Title:
Engineering Changes within A CAD Model: Analysis and Impact Prediction

Authors:
Ameni Eltaief, ameni.eltaief@yahoo.fr, LMS, ENISo, Université de Sousse, Tunisie.
Borhen Louhichi, Borhen.louhihi@etsml.ca, LMS, ENISo, Université de Sousse, Tunisie.
Sébastien Remy, Sebastien.remy@utt.fr, LASMIS, Université de Technologie de Troyes, France.
Guillaume Ducellier, Guillaume.ducellier@utt.fr, LASMIS, Université de Technologie de Troyes, France.
Benoit Eynard, benoit.eynard@utc.fr, Université de Technologie de Compiègne, France.

Keywords:
Engineering Change, CAD Assembly, Change Impact, Categorization, Cost, Time.

DOI: 10.14733/cadconfP.2018.91-96

Introduction:
An Engineering Change (EC) is defined as: "an alteration made to parts, drawings or software that has already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time"[7] . An EC occurs mainly to correct an error or to improve, enhance and adapt a product to new requirements. Nowadays Engineering Design Change (EDC) is considered as one of the most significant factors for product innovation. There is no product improvement without ECs. Companies that adopt perfect processes, suitable tools, and techniques to control and implement ECs, improve their competitiveness in all three aspects of cost, quality, and schedule[5] . Given the complexity of the product operation mechanisms and the extensive connections within the product, design changes may lead to Change Propagation (CP), a change to one part of a system will trigger a series of changes in other parts. CP is the chain reaction that occurs when one change causes another change nearby, which then causes further changes, and so on, leading to a spread of changes[5] Consequently, CP affects many aspects of the product design and requires much rework to implement. Besides, the high interconnectivity between the product components makes CP a very common phenomenon. However If the designer can predict the path, scope, and risks of the CP before a change occurs, and find the optimal change solution based on the propagation analysis result, the change risks can thus be reduced or prevented, so that the fine quality of the EDC can be assured.

So, in order to better manage an EC and predict its Change Propagation Path (CPP), it is important to analyze an occurring EC and detect its impact on the whole model. ECs influence generally the budget, the planning and the execution. The impacts of ECs are numerous and have received much attention in the academic literature and especially in the early 2000s.

Literature review:
The volume of research accomplished in the field of EC has significantly increased during the last two decades. But more academic efforts are still needed to develop tools and manage knowledge in order to facilitate and enhance Engineering Change Process (ECP) and produce good quality products. The majority of research papers talking about ECs have common limitations. It is noticed that most of the developed models face major problems when multiple changes are handled concurrently [1] ,[8] ,[9] ,[12] ,[15] , when the product is complex (increasing number of components)[6] ,[10] ,[11] or when it exists an increasing number of dependencies between the different parts of the mechanism [2] ,[10] , [13] . Also some models which are mainly based on relation between topologic faces [14] have important limitations, because it is not adopted in all companies to use topologic faces to construct the product assembly models (Topologic face relations are not always available). Moreover, the majority of constructed models

are based on purely Mathematical Approaches. Also the objectiveness of collected data can have a big influence on the efficiency of some models such as neglecting the cost that can be induced by an EC. Besides some models identify the involved components and the way they are affected and does not measure the impact or risk of a particular EC.

Main Idea:

So, the presented methods have limitations for use. First, as they do not discuss different types of changes, such as deleting or adding components, occurrence of more than one change at the same time, the existence of several scenarios for change, or the possibility of modeling the cost of change (in term of time, money…). This leads us to think about developing a model able to measure the impact of an EC based on the category of change. So initially, the main idea is to categorize the modification that can occur. It is remarkable that previous works do not concentrate on the type of the modification. And works that pay attention to this point, defined limited types of modification (generally a modification related to one part).

- Our input Data is a constrained CAD Model containing standard and/or Mechanical constraints.
- Modification Category :
    - One component by N components ;
    - N components by one component ;
    - N component by N components ;
    - The same component (its geometry) ;
    - Deleting/ Adding a Component.
- It is necessary to specify the impact of a modification before realizing it. The following aspects need to be identified:
    - The source of change ;
    - The relationships and dependencies existing within the system (between involved parts);
    - The margins of tolerance;
    - The propagation path of the change;
    - The consequences in terms of cost, quality and deadlines.
- To determine the impact of a change on the CAD assembly some study must be done:
    - Topological study (Determining topological relationships);
    - Functional Study (functional study of the system or mechanism);
    - The link diagram (To model in a simplified way a mechanism and to facilitate the understanding of this mechanism).
- After having carefully studied the impact of a proposed modification, the latter must be managed according to the established results during the impact study. 3 main cases are presented:
    - The change can be made and propagation is done automatically.
    - The change can be made and propagation is not done automatically.
    - The change must be canceled (high cost, loss of system performance, risk of instability).

