Systems Concurrent Engineering of a "Green" Car

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Abstract. In this paper we present the systems concurrent engineering approach to the development of complex products for the automotive industry having as a product a "green car". Traditional approaches focus on the product, the organizational development and product concepts of operation (CONOPS). This approach is the integration of the Systems Engineering and Concurrent Engineering approaches. Systems Engineering is a multidisciplinary and collaborative engineering approach for deriving, evolving and verifying a system solution, balanced throughout its life cycle, and that meets the expectations of stakeholders and public acceptance. Concurrent Engineering is an engineering approach that anticipates, to the initial stages of development, the product requirements from the life cycle processes such as manufacturing, assembly, testing, maintenance and logistics and disposal of the product. This paper presents the approach of Systems Concurrent Engineering. Systems concurrent engineering acknowledges that the system solution is comprised of product and organization elements. Each product life cycle concept is thought from the outset and using a top-down approach, from the product context at a given life cycle process scenario. The systems concurrent engineering approach includes in the scope of development effort, not only the development organization, but also the other life cycle processes that a given development organization performs. The approach is exemplified using the case of the development of a 'green car', a car that is environmentally friendly.

Keywords: systems concurrent engineering, systems engineering, concurrent engineering, complex product

1. Introduction

The aim of this paper is to present the systems concurrent engineering approach for the development of complex products. The approach is a way to develop a complex product more efficiently, reducing costs, shortening time and allowing a neat and easy view to anticipate what can happen throughout the product life cycle. The approach is illustrated with a hypothetical case: the development of a "Green Car".

The Green Car, a small ecological vehicle, can help to solve the problem of congestion in major cities. Less polluting than the average car, can reach speeds of 100 kilometers per hour and has a movable frame for safety and maneuverability. The idea is to unite the small size and efficiency of a motorcycle with the comfort and safety of a car, using compressed natural gas as fuel. It is cheaper to run, it is quieter and less polluting. It has lots of recyclable parts. There is already a prototype that is the result of 40 months of investigation by researchers in nine European countries [24].

In the automotive industry, a project of a new car represents an average workload of 1500 men-year, engineering work. To carry out these projects is much more difficult if the engineering approach fails to consider the system as a whole. The overall system that meets stakeholder expectations is made not only of product elements but also of organizational elements. Organizations implement the product life cycle processes. Before the introduction of Systems Engineering Techniques, the project of a new car model required the production of hundreds of car prototypes. The integration of various systems of the vehicle occurred in a time-consuming and expensive process of successive approximations made based on these prototypes.

The main objective of this work is to demonstrate through a hypothetical case "Green Car" that the systems concurrent engineering process (sub-processes stakeholder analysis, requirements analysis, functional analysis, implementation analysis) can be made simultaneously to the product and the organization and the relationships between product elements and organizational elements can be identified even at the stage of system architecture. There are other works [26,27,28,29,30,31] that complement this conceptualization and focus on the development organization requirements for engineering systems using a concurrent engineering approach. Some of those works show the importance of IPTs (Integrated Product Development Teams). This paper is concerned with the demonstration that the systems engineering processes can actually be performed, simultaneously, for product and organization, but does not enter in the realm of the organization necessary to implement it. For this purpose, please refer to those other works.

The paper is organized as following: Section 2 presents the traditional systems engineering and concurrent engineering approaches. Section 3 presents the systems concurrent engineering approach framework and method. Section 4 presents the models derived for the ‘green car’ using the approach. Section 5 discusses the advantages for improving the proposed approach. Section 6 concludes this work.

2. Traditional systems engineering approach

The products of the automotive industry are considered complex products, where the development of a new product can take from one to four years, which will change according to the approach used for implementation. This product, due to its multidisciplinary nature, requires attention throughout its life cycle.

Traditional approaches to systems engineering focus on the development of operational products based on the concept of the operation of the product. They also focus on the development organization that should be put in place to ensure that the product meets its operational requirements They do not take into consideration, from the outset, the product in context of its other life cycle processes [2, 3,6].

Along the product life cycle we design, develop, produce, use, support and dispose. All these life cycle processes can be done more efficiently if we consider their requirements on the product, from the outset of product development. Not anticipating these requirements leads to high costs of changes along the product life cycle. The later we perform changes along a product life, the more these changes will cost. Traditional Systems Engineering focuses on the development and implementation of a final product, deriving requirements to be imposed on the product life cycle processes [8].

These gaps found in the traditional approach of Systems Engineering are expected to be overcome by the systems concurrent engineering approach. Concurrent Engineering [19,20], conceptually, raises the importance of knowing, from the outset, the requirements from each stage of product life cycle and to be able to make a systemic treatment by balancing all such requirements. Concurrent Engineering has many supporting methods such as: QFD [10,13,14,18], for maximizing customer satisfaction; Taguchi [21], for maximizing product robustness; TRIZ [11], to innovate when facing requirements conflicts; Group Technology[22], for increasing production efficiency; Value Analysis [23], to balance part cost with part function value; FMEA [23], to mitigate product and process failure risks. Those methods however, together with other DFX methods tend to treat each life cycle process in isolation from one another, seeking each life cycle process productivity maximization. Also, concurrent engineering is, in practice, applied to parts design and not to systems composed of many integrated parts [5].

3. The systems concurrent engineering approach

The systems concurrent engineering approach applies concurrent engineering along the stakeholder analysis, requirements analysis, functional analysis and implementation (also called physical or architecture) analysis sub-processes of the systems engineering process. Those analysis sub-processes are applied not only to the operational scenarios but also, to the other product life cycle processes scenarios. This anticipates, to the early stages of the systems architecting, the requirements, functions and parts needed along the product life. Those analysis sub-processes are also applicable to the organizations performing those product life cycle processes. The analysis sub-processes can be performed, concurrently, for product and organization. The process is recursively applicable at each layer of the system breakdown structure.

