysis of parameters to be included as cost drivers for the manufacturing overhead. In this study inter-relationships of different levels of cost drivers in manufacturing of automobile were analyzed. Data was collected from 74 companies and an empirical study was conducted on that data. Both volume related and complexity related variables were considered. The study showed that manufacturing overhead was twice of direct labor. Volume and activity form a positive share in the overhead cost [3]. To have a proper cost estimate it is important to know the activities that influence cost. An experimental design study has been conducted to show time as a cost driver. In this experiment a subset of 20 tasks is assigned to participants and time for each and every activity is measured. To keep the coherence of the tasks they are simply aggregated in a group of three major tasks. The results showed that errors related to aggregation and measurement in the overall cost estimate could be reduced if time is taken as a cost driver [4]. Cost estimation methods and approaches are complex and like the tools required for costing, proper knowledge of the cost parameters or cost drivers play a very important role. System requirements, functional hierarchy and physical hierarchy plays an important role in cost parameter information. Knowledge of parameters and proper distribution in a life-cycle is necessary for managing complex situations [5]. Thus it can be concluded that for attaining a proper cost estimate, cost driver analysis is necessary and important so that the cost drivers which contribute the most are not left from inclusion in the overall cost analysis.

III. Cost Estimation Procedures

A very important inference from the above study made is the real knowledge of the cost estimation procedures. After a well-established fact that cost driver analysis is important and for that, proper life-cycle needs to be established, learning of cost standards or practices should be made to understand the importance of life-cycle. For developing a cost model or a cost estimate, scope and schedule development is the first step. This is carried out with the help of a WBS which gives a complete decomposition of the process or a project. The purpose of a cost model is to establish a process plan quantitatively well in advance with calculative risk factors for which life-cycle processes needs to be well established. This can be well understood from fig. 1.

Fig. 1: Cost Estimation Knowledge Flow

The two major types of procedures like, (i) performance based and (ii) project based, could be used for development of cost estimation [6]. For any type of estimate, proper knowledge of the process cycle needs to be maintained. Aerospace is one of the most complex places of project as well as process planning. A procedure adopted for costing by NASA reveals the same steps of WBS, but now in the aerospace realm. Here the cost estimation is done for both the agency and the stakeholders. Before even starting to develop a cost estimation plan a project life-cycle is defined with identified points for cost estimation. The cost estimation starts with inputs from the customer, WBS and technical descriptions, followed by development of cost methodology and finally cost estimation and assessment. Project management is achieved by integration of both WBS and CBS in the life-cycle [7]. Cost estimation procedure followed in another tough situation is in the 'LCLS' project management. Here cost estimate is conducted for the intention of Execution Plan, Process Plan and Value Management. For the detailed cost estimate RBS is used. Here the resources associated with the process/project life-cycle is calculated and aggregated for achieving an overall estimate. Design, management and judgement factors are all considered as cost drivers and thus included in the life-cycle [8]. Even for cost estimation for transport projects, proper management of knowledge related to the process breakdown and the associated tasks needs to be carried out. After having a baseline estimate of the tasks a risk assessment is conducted and then applied to the process life-cycle. Historical data, market conditions and project information form the basis for cost estimation. It has been observed here that for true estimation, proper planning, scoping and designing needs to be done, only possible with proper life-cycle breakdown and analysis [9]. Even in the realm of software project planning and cost estimation, the basic structure remains the same. Project size, duration and effort are quantified. Proper process knowledge and WBS are the techniques used to make a cost estimate plan [10]. From this discussion it is clear that life-cycle processes plays an important role in cost estimation and thus need to be properly defined for a clear and precise estimate.

IV. Carbon Footprint

Measure of Greenhouse gases emitted by an activity, process or a product is termed as carbon footprint. Earlier it was considered to be a direct effect but now both direct and indirect influence are taken as carbon footprint. Global warming was the trigger for studying the effects of any activity on the environment. With the increase in environmental awareness and taxes introduced by various governments, carbon emissions have become a major cost contributor and a factor to be considered by the designers [11]. A report on the emission of carbon and thus the foot-printing associated with the activities in the industry suggests, that the energy utilized and wasted in an organization is quite high and also distributed among various sections. Production of materials, distribution, consumption and recycling are the major contributors of these emissions and thus add up into the cost of a product indirectly [12]. As the need for analysis of carbon footprint became important in manufacturing as well, composite manufacturing was also analyzed. Life-cycle analysis technique was used to access environmental aspects associated with a project or a process. In this study four stages were taken into account in a FRP using pultrusion method. Energy use over the entire life-cycle was calculated and it was found that lighter materials are more favorable for saving life-cycle energy. A drawback was that as the study used only four processes and also one manufacturing technique, it was not comprehensive and also could not be quantified [13]. With the use of advanced materials in more and more applications, its viability both economically and environmentally are in question. A detailed analysis is done on different applications and the green effect composites have on the overall use. It has been found that after-sales use of composites in most of the applications is greener than conventional materials because of their light weight and increased overall efficiency. Another ironical discovery is that manufacturing, processing and maintenance are contributing more to the greenhouse gases and thus inefficient [14]. It has been observed that composite recycling is economically and environmentally viable than using a new manufactured composite raw material. Specifically thermosetting composites and the glass fiber as well as carbon fiber reinforcements are recyclable. 16% reduction in carbon footprint is observed when using recycled composite cementing technique [15]. From the study it is observed that different processes have different impacts in emissions and also contribute to cost significantly. If carbon footprint is quantified as a cost value with the life-cycle of a product a decent analysis of the process/project could be done. Thus including carbon footprint in the life-cycle is viable.