Impact of ECs:

ECs impact all determinants of competitive advantage: cost, quality, and time-to-market of products [5] So it is crucial that a presented EC be well planned before its execution. Also it is important to build up a full picture of possible impacts of this change on the other system's parts; this phase is called impact analysis phase (Fig. 1). This includes: describing the reason for the change; categorizing change; determining the affected parts; determining the affected attributes; describing the proposed solution, and identifying the cost and schedule impacts. Now, we are able to take decision, if this change will be executed or ignored.

A framework is developed using the Application Programming Interface (API). It is principally based on the topological, geometrical and functional relationships existing between the different parts of the CAD Model. The CAD assembly model encloses important information which needs to be extracted using API and exploited later on to generate the different existing SAs from a CAD assembly model. The assembly sequence generator collects data from an assembly model created in a CAD Model. Once the assembly model is loaded, the algorithm starts by enumerating the different existing components, and extracting the assembly constraint data. Then the part data extraction, that aims to explore and make easy the use of the topological and geometrical data of each part: Vertex (coordinates); Edge (associated vertex, length); Wire (associated edges, orientation, and length); and Face (associated wires, normal, area, volume).

Moreover, an assembly is a set of parts linked together by assembly constraints or mates. These constraints have several attributes, such as the type, the parameters, and concerned parts[3] [4] . All of these data are extracted and saved in a database of the assembly to be used later. The Mate Data Extraction Algorithm explores the assembly constraints present in the feature manager design tree. Then, it checks their nature and collects from each one: the name, the type, and the parameters. The recognition of the constraint type is very important. In fact, it gives an idea of the nature of contact between the different mated components and the nature of the allowed movements and motions. This information is useful for the generation of the existing SAs. In reality two components are assembled together through geometric entities (surface, edges…). As a result, collecting data from ''Mates'' entities are very useful to:

- Get the geometric Impact on other design change ;
- Impact on the bill of material ;
- Impact on structural arrangement ;
- Impact on safety ;
- Impact on equipment specification.

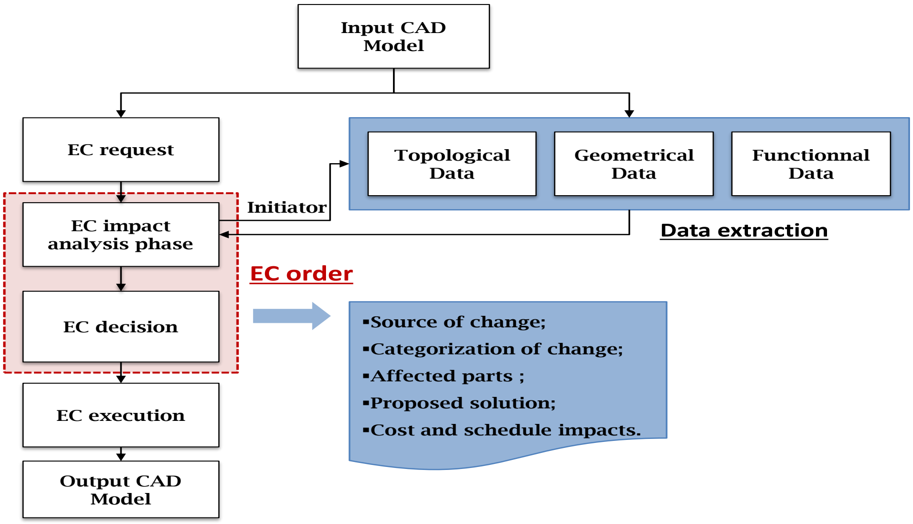


Fig. 1: EC proposed process.

An engineering change request (ECR) form is used to describe a suggested enhancement or modification or to declare a problem with a product. The form initiates the change process, it promotes discussions to help determine the impact of a change and the best possible solution. It is the predecessor for an engineering change order (ECO), which describes the details of a change and may specify how a change should be implemented. Once the EC request is received, the impact analysis phase starts, describing the source of the change and its category, determining the concerned parts, describing the proposed solution, and identifying the cost and schedule impacts:

- Impact on other design change ;
- Impact on the bill of material ;
- Impact on structural arrangement ;
- Impact on safety ;
- Impact on equipment specification.

