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Soft Modeling of Engineering Changes in System Dynamics (Case Study: Automobile Industry)

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ABSTRACT

Effective management of engineering changes in the Automotive industry is an essential ability in new product development, and products evolve in an environment with an iterative nature and increasing changes from the idea stage to the final product and shortening the life cycle of products and also the duration of product Launch from The idea-to-market stage is a severe requirement of a competitive environment. First, the complexity of the product development environment, the challenges of engineering changes and the need to control and governance its effects in a competitive environment in the vehicle development process are described. Then by literature review, an approach to modeling engineering change management using two hard and soft models has been introduced.in our modeling approach, the assumptions of cybernetics and system dynamics approaches have been practiced in building causal loop diagrams that integrated SOFT effects with HARD dimension parameters. Using this approach to develop simulation scenarios, strategic managers have better insight into effective management of engineering changes to find appropriate policies configuration to control its effects in a competitive environment.

Keywords

Product life cycle (PLC), System dynamics, Engineering change governance, Hard and soft modeling.

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1. Introduction

Engineering change management constitutes a wide-ranging product development basic challenge, introducing considerable uncertainty into the execution of product introduction operations. In the new product introduction, process modifications vary depending on the stage of the project. Variations in the early stages of the project are addressed with design iterations. In contrast, after the product design is augmented, changes are explored using a formal Engineering Change Proceedings. The practices of engineering changes in the automotive industry have complex dimensions, particularly under a joint setting where various autonomous institutions work together for a common target with a complex structure. Since engineering change management is a technical, social system, the existing literature shows significant gaps in examining the complexity of both social and technical subsystems. To ensure a comprehensive approach to engineering change management design, an overview of design elements and their interdependencies is required (Schuh et al., 2018). By enabling planned engineering change management, professionals can improve overall engineering program management and related complexity (Mehr et al., 2021). This paper proposed a digital twin for engineering change to enable continuous quantitative evaluation (hard and soft) and refinement of engineering change governance. According to Shakirov et al., (2021), digital twins may also be practised to analyze systems at the junction of process and organizational fields. In particular, the value of using essential tools such as the design structure matrix (Becerril et al., 2016) from systems engineering principles and basic simulation techniques, such as discrete event simulation for modeling the product introduction, engineering changes and complexity analysis, is emphasized (Li, 2012). Hence Much attention should be given to the diverse origin of uncertainty inherent in engineering practices. Sometimes this cognitive uncertainty is caused by the lack of knowledge about the operation system and its causal relationships (i.e. ambiguity), as well as the apparent uncertainty caused by natural changes in the values of system variables. This paper presents a framework in the form of hard and soft models to explain the interactions between different parameters of the new product introduction process and engineering change management. Hard operational entities (idea, 3D, 2D, etc.) are modeled in systems based on the PLM model (product life cycle). Also, by using the model of a system dynamics simulation model that shows the processes of new product introduction and engineering change framework for a value chain, process (causal) factors are simulated in the soft dimension to understand the interactions of hard parameters and analyze the effects of the change. The finding shows that most relations and interactions between factors and variables significantly affect the launch time of new product development. By using this framework, managers and executives can develop appropriate management policies to configure interactions of engineering processes and engineering changes and investigate uncertainty and complexity in managing their product development projects.

Companies always need changes in their product development system to maintain competition in the market share. But many new product development programs fail because of a lack of attention and effective control of the dynamic nature of essential success factors such as time, cost, quality, scope and change management. The boundary and dimensions of engineering changes are critical factors directly related to other factors. Therefore, to maintain competition and focus on scope, there is a need to manage effective changes in new product introduction programs - a competitive organizational strategic weapon (Rodrigues et al., 2006). To remain competitive, organizations need to develop policies to control and analyze any required changes in their new products that affect the value chain because of specific problems or evolving market conditions and customer requirements. Further, companies need a modeling approach examining and analyzing the scope of engineering change management policies and their effects in the operational dimension (hard) as well as modeling the strategic dimension (soft) using system dynamics models to study complex interrelationships of the influential factors of the product development system in engineering changes (time of product supply to the market, quality challenges, effects in the supply chain, market share and cost). (Bock and Feeney, 2013).

Therefore, the research is presented as follows. How can global manufacturers manage the complexity of Product Hard Parameters Changes and its Soft Effects in different processes and geographical disciplines to respond exactly and quickly to changing and diverse customer demands and suitable Engineering selections to maintain market competition?

2. Theoretical background

2.1. Managing complex changes in the product business

The need to pay attention to the complexity of engineering change, which is a function of sometimes *linear, non-linear, multi-stage and repetitive relationships* in the components of the business organization, product, process, design team and environment in order to obtain an overview of the scale and connections It is necessary through a comprehensive approach. The reason for this is the vast potential of an engineering change. A simple technical change may have non-technical effects on various attributes such as process, time, organization, and product brand. Reflecting on the potential impact of engineering change allows for consideration of the complexity dimensions of change (hard and soft) that will be explained later. A summary of studies conducted by researchers in different engineering change management dimensions is presented Table 1.