Hitchins [4] states that complexity can be understood by what he calls complexity factors. They are variety, connectedness and disorder. Variety accounts for the number of different elements you have in a set. Regarding products, variety refers, for example, to the number of different parts a product may have, number of different functions it accomplishes, number of different requirements categories it is supposed to meet, number of different stakeholders it should satisfy. Connectedness refers to the relationships among elements. For example, how parts interact, how functions affect one another, how requirements conflict to each other, how value flow among stakeholders. Disorder refers to the level of tangling of those relationships. For example, is there a structure pattern for deploying stakeholder requirements through functional concept up to implementation architecture?

The system concurrent engineering approach is supported by a framework to address complexity in product development – the total view framework evolved from Loureiro [7], shown in Figure-1. The framework has three dimensions: the analysis dimension with the four analysis sub-processes (stakeholders, requirements, functional and implementation); the integration dimension with the product and organization elements to be integrated; the structure dimension with the system breakdown structure hierarchy. The analysis dimension addresses the variety complexity factor. The integration dimension addresses the connectedness complexity factor. The structure dimension addresses the disorder factor. According to Alexander [1] all structures evolve into a hierarchy.

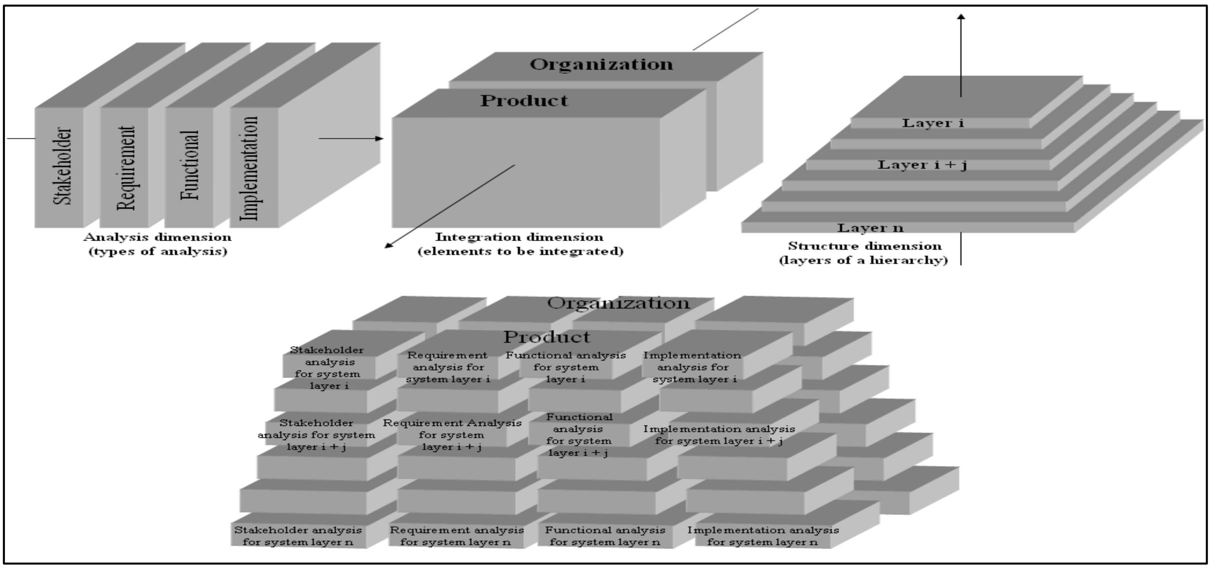

Figure 1. A framework to address complexity in complex product development – the total view framework

The systems concurrent engineering approach must be applied at each layer of the system breakdown structure. Figure-2 shows the method called concurrent structured analysis method evolved from Loureiro [7] that is used in the approach.

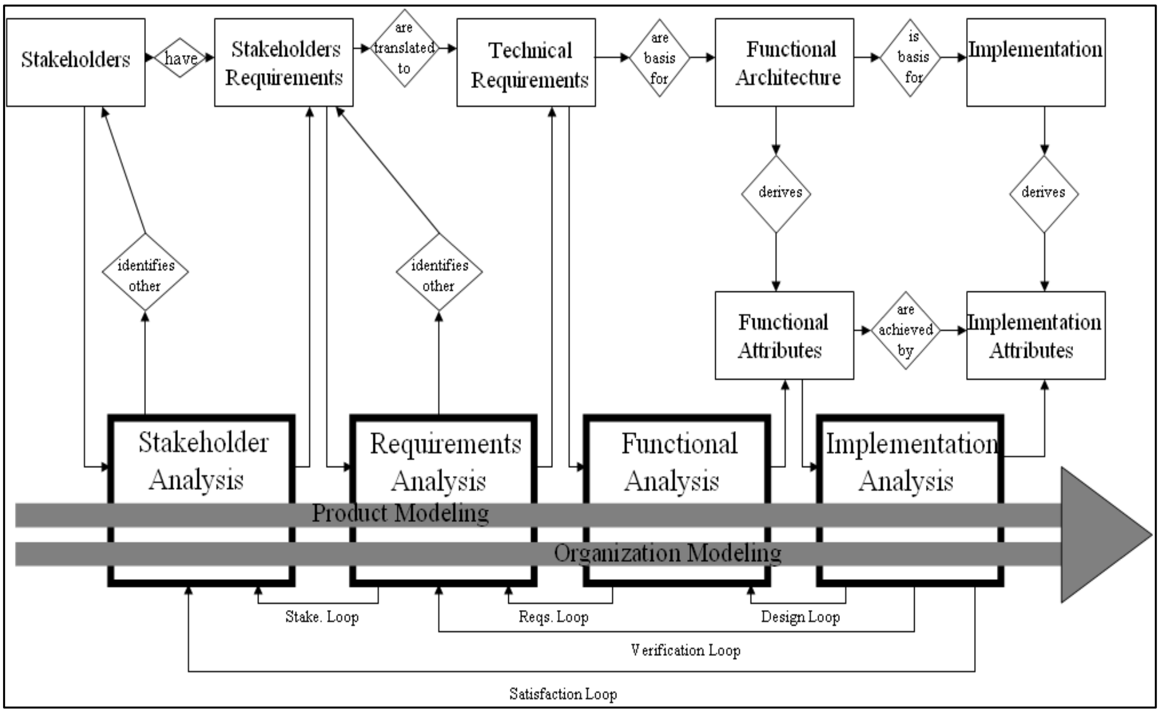

Figure 2. A method within the total view framework – the concurrent structured analysis method

Figure 3 presents the steps by which the analysis sub-processes are performed concurrently for product and organization.