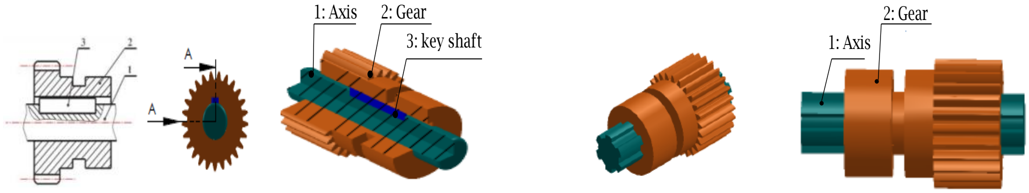
In order to determine detailed possible impacts of an EC after determining its category and source, we have to dispose of a data base containing all necessary information such as engineering and manufacturing cost of each part. Since time is considered as one of the most influencing factor, so we have to take it into consideration: time of redesign and the hourly rate and cost. Knowing that, a proposed EC can even engender the redesign of the whole CAD system. Model. An EC can be canceled, in some cases, if its execution will cause a high cost, or a loss of quality, etc.

In order to validate the proposed model able to determine the impact of a proposed EC based on a simple categorization of changes that can affect a CAD Model. A CAD assembly of a gear and an axis assuring a linear motion is used. Basically the linear motion is guaranteeing thinks to the slide link and using the key shaft. So initially our assembly is composed from 3 components (*solution1:*Fig. 2*(a)*). Then, in order to improve the liner guidance, the designer have to change the technological solution. Thus three different solutions are proposed.

- *Solution1*: Initially our assembly is composed mainly from 3 components (Fig. 2(a)). Then the designer chose to change the technological solution. Thus three cases are taking place.
- *Solution 2:* Modifying the assembly by creating external grooves on the axis and internal groove on the gear. In order to minimize the number of used components. So here we have deleted a Component from the initial assembly (Fig. 2(b)). It is apparent that the geometry of the whole assembly is hardly affected while deleting the key shaft. The margins of tolerance also are affected. Moreover the cost of manufacturing of the assembly components is also being affected, because the shapes of the parts are becoming more complex.

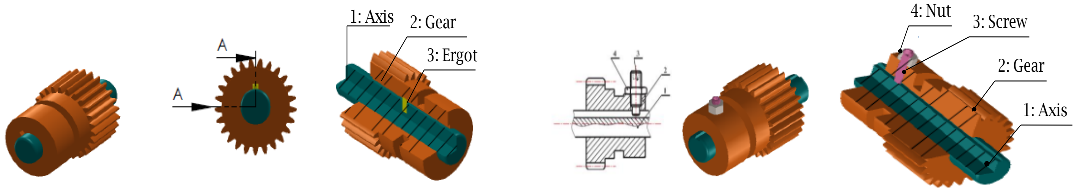
- *Solution3:* This solution proposes modifying the key shaft used earliest by an ergot (Fig. 3
- Fig. 3(a)) (***1component by 1 component***). In this case the impacts of the modification are less important and significant. Only small modifications are necessary.

- *Solution4:* Modifying the assembly by means of adding a groove screw (Fig. 3
- Fig. 3(b)). So the key shaft (***1 component***) used initially, is substituted by a groove screw and a nut (***A group of component***). The impact of this modification (1 component by N component) is visible. Some features are modified and some others are created, in order to be coherent with the added components.



(a) **(b)**

Fig. 2: (a) Solution 1, (b) Solution 2.



(a) **(b)**

Fig. 3:(a) Solution 3, (b) Solution 4.

Thanks to the proposed Model and the disposed Data shown in

Tab. 1 (of a real design office), the proposed solutions will be evaluated in order to determine their feasibility. Then the scheduled cost are also determined. So the designer is now able to decide if this kind of modification will be executed or canceled.

Time (min)						
Entity	Engineering Time	Manufacturing Time				
		Turning	Broaching	drilling	Milling	sawing

Axis	60	10	30	10	5	
Gear	60	10	30			10
Key Shaft	30	-	-	-	-	10
Cost (€)						
Entity	Manufacturing hourly cost	Engineering hourly cost	Purchasing Cost			
Assembly	40 (€/Hour)	30(€/Hour)				
Screw	-	-	According to Catalog			
Nuts	-	-	According to Catalog			

Tab. 1: Available data.