V. Analysis

For the use of composites in various fields it is necessary to understand the generic life-cycle that has to be followed. Not only this for having proper process and product management, understanding of the cost drivers become necessary for which proper life-cycle plays a very important role. A detailed analysis is conducted considering five different composite materials. Different phases in the overall process are analyzed based upon the overall cost contribution and comparison is made with the current processes. After the analysis, a generic life-cycle is defined for use in the process/project analysis for composite material parts.
Data sets for the different material parts along-with the proposed processes breakdown are shown in Table I. These data sets are derived from various composite reports by governmental organizations and NASA files. Another table averaging out values of the processes is shown in Table II. Table III on the other hand shows the PBS and CBS as per conventional Life-Cycle method. The processes which are not considered in the conventional method are given a value '0' in the related column. This table is compared to the table II and a rationale of defining a comprehensive life-cycle for composite material is arrived. The comparison is shown in fig. 2 as a combined graphical representation.

Table 1: Detailed Process Breakdown & Cost

Composite Materials	Life-Cycle Processes										
	Decision	Procurement	Manufacturing	Design	Assembly	Testing	Inspection	Packing	Material Handling	Storage	Maintenance & Disposal
	% Overall Cost										
CFRP	7	11	44	8	12	3	2	2	1	1	9
GFRP	6	12	40	8	6	6	4	6	1	3	8
MMC	8	11	42	9	6	4	4	4	3	2	7
CMC	8	9	44	9	4	8	2	2	4	2	8
AFC	11	9	37	7	8	9	3	2	1	1	12

Table 2: Averaged Process Breakdown & Cost

Composite Materials	Life-Cycle Processes										
	Decision	Procurement	Manufacturing	Design	Assembly	Testing	Inspection	Packing	Material Handling	Storage	Maintenance & Disposal
	% Overall Cost										
	8	10	41	8.2	7.2	6	3	3.2	2	1.8	8.8

Table 3: Averaged CBS in Conventional Method

Materials	Life-Cycle Processes										
	Decision	Procurement	Manufacturing	Design	Assembly	Testing	Inspection	Packing	Material Handling	Storage	Maintenance & Disposal
	% Overall Cost										
	14	0	48	18	0	0	11	0	0	0	9

It can be seen from table 3 that only major processes are considered and rest all are coupled into those major processes. The value '0' does not mean that the related processes don't consume any cost, but, just indicate that they are not considered separately in the conventional method, but coupled into one of the major processes. This is clearly not a good way of analysis and strongly suggest a new process chart. The comparison is represented as a graph in fig. 2.

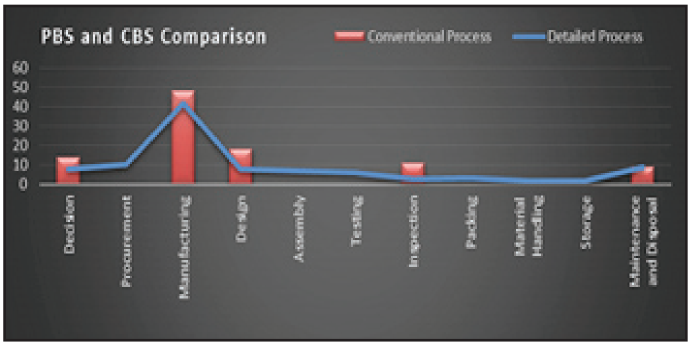

Fig. 2: Combined Analysis Representation

It can be seen clearly that for detailed analysis and process optimization, conventional method is not correct and concise. It is good for early and fast estimate but not for a detailed analysis like LCCA and process optimization. The aspect of time utilized in analysis for process optimization is based upon how the division of activities have been done. Once a detailed process life-cycle is outlined, the activities become noticeable and much easier to locate in the overall process, making them easy to analyse and less time consuming. Thus the application of this would also reduce the overall time for conducting optimization. Even activities like financial planning could be easily conducted with proper distribution/allocation of capital costs for different phases in the overall process/project activities.