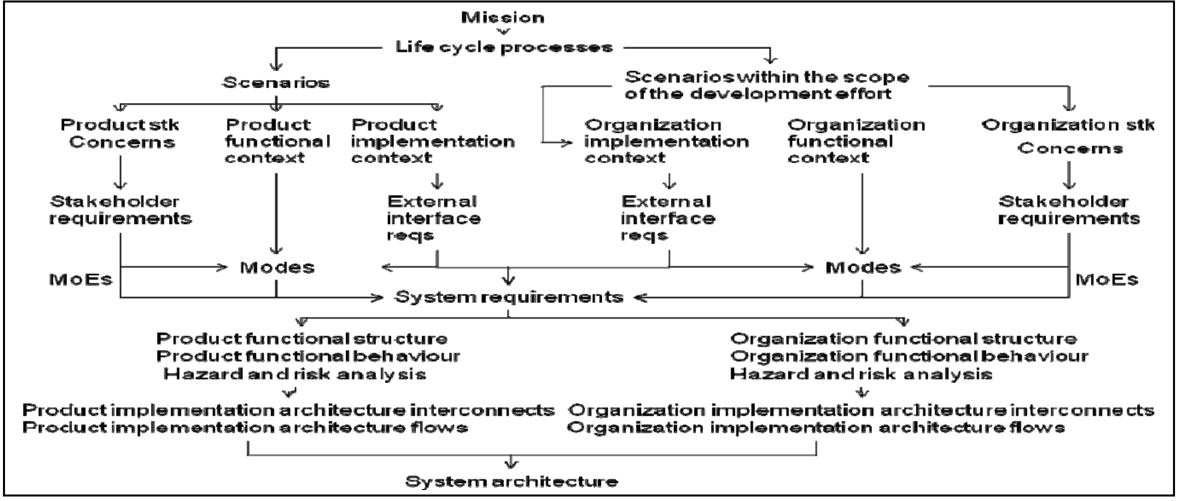

Figure 3. The system concurrent engineering method in detail (Source: Loureiro, 2010 [9])

4 The "green car" system concurrent engineering

This section illustrates the steps presented in Figure- 3 highlighting where the proposed approach is different from traditional approaches. The proposed approach is stakeholder driven, whereas traditional approaches are customer or user driven. We can see that analysis is performed for each life cycle process scenario, simultaneously, for product and organization. Traditional approaches focus on product operation and development organization.

4.1 Analysis of Stakeholders and their requirements

The whole product life cycle contains the following stages: development, manufacturing & assembly, test & calibration, distribution, sales, use & service and disposal, in which there are a number of stakeholders directly or indirectly related to each stage, which have their own needs and requirements. Once the nature of the stakeholder interaction is clearly defined for the different project phases, then could use the concepts of IPT design process by defining where an IPT approach needs to be applied during each phase. A single IPT may oversee an entire project over its entire lifecycle, or IPTs may be formed and deployed at any stage of the project lifecycle, from the initial project definition phase through the operational phase or any point in between. Nor is an IPT necessarily needed at all points in the project lifecycle. Different IPTs may be needed at different phases and may even work in parallel at different points [25]. As already indicated in the framework, the whole study will be done taking into account the product and the organization simultaneously

4.1.1 Analysis of Life Cycle Scenarios

The scenarios of the life cycle are those states the product may assume during its life cycle. For the sake of exemplifying the approach, this study will only consider those scenarios shown in Table-1.

Table-1: Examples of life cycle scenarios

Organization	**Development**	Conception	Advanced Design	Components Design	Tests and adjustment	*Ramp-up* Production
	Sales	Logistic Planning	Deliveries	-	-	-
Product	**Operation (Use)**	*Start* Hold	Low speed	High speed	Collision	-
	Disposal	Disassemble	Specialist analysis	Conditioning	Repair	-

4.1.2 Scope of Development Effort

The scope of the development effort includes: 1) the product in all of its life cycle process scenarios, 2) the development organization, and 3) other life cycle processes also performed by the organization that develops the product. For example, the organization that develops our green car, also performs the sale process. For the sake of exemplification, only the life cycle process scenarios presented in Table-2 will be object of further analysis.

Table -2 Development of the Scope Effort

Organization	**Development**	Conception
	Sales	Deliveries
Product	**Operation (Use)**	High Speed
	Disassemble	Disassemble

4.1.3 Identification of Stakeholders and their Interests

Table-3 presents the stakeholders identified and their interests.

Table -3 Stakeholders and their Interests

	PRODUCT	
Chosen Processes	**OPERATION**	**DISPOSAL**
Scenario	**High Speed**	**Disassemble**
STAKEHOLDERS and their INTERESTS	Driver – Ease of steering	Owner - Reduced Price
	Passengers - Noise	Government - Vehicles Recycling Politics
	Other Vehicles - Signals	Recycling plant - Ease of disassembly
	Legislators (supervision) - Identification	Community - Traffic Safety
	Population - Polluting Level	

	ORGANIZATION	
Chosen Processes	**DEVELOPMENT**	**SALES**
Scenario	**Conception**	**Deliveries**
STAKEHOLDERS and their INTERESTS	Environmental Protection Agency - Do not harm the environment	Vendors - Sales Effort and greater number of cars sold
	Customers - Satisfaction with the product	Distributors - Agility to deliver/Deadlines
	Suppliers - Fidelity	Competitors – Competitiveness
	Safety Regulators - Reduce accidents	Manufacturer - Orders
	Academy - New researches	Consumer - Contract Compliance
	Scrappers – Retreat units in poor condition	Shareholders - Investment
	Distributors - Product Quality	
	Competitors - Knowledge of technology	
	Standards organisms - Comply with standards	
	Department of Transportation - Cost Reduction	

4.1.4 Identify Stakeholders Requirements

Table 4 exemplifies the derivation of stakeholder requirements from stakeholder interests. Stakeholder interests derive MOEs (measure of effectiveness) and their corresponding requirements, as shown in Table 4.