Table 1. Complex methods and Techniques of engineering change management

ECM practices and Tools	Explanation	Source
Development of a transparent engineering change management process and procedure	A transparent engineering change management operations should include: (1) bringing up an engineering change quest, (2) identifying possible resolutions and clarification to the EC request, (3) evaluating the effects of feasible solutions, (4) selecting and validate a resolution, (5) implement the EC solution, and (6) review the feedbacks.	Jarratt et al., (2005); Wickel et al. (2015)
Determining the coordinator of engineering change activities	A person responsible for following up and coordinating the engineering change governance should be determined.	Huang and Mak (1999)
Creating a multi-disciplinary team to work on engineering change	different teams are needed, representatives from different fields; for example, design, engineering, production, purchasing and planning	Huang and Mak (1999); Sjögren et al. (2018)
Production participation in the early stages of design and engineering	The manufacturing organization are needed to be involved in the early stages of the design and engineering practices to determine future production non-conformities and implement the essential modifications at an early phase.	Huang and Mak (1999); Jarratt et al. (2011)
Participation of suppliers in the process of evaluation and implementation of engineering change and inter-organizational engineering change management operations	Suppliers affected by an engineering change should participate in the early stages of engineering change assessment and implementation to detect and evaluate all engineering change releases early. In addition, a common inter-organizational engineering change management standard is needed to ensure proper and timely evaluation of engineering change and implementation operations.	Rouibah, Caskey (2003); Wasmer et al., (2011)
Separate meetings to work on engineering change	Multi-disciplinary teams should have specific engineering change meetings. This ensures that all information related to engineering changes is considered and promptly available to all functions involved.	Huang and Mak (1999); Sjögren et al. (2018)
Centralized access and Documentation to the status and logs of engineering changes records	Engineering change information must be suitably documented and centrally stored to ensure that it is available to all departments timely. Information should be presented to allow users to track engineering change logs.	Morris et al. (2016); Sivanathan et al., (2017)
Making decisions about engineering changes at the lowest possible management level	Engineering change decisions are needed at the lowest possible management level to save resources used for engineering change implementation. Different approval levels can be used depending on the engineering change's cost or risk level.	Stevens and Wright (1991)
Computer-based techniques to support the complexity of engineering change management		
Special IT systems for engineering change management	Special IT systems developed by professionals support change engineering documentation flow, obtain and store change engineering knowledge, assist change engineering evaluation, and enable collaboration.	Chen et al. (2015); Sivanathan et al., (2017)

Configuration management systems	Configuration management systems institute and maintain related information and product integrity to effectively control product changes. These systems assist in evaluating engineering change and storing, exploring, and updating information related to engineering change.	Jarratt et al., (2005); Whyte et al., (2016)
Product Data Management / Product Lifecycle Management systems.	PDM and PLM systems help to efficiently manage and distribute data and coordinate product creation processes among stakeholders. These systems can be used to effectively assistance of the engineering change planning, approval and implementation steps.	Do (2015); Wu et al. (2014)
Building information modeling	BIM is a multi-disciplinary and collaborative environment that includes a digital representation of a product's physical and functional specifications. BIM reduces the number of emergency engineering changes and assists in evaluating engineering change releases.	Francom and El Asmar (2015); Saoud et al. (2017); Matthews et al. (2018)
Tools for reducing and promoting change		
QFD	QFD technique is used to convert customer requirements into product engineering specifications. QFD helps capture customer requirements and needs at an early phase, thus reducing upcoming customer changes.	Huang and Mak (1999)
Analysis of failure modes and effects	The FMEA technique figure and reduce the potential problems of a product. If done early in the states, FMEA reduces the number of internal engineering modifications due to errors and changes in the early design stages.	Braaksma et al. (2013)
Design tools		
Design for Manufacture and Assembly (DFMA)	DFMA is a Technique used to design products for easy and economical production. DFMA is a common tool to integrate fabrication and assembly requirements into the early design steps and prevents emergency changes in production and assembly processes.	Das and Kanchanapiboon (2011); Jarratt et al. (2011)
Design for Flexibility (DfC)	DfC aims to design systems and products where upcoming engineering changes could be quickly implemented or avoided. Changeability could be attained through the principles of simplicity, independence and modularity.	Fricke and Schulz (2005); Ross et al. (2008)
Design Freeze	Design freeze is the final gate in the design activity where design evolution stops and the records are delivered to production. This technique limits the counts of engineering changes that can occur	Dieter (2000); Eger et al. (2005); Gosling et al (2013)
Impact assessment and change diffusion tools		
Change prediction methods (CPM), design structure matrices (DSM)	CPM and DSM are techniques that apply a matrix to represent the dependencies between product components and a method to predict and analyze the effects of releasing changes.	Hamraz et al. (2015); Zhao et al. (2010)
System Dynamics	System Dynamics is a modeling framework that can be applied to analyze engineering change causes and dynamic behavior of projects by feedback loops. This methodology gives insight to managers about how engineering change impacts project performance.	Ansari (2019); Love et al. (2002)

Also, the literature includes a wide range of other studies in the field of managing engineering change: the study of design and Engineering modifications and changes in the form of change stages, change parameterization, change workflow in the form of web systems, the effect of change in terms of possible factors, and the mathematical model of change implementation

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time, to minimize the effect of change and look at the change in the form of a discrete entity and modeling it by the discrete event method.

In this study, based on field studies and experiences in the automotive industry and referring to industry experts, as well as the following reasons, we chose the system dynamics for dynamic change methodology:

- The number of engineering changes is large, and the target product (car) structure is complex.
- Discrete event modeling and seeing change as a discrete entity leads to big and massive data for tracking each entity's flow.

2.2. Product introduction system and engineering change governance

The above studies emphasize the necessity of using systematic methods, product development and different techniques to systematically manage product development and engineering changes.

