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Using Design For Variety and Axiomatic Design To Architect Automotive Underbody

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Abstract : *In today's fiercely competitive automotive market, where market segments are becoming more fragmented, incorporating flexibility into product platforms brings important competitive advantages to an automotive company. It allows automakers to respond to changing market needs with minimal increase in switchover costs. Developing robust product platform architecture is critical to successfully design a flexible product platform. Underbody subsystem plays a key role in foundation of the architecture of the automotive platform. This paper uses Axiomatic Design (AD) to provide a framework for interpreting the approaches to reduction of the Generational Variety Index (GVI) and Coupling Index (CI). Then these approaches are applied in studying the architecture of automotive underbody. This paper utilizes these prescriptive approaches to aid in developing an automotive underbody architecture that incorporates standardization and modularization in order to reduce future design costs and efforts. Application of the intuitive approaches to the automotive underbody resulted in remarkable reduction of generational and coupling indices. Then these changes are incorporated into the automotive underbody to make it more robust to future market and design changes.*

Keywords: *Product platform, Architecture, Design for Variety (DFV), Axiomatic Design (AD)*

INTRODUCTION

In the age of mass customization [1], customers need to evolve and shift over time continuously, creating a demand for large product variety; however increased variety can lead to additional product complexity, higher design and production cost as well as longer developing times for new variants. This issue is more crucial in automotive industry due to emerging and fiercely competitive markets and also complexity of automotive and its development process. The use of product platform strategy allows firms to meet these needs in a cost-competitive manner.

According to Meyer & Lehnerd [2] a product platform is “the set of common components, modules, or parts from which a stream of derivative products can be efficiently developed and launched.” Much has been written on the topic of platforming ,commonality and benefits of the product platform strategy, primarily stemming from seminal work by Utterback and Meyer [3]and Robertson and Ulrich [4] although earlier work can be found from 20 years ago [5]. These early studies mentioned a number of advantages, such as enabling future rapid product introduction, increasing model introduction rate, decreasing development cost, economies of scale in manufacturing, and faster introduction of new technology into existing product lines. Cameron et al, have broken the benefits of commonality into three categories: (1) Revenue Benefits, (2) Cost Savings, and (3) Risk Benefits [6]. Although the product platform strategy has many advantages, it can also have disadvantages. Perhaps the biggest disadvantage of commonality is the increased potential for the lack of product distinctiveness. As more components are shared, it becomes difficult to differentiate between product variants in the fragmented market [7]. Also, sharing common components between high end products and low end products can lead to cannibalization [8] and finally due to high cost of platform development and also high switchover cost to implement new technical innovation. The firms that own the platform were not willing to implement such technological innovations into already existing platforms. What is essentially required is a proactive strategy to decrease switchover cost based on future uncertainties while remaining flexible enough to support multiple variants from a single platform. In other words, embedding flexibility into product platform is an effective systematic solution to overcome disadvantages due to future changes. The word “flexibility” is defined as “the ease of changing the system’s requirements with a relatively small increase in complexity (and rework)” [9]. Simpson et al reviewed and summarized the state of the art in product family and platform design research [7] and then again reviewed recent advancements in product family design [8]. Instead of repeating such comprehensive review here, we will concentrate our discussion on some main papers which are mostly related to product platform design under uncertainty and incorporating flexibility into product platforms. Basic product platform elements are components, processes, interfaces and architecture. Thus The final form of the product platform is a collection of common and flexible components, processes, interfaces and architectures that allows the company to offer product families with distinct variants at low cost. [12]. Ulrich [11]referred to product architecture as the ‘‘scheme by which the function of a product is allocated to physical components.’’ He defined it as: (1) Arrangement of the functional elements; (2) Mapping from the functional elements to the physical components; and (3) Specification of the interfaces among the interacting physical components. This paper further defines product architecture, provides a topology of product architectures, and articulates the potential linkages between the architecture of the product and five areas of managerial importance: (1) product change (2) product variety (3) component standardization (4) product performance and (5) product development management. He explained that "Products with integral architectures require changes to several components in order to implement changes to the product's function". Furthermore, he described that "a modular architecture increases the likelihood that a component will be commonly useful. An ultimate modular architecture, which contains a one to one mapping from the functional elements to the components means that any component could have only one function. As a result of such architecture, any component with a specific function could be used in any other product applications which the corresponding function is required. On the contrary, the components of an integral architecture could not be used in another product if the combination of the functional elements differs with the base product. Commonality of component interfaces in different products is another outcome of the modular architectures. In such cases, a component could be replaced without needing a change in the surrounding components. In other words, the interfaces are decoupled in a modular architecture. He also emphasized on the role of product architecture in having a robust design against future changes.