Table -4 Stakeholders, Interests, MOEs and Requirements

STAKEHOLDER	**INTERESTS**	**MOE's**	**REQUIREMENT**
Suppliers	Fidelity	Orders made/ Requests per month	Purchase of car components in accordance with the specifications and quality defined.
Vendors	Sales Effort - Increased number of cars sold	Monthly Sales Shares	The monthly production of the product must ensure the commitments made to customers.
Driver	Ease of Steering	Shorter response time to answer the driver commands	The response time to commands made by the driver must be at the forefront of the standards of the industry.
Recycling Plant	Ease of disassembly	Man-hour taken to disassemble the car	The Green-Car design features will provide a simple process of disassembly.

Table-5 shows the analysis of requirements from Table 4.

Table -5 Detailed Requirements

ID	Requirement	Type	Application	PPO	Restriction	Verification
Conception	Purchase car components in accordance with the specifications and level of quality defined.	C	M	O	No	T
Deliveries	Monthly production of cars will ensure the delivery of 100% of the commitments done.	D	M	O	No	I
High Speed	The vehicle must have an acceleration system to speed up the speed of 100km/h in 5.9 (+ / - 1) seconds.	D	M	Pd	No	T
Disassemble	Staff should be trained to disassemble, to identify and to segregate the parts at the appointed time.	D	M	Pd	No	I

Type: Condition (C), Function (F), Performance (P), Interface (I). **Application**: Mandatory (M), Desirable (D), Optional (O).

PPO: Product (Pd), Process (Pr), Organization(O) **Verification:** Test (T), Inspection (I), Demonstration (D), Analysis (A)

4.2 Functional Analysis

The goal of functional analysis is to analyze the functional structure and the functional behavior of the system. Functional structure contains the system functions and the flows of material, energy and information between functions. Functional behavior refers to the logical, causal and temporal aspects that triggers, start, continue or stop system functioning. Functional analysis starts by establishing the functional context of the system. The functional context defines the boundaries of the system, the elements in the environment of the system and external functional interfaces, that is, the exchanges of energy, information and material between the system and its environment. From the functional context, functional structure and behavior are derived. The difference from traditional approaches is that, in the systems concurrent engineering approach, the functional context is identified for the product in each of its life cycle process scenarios not only operations. Also, the functional context is analyzed for the life cycle process organizations within the scope of development effort.

4.2.1 Functional Context of the Product

Figures 4 and 5 show the functional context of the product in two of its life cycle process scenarios (in practice, it must be done for every life cycle process scenario), for the sake of the approach's exemplification. Figures 4 and 5 show the exchanges of energy, material and information between the product in a given life cycle process scenario and its corresponding environment.

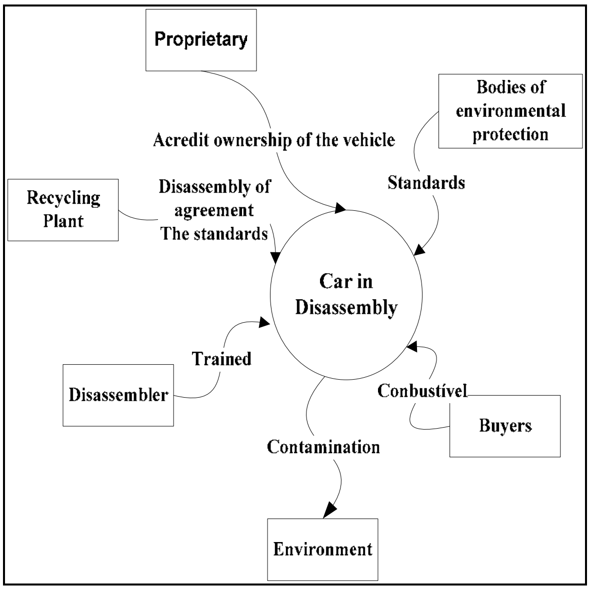

Figure-4 Functional Context
Scenario: Dismantling

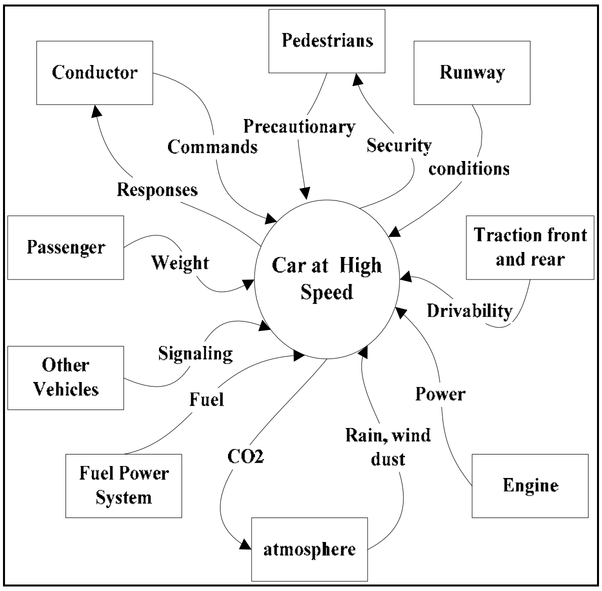

Figure-5 Functional Context
Scenario: High –Speed

4.2.2 Functional Context of the Organization

Figures 6 and 7 show the context of the organizations performing two life cycle process scenarios within the scope of development effort (in practice it must be done for every organization performing a scenario within the scope of development effort). Figures 6 and 7 show the exchanges of energy, material and information between the organization implementing a given life cycle process scenario and its corresponding environment.