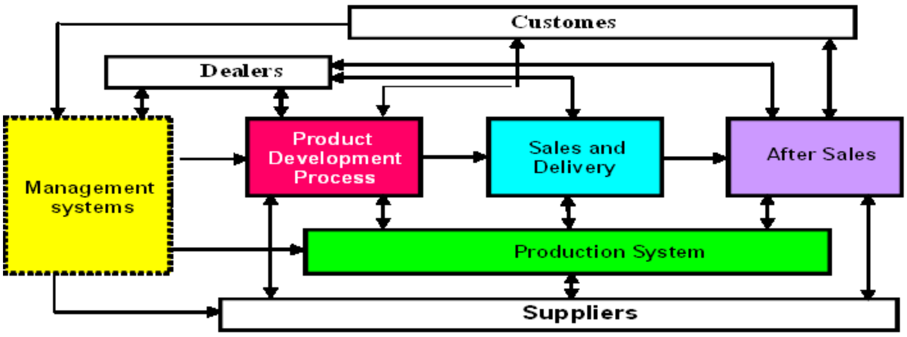

Figure 1. The comprehensive system of manufacturing companies in the automotive industry (Ford)

One of the critical systems in Figure 1 is the product development process of the automobile industry; this system, using the V methodology (Hartman and Kenley, 2015) of systems engineering (Figure 3) and the Stage-Gate system (Cooper, 1976). The model of physical requirements in a systematic way is mapped into functional areas and from functional areas to the design parameters and from the design parameters to the physical domain of the product (Fei et al., 2021).

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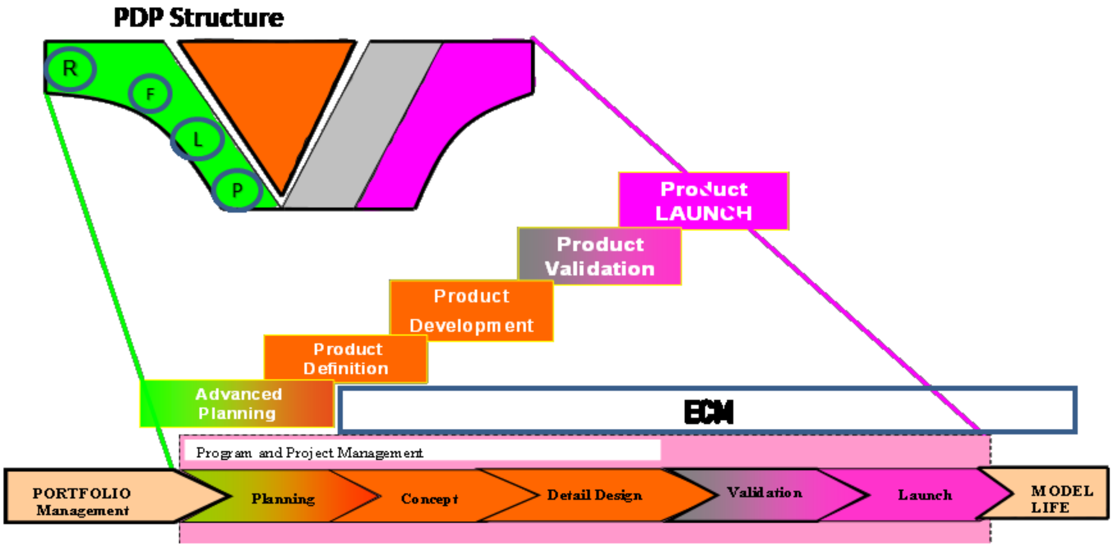

Figure 2. Model-based systems engineering in the vehicle development process

The input of this system is ideas or issues of engineering changes with an internal or internal origin: research and development, technical or external issues: market, competition, laws, regulations, norms. As a result, product improvement or development processes are initiated to improve (change requests) with reports on system problems or suggestions and ultimately make changes to the specification, including when they are produced. Change operation as a part of system development prioritizes change requests, and proposed change orders are attention based on the impact criteria on the productivity and profitability of the engineering organization instead of paying attention to the extent to which the orders make the change request.

A proposed change order may fully respond to the change request but have a negative impact on the organization's productivity and profitability. In contrast, another change order may partially respond to the request and improve the organization's productivity and profitability. In contrast to common terminology, change requests describe the situations that lead to the requests. For example, when systems behave in undesirable ways, instead of suggesting system modifications that the requesters believe will eliminate the undesirable behaviors, they describe the undesirable behaviors and the circumstances in which they occurred. Change requests enable engineers to determine the importance and priority of handling change requests and consider more and possibly better change orders for the same requests. Change requests that only suggest system changes are changed orders that engineers are forced to guess the underlying situation. When wrong guesses may reject legitimate and acceptable requests or propose solutions that do not solve the real problem, engineering change processes require considering requested changes and the impact of potential change orders on the rest of the system and the engineering organization producing it. Change issues must usually be prioritized due to system development and production resource constraints and analyzed for the possibility of cascading changes. Another issue is the iterative and repetitive nature of new product introduction and development processes, which assumes changes are made during new product development processes. However, changes after the completion of the new product introduction program and the launch of the new product to the market must be directed through a formal process called engineering change management. In the ECM, any changes in the product record and data after the finalization of the design must be communicated and transferred to all the related stakeholders. The purpose of EC is to improve the product by different measures, including correcting errors related to design, upgrading technology, or improving product performance. Due to the increasing effects of the engineering change management process on the product launch, lead time and cost, its importance in competitive environments and respond to new and changing market opportunities is very high. In many situations where the manufacturer is involved in engineering change management due to customer-supplier relationships, the complexity of the engineering change management process increases significantly. So it will be essential to create a set of PLM client-server procedures and systems that controls the interaction and flow of information between the different stakeholders (Tavcar and Duhovnik, 2006). When the complexity of the engineering change management process increases due to the involvement of multiple organizations, it becomes necessary to study the effects of some engineering change management procedures and policies on the entire supply chain and Original Equipment Manufacturers (OEM) before the actual implementation of the course of action and policies (Mutingi et al., 2015). In such environments, the engineering change management process simulation provides an understanding of the critical factors affecting the engineering change management operations and assists in identifying the process's weak components. Also, by simulating the engineering change management process, the effects of policy changes can be seen without actually implementing them.