VI. Combined Composite Life-Cycle

From the above study and analysis conducted, it can be well rationalized that a new life-cycle has to be developed for composite part cost estimation. Another aspect of the study involves the implementation of carbon footprint. From the study conducted and the data analysis derived from different research papers related to carbon footprint, a combined pie chart showing contribution of different phases of a life-cycle in the overall cost of a product is shown in fig. 3 [11-15]. Here phases like after sales and environmental clearance are also included which form a part of the product use and also contribute to the running cost of a product. This cost was not very important in the previous studies but as some companies have started leasing the products for use keeping the load of after sales on themselves, have made these costs important for a product study. Also new taxation policies on environmental emissions have led to inclusion of carbon footprint as a monetary burden in the cost analysis inside a company or an organization. Here both direct and indirect aspects of an activity contributing to energy use are mapped. The energy use is then distributed among the processes and multiplied with the energy prices per emission using an open source web based tool, named as "Carbon Calculator." This way quantification of the carbon footprint is done and thus included later in the overall life-cycle.

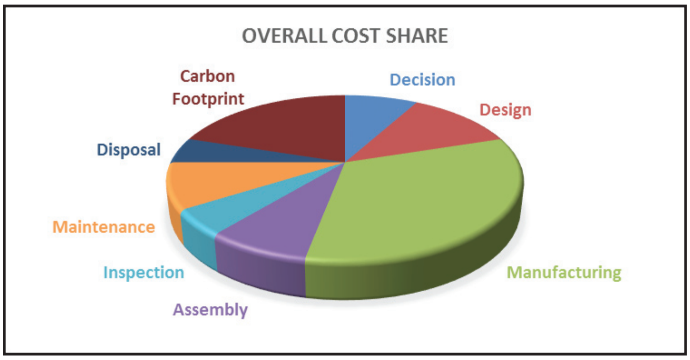

Fig. 3: Cost Share Pie Diagram

Based upon the pie chart it is seen that carbon footprint cannot be excluded from the life-cycle being a major contributor of the overall cost. The proposed life-cycle is shown in fig. 4.

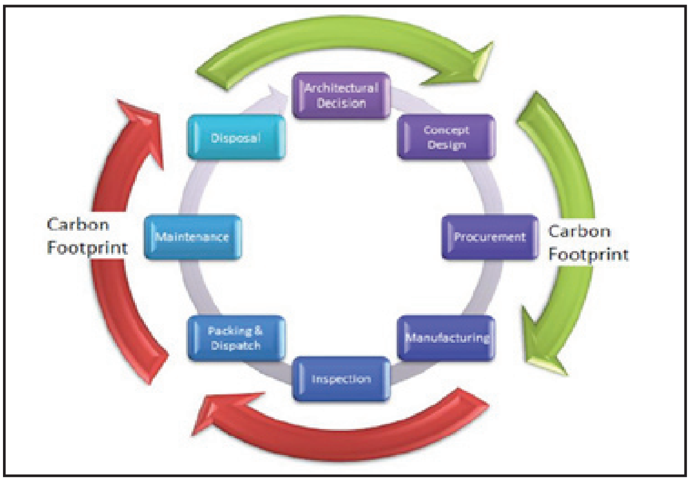

Fig. 4: Combined Life-Cycle for Composite

The Combined life-cycle is made by coupling those activities together which have minimal effect on cost and thus they become significant when coupled together. This way all the activities are covered but in a generic form. This can now be used for any analysis and form the basis of WBS which can provide a detailed CBS that can be used for both process and project management. Another important use of this is in the cost estimation which in other words form a part of process/project management. Process optimization and business structuring can also be carried out with the help of this chart and thus can be used as a basis for all composite material parts study. As this study has taken data for composites from open source material, the scope of modification still lies for application in conventional materials.

VII. Conclusion

Cost estimation is an important aspect of process and product management. To achieve a proper cost estimate it is important to understand the process activities in detail and their corresponding cost drivers. Conventional methods and life-cycle are not able to fully utilize the WBS because all the activities are not included in the life-cycle. Detailed analysis can only be carried out if all the activities contributing to the overall cost are included in the life-cycle of a product. In case of composites due to high level of complexity and vast mixture of manufacturing techniques involved, it is important to have a generic life-cycle where CBS can be implemented with a considerable amount of precision. Carbon footprint is an area which was not included in the overall cost, but being a considerable contributor especially in case of composites, need to be included in the LCCA.

This paper has presented a review of cost driver study, cost estimation procedures and carbon footprint and has thus presented a rationale of developing a detailed life-cycle for proper project/process management. Here data has been analyzed taking overall cost into consideration and both proposed and conventional method has been analyzed. This paper has thus defined a detailed life-cycle for composite material part with carbon footprint as an integral part throught the life-cycle. The application of this generic life-cycle can be made in knowledge management, costing and business planning/management. The drawback with this study is that it is concentrated more on composites due to data collection from composite material guide books and NASA files (available as open source material), but with inclusion of knowledge from other realms, it can be applied to wider fields other than composites. Another drawback is that as the data is an open source material, the possibility of it being not precise cannot be denied. Because the life-cycle defined is proposed taking the contribution of phases in the overall cost and not the actual value, the process distribution of this life-cycle does not get affected with any data discrepancies.

VIII. Acknowledgement

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