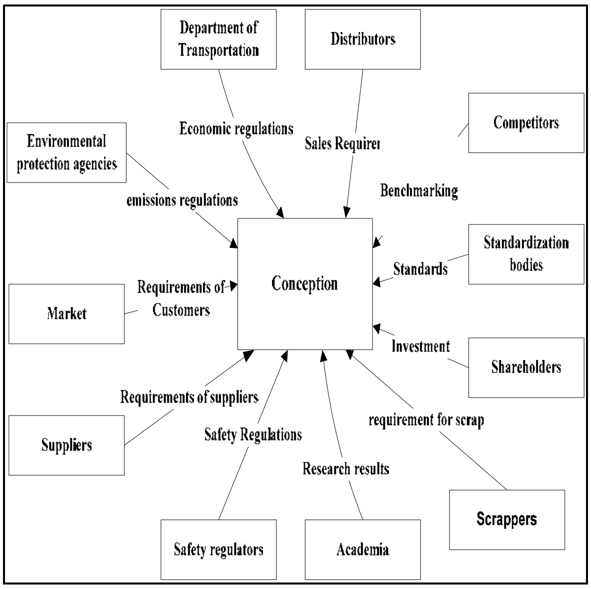

Figure-6 Functional Analysis
Development – Design

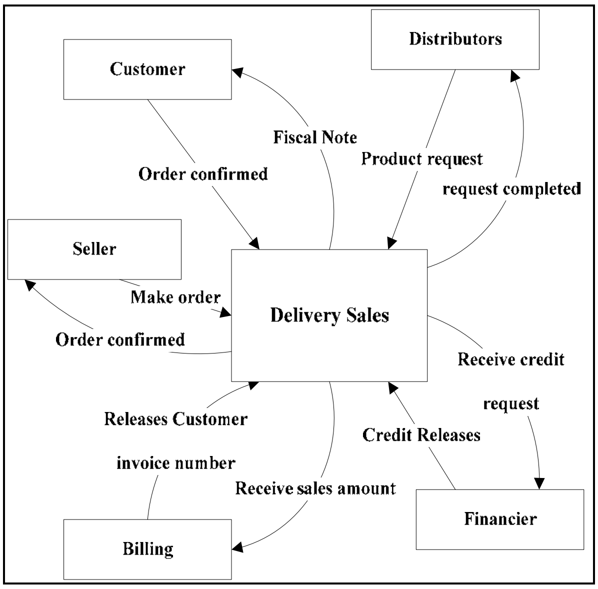

Figure-7 Functional Analysis
Sales – Deliveries

4.2.3 Behavior analysis of the scenario 'car in high speed'

The state transition diagram is a modeling tool that describes the behavior of the time dependent system, where a state is a set of circumstances or attributes that characterize an object at any given time. They are currently used in UML methodology (Unified Modeling Language). Jorge Marmion (2004) describes the diagram as a tool that models the states that an object can have, events that change its state, the circumstances that change its state and system responses to changing states (action) during the life of the object. To aid the understanding of its use, it is necessary to understand what are state, event, transition and action. A state is any condition in which an object satisfies a condition, performs some action, or waits for an event. An event is any occurrence that causes a state transition. A transition is the change of state of an object. An action is a response to an object state change. Figure 8 depicts the state transition diagram for the scenario ‘car in high speed’.

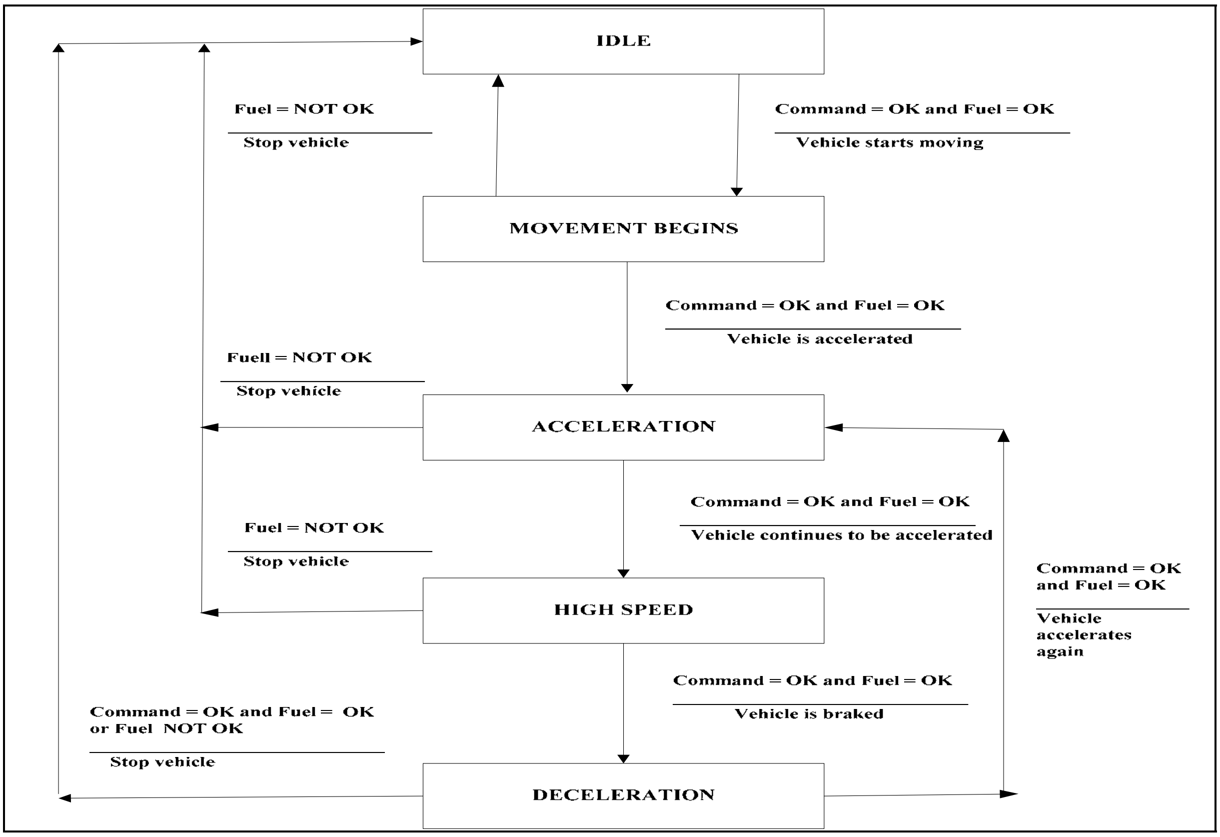

Figure-8 State Transition Diagram

4.2.4 Hazard and Risk Analysis

During functional analysis, it is time for identifying the functions that can mitigate risks.