2.3. Hard and soft modeling of engineering changes

Model-based methodology and approaches are a digital framework for specifying systems and products that integrates engineering concepts into computer languages and enables engineering-friendly computational assistance for developing system characteristics and definitions. They are famous for providing significant performance improvements in system characteristics and definition than document-based methods. Using modeling languages and approaches, engineers create system models that express engineering cognitions, decisions and choices in digital ways. One of the essential capabilities of model-based methodologies for engineering changes is to facilitate the "propagation of changes" (Giffin, 2007). Management of engineering changes requires modeling beyond the relevant system itself. Changes must be separated from the modeling specifications (hard model) so that the same changes can be made in several specifications. For example, applied to common aspects of different types. In addition, change models enable the specification developers and other practitioners easily understand and figure out how the new specification and parameters have changed and determine its impact and effects on their tasks (Figure 3). Also, the effects of changes and cause and effect loops, and change dynamics over time require soft modeling (Grzegorzewski et al., 2019).

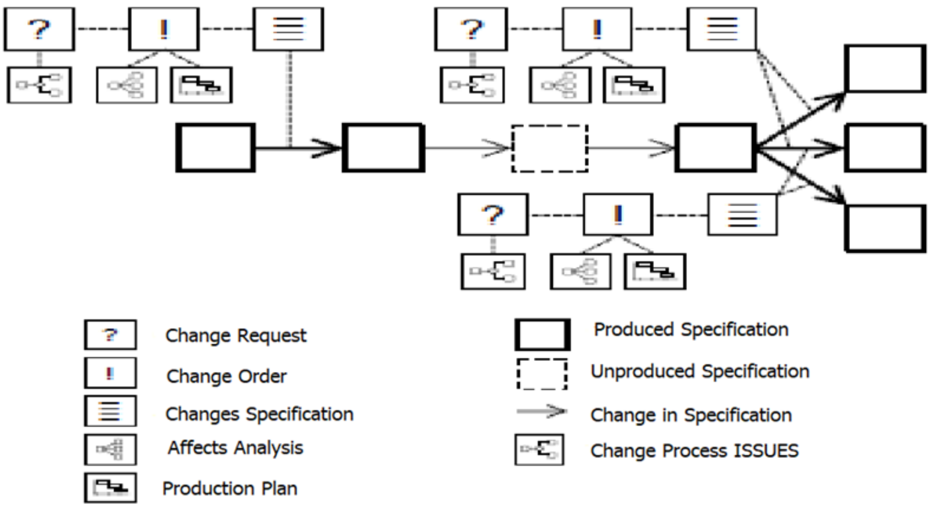

Figure 3. Engineering change modeling

More modeling techniques could be used to model any system, but a number of them are more suitable for modeling specific systems or certain aspects of systems. For example, Integrated DEFinition (IDEF0) is a family of modeling languages that starts with and is more suitable for systems and software engineering work (Fei et al., 2011b). While the functionality of the IDEF family has expanded from the most functional modeling language in IDEF0 to the simulation modeling languages in IDEF3 and above, they are more suited to modeling functional and data relationships in systems. Analyzing feedback mechanisms with proportional and rate functions in the system dynamics model is unique (Reddi and Moon, 2013). Engineering changes may occur at different stages during the multi-generational product life cycle, from the requirements in the design stage to the production product, and various parameters are involved in the cause-and-effect loops. For a deeper understanding, find the dimensions of change and feedback mechanisms; this section examines the dynamic (Soft) modeling framework of change management.

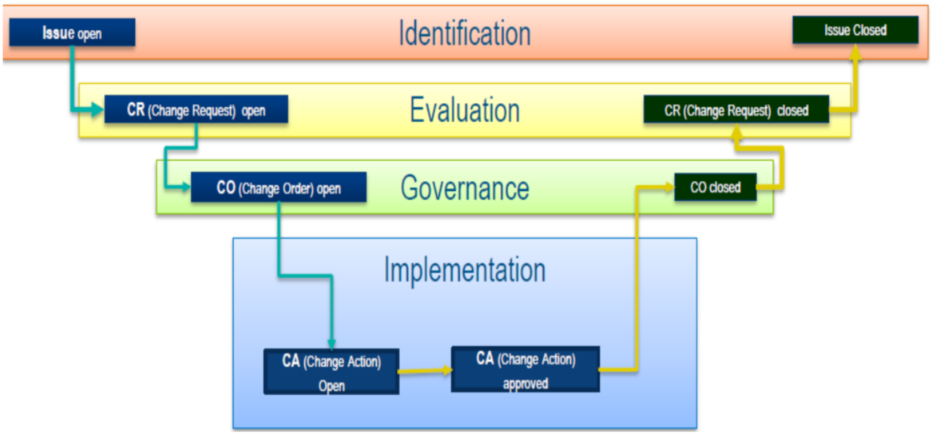

Figure 4. The levels of engineering changes and the need for soft modeling of the effects

As mentioned earlier, engineering change management consists of four levels (Figure 4). One of the steps is to evaluate and estimate the impact of engineering changes of any solution for engineering change requests, considering the risk of its implementation, for example, the impact of changes on design and production plans.