Conclusion:

ECs are an essential characteristic of the product development process. The main goal of these changes is to enhance the performance of the product. It is noticed that ECs can occurred throughout the whole product life cycle. Therefore this kind of changes can cause a serious profit loss if they are not managed effectively. But us they are considered necessary to improve the product's quality. It is demanding to predict ECP and their impacts. CP causes important delays and unpredicted spending. It has been revealed that it is primordial to figure out the change impact, likelihood and propagation paths of engineering changes in order to effectively manage them.

References:

[1] Chen, C.-Y.; Liao, G.-Y.; Lin, K.-S.: An attribute-based and object-oriented approach with system implementation for change impact analysis in variant product design. Computer-Aided Design, 62, 2015, 203–217. https://doi.org/10.1016/j.cad.2014.11.006

[2] Clarkson, P. J.; Simons, C.; Eckert, C.: Predicting Change Propagation in Complex Design. Journal of Mechanical Design, 126(5), 2004, 788. https://doi.org/10.1115/1.1765117

[3] Eltaief, A., Louhichi, B., & Remy, S. (2018). Associations management and change propagation in the CAD assembly. Computer in Industry, 98, 134-144. https://doi.org/10.1016/j.compind.2018.02.012

[4] Eltaief, A., Louhichi, B., Remy, S., & Eynard, B. (2018). A cad assembly management model: Mates reconciliation and change propagation. In Lecture Notes in Mechanical Engineering (pp. 459–471). https://doi.org/10.1007/978-3-319-66697-6_45

[5] Hamraz, B. (n.d.). Engineering Change Modelling Using a Function-Behaviour-Structure Scheme, A thesis submitted to the University of Cambridge, Department of Engineering, for the degree of Doctor of Philosophy, 2013.

[6] Hamraz, B.; Caldwell, N. H.; Clarkson, P. J.: A matrix-calculation-based algorithm for numerical change propagation analysis. IEEE Transactions on Engineering Management, 60(1), 2013, 186–198. https://doi.org/10.1109/TEM.2012.2203307

[7] Jarratt, T.; Eckert, C.; Clarkson, P. J.; Schwankl, L.: Product architecture and the propagation of engineering change. Design 2002: Proceedings of the 7Th International Design Conference, 2002, 75–80.

[8] Louhichi, B.; Rivest, L.: Management of associations within digital mock-ups for improved collaboration. IFIP Advances in Information and Communication Technology, 388 AICT, 2002, 411–423. https://doi.org/10.1007/978-3-642-35758-9_37

[9] Louhichi, B.; Rivest, L.: Maintaining consistency between CAD elements in collaborative design using association management and propagation. Computer in Industry, 65(1), 2014, 124–135.

[10] Masmoudi, M.; Leclaire, P.; Zolghadri, M.; Haddar, M.: Change propagation prediction: A formal model for two-dimensional geometrical models of products. Concurrent Engineering Research and Applications, 25(2), 2017, 174–189. https://doi.org/10.1177/1063293X17698192

[11] Reddi, K.; Moon,Y.: A framework for managing engineering change propagation. Mechanical and Aerospace Engineering, 6(5), 2009, 461–476.

[12] Saoud, L. A.; Omran, J.; Hassan, B.; Vilutienė, T.; Kiaulakis, A.: A method to predict change propagation within building information model. Journal of Civil Engineering and Management, 23(6), 2017, 836–846. https://doi.org/10.3846/13923730.2017.1323006

[13] Ullah, I.; Tang, D.; Wang, Q.; Yin, L.: Exploring Effective Change Propagation in a Product Family Design. Journal of Mechanical Design, 139 (12), 2017, 121101. https://doi.org/10.1115/1.4037627

[14] Yin, L.; Tang, D.; Kang, Y.; Leng, S.: Topology face–based change propagation analysis in aircraft-assembly tooling design. Proceedings of the Institution of Mechanical Engineers,Part B: Journal of Engineering Manufacture, 230(1), 2014, 120–135.https://doi.org/10.1177/0954405414558695

[15] Yin, L.; Tang, D.; Wang, Q.; Ullah, I.; Zhang, H.: Engineering Change Management of Product Design Using Model-Based Definition Technology. Journal of Computing and Information Science in Engineering, 17(4), 2017, 41006. https://doi.org/10.1115/1.4036121