Sources of hazards are circumstances imposed by the elements of the environment, flow failures and the malfunctioning of any function of the system. Once hazards are identified, it is necessary to identify their consequences and causes and to prioritize the ones for which mitigation will be sought. FMECA (Failure Mode Effects and Criticality Analysis) is a tool that allows such prioritization. Table 6 exemplifies an FMECA considering system failures as sources of hazards.

According to Table-6, for each failure that can happen, we must examine: danger, consequence severity (G:1-5), cause, probability (P:1-5), difficulty of detection (D:1-5), risk (GxPxD) and the actions that should be taken.

According to the risk factor obtained, it shows that there are failures that have greater risk than others and therefore should be prioritized. Actions to avoid or mitigate their risk can be implemented by detection, preventive, protective or corrective functions.

Table 6 exemplifies an FMECA for product, but the same must be done for organization, starting from its context analysis.

Table-6 Failure Mode, Effects, and Criticality Analysis

PROBLEM	DANGER	CONSEQUENCE	GRAVITY (1 to 5)	CAUSE	PROBABILITY (1 to 5)	DETECTION DIFFICULTY (1 to 5)	RISK G x P x D
Front and rear traction problems	Vehicle out of control	Loss of control	4	Holes in the track	2	4	32
Brake problems	Vehicle don't stop	Accidents	5	Worn brake pad	4	2	40
Front lights problems	Vehicle is a threat to population	Accidents	4	Strong raining and lack of preventing maintenance	3	2	24
Direction system problems	Vehicle out of control	Accidents	5	Lack of preventing maintenance	2	3	30

PROBLEM	ACTIONS
Front and rear traction problems	**Improve traction system**
Brake problems	**Add sensors that tell of the brake pad wear**
Front lights problems	**Monitor preventive maintenance**
Direction system problems	**Monitor preventive maintenance**

4.2.5 Behavior Analysis of the Disassemble scenario

Figure 9, presents the behavior analysis of the product in disassembly.

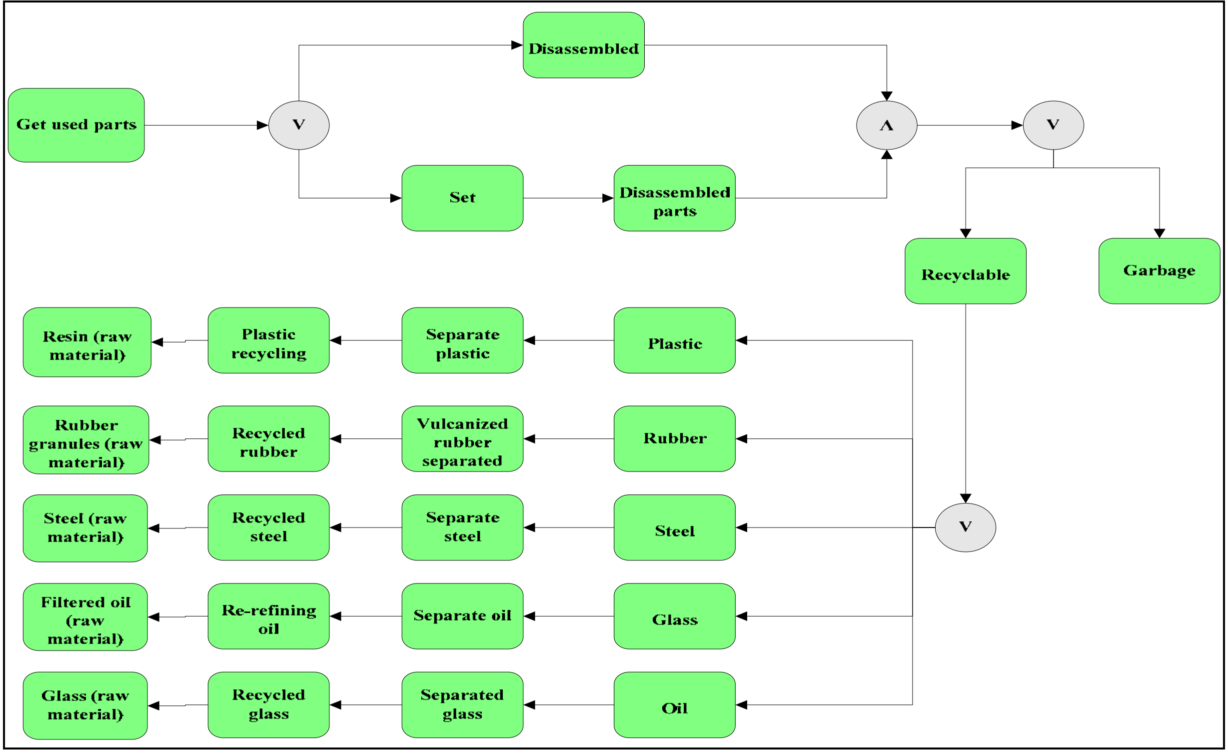

Figure-9 Diagram of Behavior - Disposal / Disassemble

4.3 Implementation (or physical or architecture) Analysis

According to the IEEE [7], an architecture is the highest level of a system in its environment. The architecture, in a given period, is the organizational form or structure of a system or components and their interactional interfaces.

To define the architecture, it is necessary to identify the sub-systems and their interfaces. Each subsystem and interface must be specified.

Implementation analysis is also performed, concurrently, for the product and its life cycle process performing organizations.

4.3.1 Product Architecture Flow Diagram

Figure 10 presents an architecture flow diagram of the car in the ‘high speed’ scenario (see also [16,17]).