When a stakeholder makes an engineering change at the requirement, function, or component level, release risk is calculated to the extent of the risk of changes in tasks. Two cases are distinguished; engineering changes can start a new task or cause rework in an existing task. To study the dynamics of this issue, the need to develop soft models of engineering changes to analyze the dynamics of the project and the impact of changes on others.

3. Methodology

System Dynamics is a modeling approach and methodology used to model, study and manage complex systems. System Dynamics identifies system variables and defines their links (relationships) to create system structure. A model grounded and based on system structure is simulated to identify the system's leverage points. The relevant model includes accumulation, flows, time delays, variables and feedback loops, representing a system or a part of a system. Here, "system" refers to interdependent or independent components or entities that work together for a common purpose. A system component can be considered a system itself; its dynamics are grounded on causal loop diagrams (CLD). Causal loops diagrams (systems thinking diagrams) are "mental maps" of the system or problem involved. An SD model consists of system variables connected through CLD. These diagrams may or may not be complete or accurate because they are visual representations of the system by Relevant stakeholders are

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understood. A sink with input and output can represent a build-up in an SD model. The sink level fluctuates depending on the flows passes through the inlet and outlet valves, while the accumulation level is also defined by the inlet and outlet rates quantities. Accumulation accumulates and stores streams at a quantity equal to the difference between the input and output rates. Inventory quantities determine the status or state of the system at any point in time; flows are defined by "auxiliary variables", which are functions and accumulation functions, and the logic of the process as a whole in these variables. Rectangles figure out accumulations or state variables, while flows are shown by into and out arrows of the accumulation, indicating inflow and outflow. The valves on the arrows control the magnitude of flows into and out of stacks or state variables. The source is displayed with a cloud icon. The source has an arrow going out, while the sink has an arrow going into the cloud; together, these define the range of the model.

3.1. Methodology of system dynamics modeling of new product introduction processes and engineering change governance

Dynamic and cybernetic system for modeling engineering change governance in a new product introduction program by separating and classifying the type of collaboration between manufacturers and operations characteristics such as resources, resource combination, phase overlap, processing quality, processing rate, allocation priority, sourcing, change propagation and grouping of engineering changes and evaluating its impacts on OEM performance is studied.

3.1.1. Causal loop problem and diagram

Using system dynamics with causal loop diagrams, an organisation's new product introduction and engineering change management are modeled to identify the relationship between the parameters of the new product introduction process and engineering change operations. The causal diagram above shows the system variables in the processes; it identifies new product introduction and engineering change management and shows the effect and chain relationships. Arrows indicate links and relationships between system variables, and the type of relationship between variables is indicated with a sign at the head of the arrow. It is assumed that, at best, a company cope with changes in its market share by making changes to its products to gain or maintain its market share depending on the direction of the change. Any change initiated by an organization to modify a product is generally considered an engineering change. From the CLD (Figure 7), six loops can be identified:

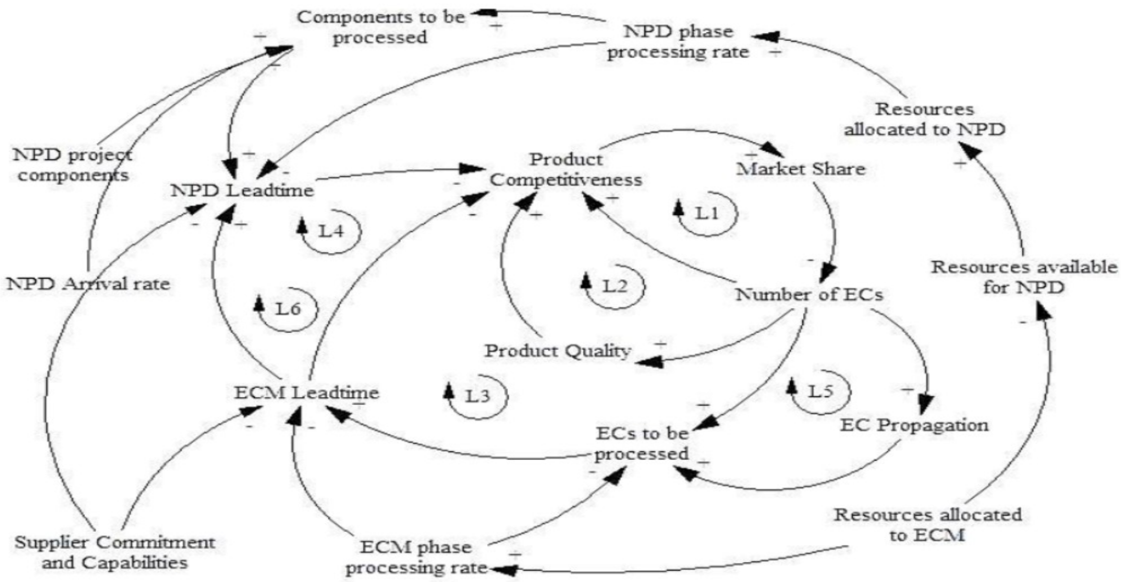

Figure 5. New product introduction and engineering change governance Causal loops and process parameters