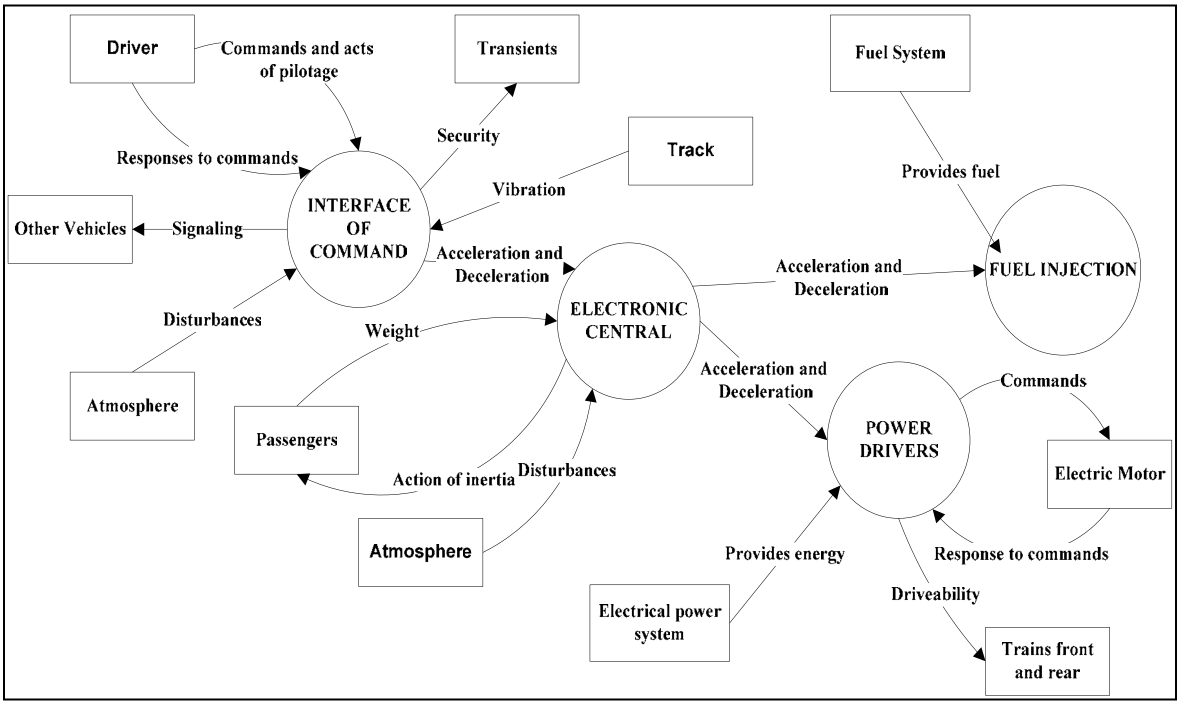

Figure-10 Flow Diagram of Product Architecture

4.3.2 Physical Interfaces of Product

Figure 11 presents the product physical interfaces, showing the physical connections between parts (see also [16,17]).

4.3.3 Allocation Matrix of Product Functions

Table – 7 relates the parts depicted in Figure 10 to its functions that resulted from functional analysis. The functional architecture of the product in that scenario has not been presented in this paper.

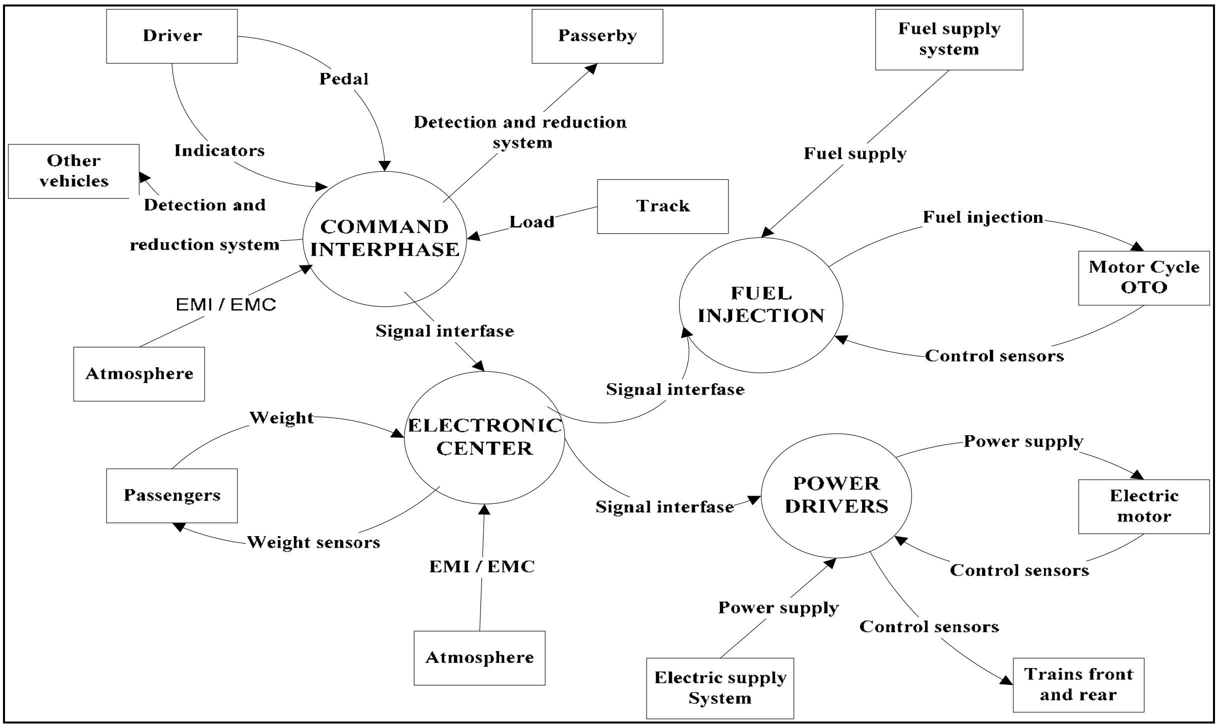

Figure-11 Physical Interface of Product

Table – 7 Matrix of the Product Allocation Functions

		Subsystems			
		Electronic Accelerator	Electronics Central	Power Driver	Fuel Injector
Functions	Provide Command Interface	🟦			
	Provide Data Treatment		🟦		
	Provide Supply Power			🟦	
	Provide Fuel Injection				🟦

4.3.4 Organization Architecture Flow Diagram

Within our scope of development effort we chose the organization that implements the sales process. Figure 11 exemplifies the relationships among the elements of the sales organization.

4.3.5 Physical Interfaces of Organization

Figure 12 exemplifies the physical interfaces identified for a marketing organization.

4.3.6 Matrix allocation functions of the Organization

Table 8 shows the allocation of organizational functions to organizational implementation elements.

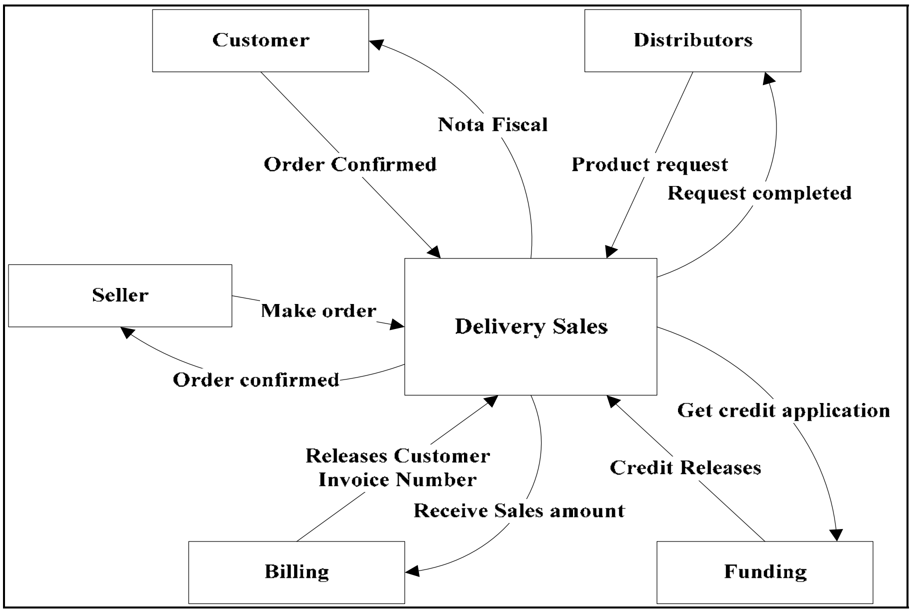

Figure-11 Flow diagram of Organization Architecture

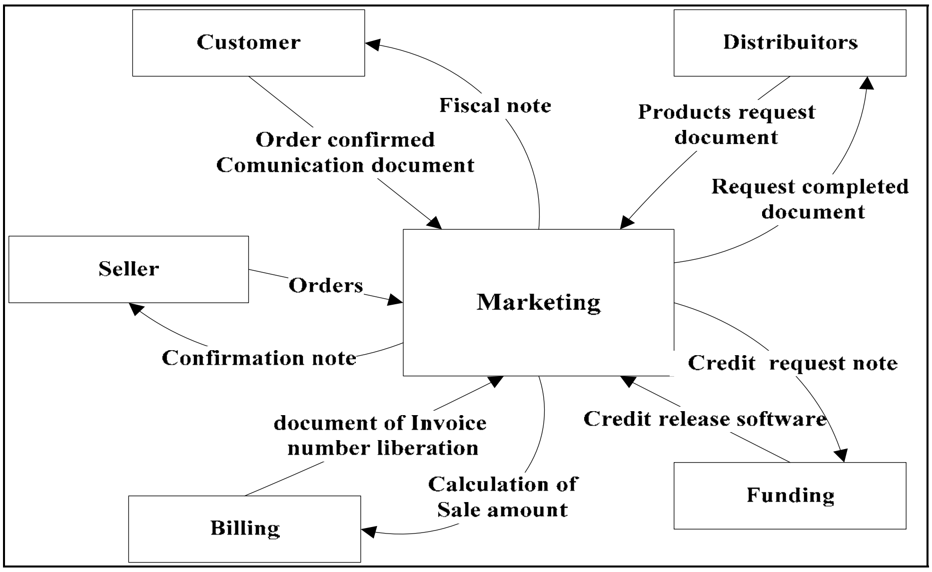

Figure-12Physical interface of organization

Table – 8 Matrix of the Organization Allocation Functions – Commercialization

Item	Function	Secretary	General Manager	Marketing	Logistics	Sales	Legal Advice	Human Resource	Technical Advice	Production
1	Monthly production of cars will ensure the delivery of 100% of the commitments made	**S**			**S**	**R**			**O**	**S**
2	Regulations and Standards Control						**S**		**R**	
3	Customer Management	**S**	**O**	**R**		**O**				
4	Distributors Management	**S**		**S**		**R**	**S**		**S**	**O**
4	Supplier Management	**S**			**R**	**O**			**S**	**O**
5	Scrappers Management	**S**			**R**	**S**	**S**		**S**	**S**
6	Academic Coordination	**S**		**S**				**R**	**S**	
7	Benchmarking	**S**	**O**	**R**		**S**	**S**		**S**	**S**

S – Support **R – Sponsor** **O – Orientation**

5. Discussion

In complex systems, such as automobiles, it is important to take into consideration the needs and expectations of the stakeholders related to all stages of product life cycle and not just those related to the operational stage. Throughout the theoretical foundations presented and the case study of the development of a "Green Car", the Systems Concurrent Engineering approach presents itself as an alternative to fill the gaps of the traditional approach of Systems Engineering.

The traditional approach to Systems Engineering focuses on product concepts of operation (CONOPS) and development organization. This paper shows that it is feasible to analyze the product and the organizations that perform its life cycle processes, simultaneously, along the systems engineering process and, therefore, capture the interactions between product and organization elements from the outset of product development. The approach showed that stakeholder analysis, requirements analysis, functional analysis can be developed simultaneously for product and organization. The opportunity for anticipating to the early stages of product development, the product interaction with the organization elements, along its life cycle, reduces late changes, reduces life cycle cost, reduces development time, reduces market risks, maintaining product quality.

6. Conclusion

The paper presented the systems concurrent engineering approach applied to the development of a green car. The approach was exemplified by modeling requirements, functions and implementation elements, simultaneously, for the green car product and for the organizations that implement the green car life cycle processes (only those within the scope of the green car development effort).

7. Acknowledgement

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