- L1: Market Share—Number of ECs—Product Competitiveness
- L2: Market Share—Number of ECs— Product Quality—Product competitiveness- Market Share
- L4: Market Share-- Number of ECs— ECs to be processed—ECM Lead time—NPD Lead time —Product competitiveness- Market Share
- L5: L4: Market Share-- Number of ECs— EC propagation-- ECs to be processed—ECM Lead time——Product competitiveness- Market Share
- L6: Market Share-- Number of ECs— EC propagation--ECs to be processed—ECM Lead time—— NPD Lead time —Product competitiveness- Market Share

At the L1 loop, a decrease in market share increases the number of engineering changes, increasing the product's competitiveness and higher product competition increases sales and market share. The second loop (L2) includes the market share of the engineering change link and then the impact of the number of engineering changes on the quality of the product, so the number of engineering changes increases the quality of the product, which in turn improves the competitiveness of the product in the market and understandably increases the market share of the product. For the L3 loop, any increase in engineering changes increases the number of engineering changes to be processed, increasing the engineering change management delivery time. Any increase in engineering change management time increases response time to any market opportunity and thus reduces product competitiveness. For the L4 loop, any proposed engineering changes before the product launch increases the lead time. Also, a rise in the response time reduces the product's competitiveness level. For the L5 loop, a rise in the number of engineering changes escalates the number of engineering changes to be processed, which again lengthens the engineering change management delivery time. Any rise in engineering change management lead time increases response time, making the product less competitive and maybe a fall or loss in the market share. In the cases shown in loop L6, if engineering changes and releases occur before the product is released, this will expand the lead time to develop the new product. Any rise in the delivery time of new product development delays the product's market launch, which reduces the product's competitive ability (due to customer trust lost and other product sales) and then the product's market share. While L1, L2 are negative loops, L3, L4, L5, and L6 are positive loops. Most likely, the result will be the combined effect of all these loops.

3.1.2. Organizational models based on system dynamics explain how manufacturers interact with the company in product development.

Organizational patterns have been proposed because OEMs interact with their suppliers at more or less fixed stages in the new product introduction process. Communication with suppliers may involve the physical transfer of materials or just the sharing of information. These suggested patterns are measured grounded and based on the new product introduction process and their participation in the company's new product development phase and stages (Figure 8).

3.1.3. The dynamic model of engineering changes

The following template represents an original equipment manufacturer or an organization in general. The template forms the process framework of new product introduction and engineering change governance of the organization and provides the possibility of interacting with suppliers at the right time. The new product introduction and development process includes five main phases and stages: concept generation, detailed design, prototyping and testing, production ramp-up, and product assembly and testing. The engineering change governance process includes several steps, such as proposing an engineering change request, approving an engineering change, planning and implementing an engineering change, and documenting an engineering change The main factors that affect the workflow of NPD stages and engineering change operations governance are point out and determined in the model as variables that can be changed to modify the model's behavior accordingly. A new product development program

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is assumed to progress at a specific rate (e.g. one or more projects per year). Each new product introduction program can be broken down into smaller, independent parts called "components". As the design progress, the number of new product development components is determined, and the components are transferred to the relevant organizations for processing. These organizations include companies and suppliers participating in the new product introduction process from the concept phase. Organizations design and test product design in three stages: concept, detailed design, and prototyping. Once the product prototype is tested, production ramp-up begins with the goal of producing the product at a value determined by sales forecast estimates.

Feedback loops assume a specific percentage of error in the process at each phase and stage of new product development. For example, during a concept processing task, components with conceptual errors are collected separately and sent to the loop to rework the concepts, introducing a delay controlled by the error detection rate quantities. Errors in later stages of NPD are also assumed to propagate to earlier stages of the process. For example, a specific fraction of discovered design errors are sent to concept processing, assuming error propagation that has led to the re-evaluation of concepts.

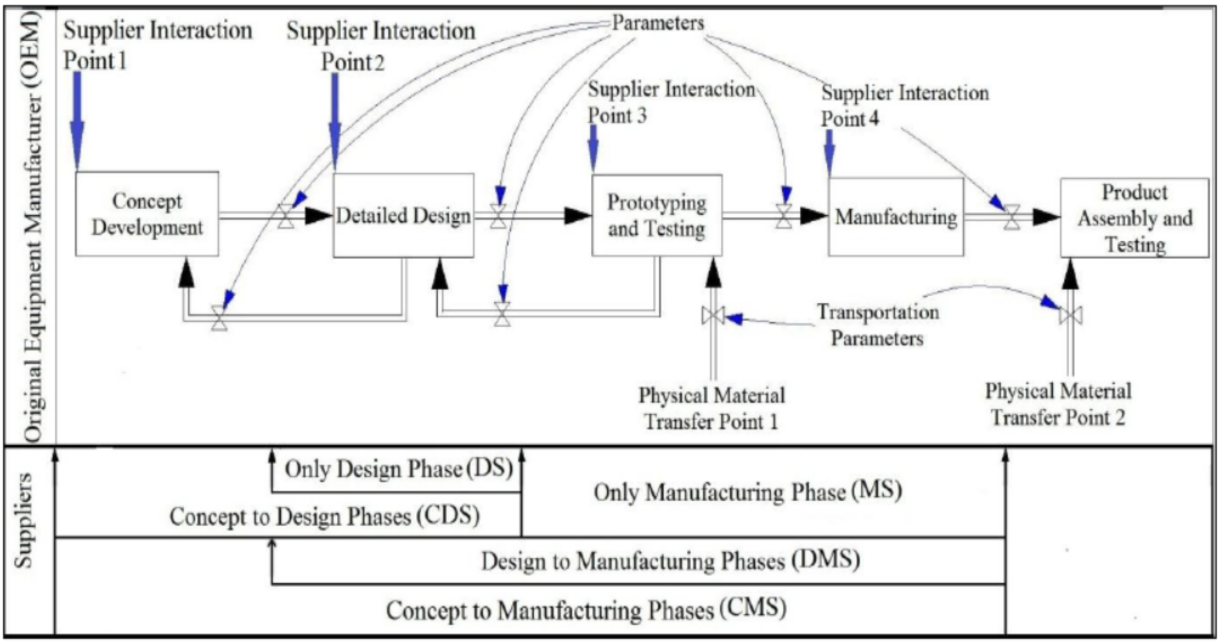

Figure 6. Schematic form of organizational patterns of interaction with the manufacturer and its role with the OEM

Components (detailed designs/design concepts in the form of production drawings/selected technologies) are sent from the company to suppliers for prototyping as detailed component designs are completed. Prototype components (manufactured prototypes) are returned to the company as manufactured by suppliers. After the successful assembly and testing of the product

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prototype, the parts are transferred to suppliers for increased production. Parts (ready for product assembly) flow from the suppliers into the company for product assembly and post-production testing. Changes discovered during and after prototype assembly are considered engineering changes and are processed using the standard engineering change management process. When discovered, components affected by change engineering are transferred to engineering change management, where the engineering change is analyzed, planned, implemented, and documented. The diffusion of changes is included in the text with the help of a diffusion index with a value higher than 1 and determines the diffusion of engineering change among components. It is also assumed that suppliers and customers introduce engineering changes. Components affected by change engineering flow from engineering change management, where the engineering change is planned and analyzed, back to suppliers or the company for implementation to the manufacturing stage for rework (Reddi, 2011).

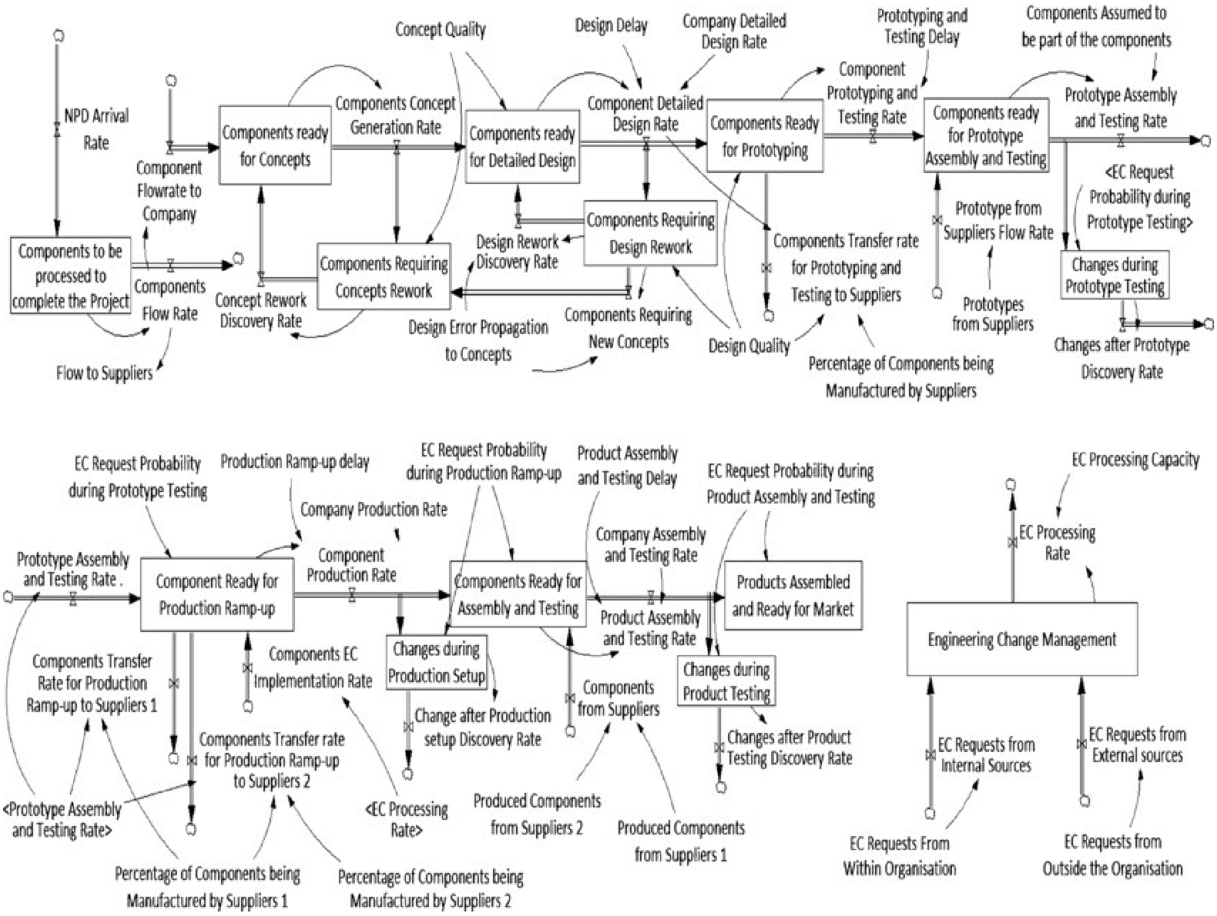

Figure 7. OEM model template

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3.1.4. Models for distinguishing supplier interaction in new product introduction and engineering change governance

The OEM model described above is drawn accordingly to represent the suppliers involved in the various stages of product development. For simplicity, suppliers are assumed to be involved in various stages, from concept development to product testing. This model shows cases where the company defines the specifications and the supplier designs and manufactures the parts. When the number of components that are part of the new product development project and each supplier manage it, they flow to the supplier. The supplier develops the concepts, designs the product and produces the prototype according to the guidelines set by the company. The components are returned to the company in the form of prototypes for assembly and testing of the prototype. After assembly and successful testing of the prototype, the parts are sent to the supplier for production. The components produced for product assembly and testing flow to the company during production.

Engineering change management has requests from internal and external sources. External sources include the company and downstream suppliers, if any. As in the Initial model, the components affected by the engineering change are multiplied by a diffusion index to address the engineering change diffusion. Below are summarized four models of the system dynamics for separating the cause and effect loops of constructive interaction with the company from the above model:

1- Involved in design and construction 2- Only in construction 3- Only in conceptual and design phase 4- Only in the design phase

The first state represents the supplier who designs the part according to the specifications provided by the company. The manufacturing company completes the part concept, decides on specifications such as technologies, performance requirements, etc., and sends the part specifications to the supplier. Parts are transferred from the company to this type of supplier after the concept production stage. The supplier designs the parts according to the specifications received from the company. The part is prototyped and transferred to the company for assembling and testing the prototype. After successful product prototype testing, parts are sent to the supplier along with sales forecast information to increase production. The supplier produces the parts and sends the product to the company for assembly and testing. This supplier's engineering change management process handles engineering change requests from external and internal sources. Each engineering change has a release index, which uses a value greater than 1 to indicate the components affected by the release of the change. The second stage is a supplier only involved in the production phase. This model represents a supplier not engaged in the manufacturing or, at least, in the company's product design. As the company completes the detailed design of the parts, a portion of the parts produced by the suppliers are sent to the suppliers who produce the prototype parts and return them to the company. Once the assembly of the product prototype has been tested and approved for scale-up production, the components flow to the supplier who manufactures them and is shipped to the company for product assembly and testing. In this case, engineering change management handles requests after production setup. It mainly analyzes the engineering change to decide if the part needs to be reworked or if it should be made from scrap. This type of supplier has an engineering change governance process, but it is assumed only to plan the engineering change implementation process. Third pattern; full-service Supplier involved in concept and design: This pattern represents design partners who are only involved in the stages of the conceptual and detailed design of the product life cycle. After the components of new product development are specified, the components flow from the company to the supplier. Parts are returned to the company as the designed parts. This supplier does not have a separate engineering change governance process but participates in the company's engineering change management process. The fourth pattern of a supplier that only participates in the detailed design shows that the company chooses the appropriate technology and characteristics of the desired components for design and manufacture. After selecting the appropriate technologies, the company may outsource the design work to an engineering partner that specializes in those technologies. The concepts of the parts are transferred to the supplier, who designs the parts and sends the designs to the company after completion. The feedback loop mechanism provided in the template indicates errors in the design process. This type of supplier does not have a separate engineering change management but participates in the company's engineering change governance process.

4. Conclusion

In any case, engineering changes are inevitable. Also, the need to pay attention to the repetition and the source of repetition of change is necessary. The origin of the identified changes or problems and errors results from the activity results (data and design information), new requirements' introduction, or the design scope's enlargement.

The need to pay attention to the complexity of engineering change, which is a function of the product, process, design team and environment, can be explained in the frameworks of hard models (algebraic relations) and soft models of cause and effect (differential relations) and this issue in the soft model in the variables under the title of the number of changes, the number of repetitions, the uncertainty of the solutions, the effects of the learning curve, the completeness of the solution, the uncertainty of the environment and other topics are analyzed, and the balancing and reinforcing circles are identified and then the necessary policy can be made for the problem and developed and evaluated the dynamic hypothesis of engineering change.

This study presented the soft modeling paradigm of the engineering change management process throughout the new product introduction environment to study the dynamics and effects of policy on supply chain operations. The important suppliers in the engineering change management process can be identified by modelling the engineering change management and analyzing the results. Consequently, appropriate precautions can be taken to avoid bottlenecks in the process. The simulation study assumes that each organization has similar initial stages in the new product introduction and engineering change governance processes. At the same time, their details may differ in the policies of processing tasks of engineering change and new product development. Organizations that are part of the supply chain interact with each other at specific points in the new product introduction process. Suppliers interacting with the company are categorized and grouped based on their participation in the new product development process. It is also assumed that the basic structure of new product introduction and engineering change governance processes is the same in a group of suppliers. At the same time, their level of cooperation with the company may differ. In order to use commonalities between new product introduction processes and engineering change governance of supply chain organizations, a set of company and supplier standard patterns were introduced and presented for modeling new product introduction processes and engineering change governance throughout the supply chain.

According to the above models, the comprehensive model could be developed to analyse new product introduction and engineering changes and their effect on the value chain and the market. The parameters of the model and the relationships of differential equations applied in the model, the policies of change and structure, the configuration of the value chain, optimization of parameters, outsourcing and its effect on reducing lead times, ranking and tiering of manufacturers and other challenges can scenarioized and simulate.

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