Martin and Ishii [12] described the Design for Variety (DFV) method, to develop standardized and modularized product platforms. The authors used the Generational Variety Index (GVI) and Coupling Index (CI) to aid in designing a product platform that can be easily changed in the future. In this paper, GVI is defined as an ‘‘indicator of the amount of redesign required for a component to meet the future market requirements.’’ it is an indicator of which components are likely to change over time. The CI ‘‘indicates the strength of coupling between the components in a product. The stronger the coupling between components, the more likely a change in one will require a change in the other.’’ From the coupling matrix, two indices are derived. The sum for a column indicates the strength of the information supplied by that component to other components and is referred to as the Coupling Index–Supply (CI–S). The sum for a row states the information being received by each component and is referred to as the Coupling Index–Receive (CI–R). These indices are further explained as follows: The coupling index–receiving (CI–R) indicates the strength (or impact) of the specifications that a component receives from other components. The coupling index–supplying (CI–S) indicates the strength (or impact) of the specifications that a component supplies to other components A water cooler is used as an illustrative example to demonstrate this method, in which the GVI and CI for seven major components are calculated. Then, for the components with high GVI and CI, flexible designs are introduced to reduce GVI and CI and subsequently, lowering future redesign cost. Nadadur et. al [15] described the application of GVI technique in studying the evolution of the apple iPhone,and they again emphasized that" The main utility of GVI is in providing designers with a quantifiable method to estimate the extent of future changes in the designs of products. This is useful in decision-making concerning the incorporation of flexibility into different components and subsystems".

As a research that applies flexibility to the automotive field, Suh et al [14] presented a platform design process in response to future uncertainties. This flexible platform design process (FPDP) takes exogenous uncertainties into account and incorporates the concept of flexible elements. They investigated the body-in-white (BIW), but they didn't use GVI and CI explicitly in their research and employed change propagation analysis instead.

In this paper, a perspective of existing approaches for creating modularity and standardization are introduced based on Axiomatic Design principles. Thus for the first time, the Axiomatic Design Principles are interpreted as approaches to achieve a flexible design against the future uncertainties. Then, the floor panel architecture along with its functions and GVI and CI uncertainties for a normal B-segment (it can be applicable to upper segments) vehicle is calculated. Finally, by implementing the approaches which are interpreted based on AD, the reduction of the mentioned indices as well as a robust architecture to the changes is achieved.

2. Using Axiomatic Design principles for explaining flexibility related issues

2.1. Axiomatic Design framework [16], [17]

Axiomatic Design is a structured design method created to improve design activities by establishing criteria on which potential designs may be evaluated and by developing tools for implementing these criteria [60].

Four successive domains are defined in the design world which are customer, functional, physical and process domains respectively. Axiomatic design deals with these design domains which are known by the characteristic vectors including Customer Attributes (CAs), Functional Requirements (FRs), Design Parameters (DPs) and Process Variables (PVs). Definition of design is more clarified using these concepts: Design of products and design of processes are defined as quality of mapping from the functional domain to the physical domain and from the physical domain to the process domain respectively. FRs are the smallest sized-set of independent requirements which completely satisfy the functional need of the desired product. The main physical variables in the physical domain which characterize the system in such a way that satisfies all of the functional requirements are called DPs. The axiomatic design framework is developed to improve the DPs using the two design axioms [18]:

- Axiom 1: Independence Axiom- Maintain the independence of all functional requirements.

• Axiom 2: Information Axiom- Minimize the information content of the design.

The relationship between DPs and FRs is described as follows:

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

In Eq.1, [A] is the design matrix which describes the design's characteristics. In fact, design of a product is performed using this equation. The design matrix is a square matrix which is equal to the number of FRs and DPs in the number of rows and columns respectively. For example, for a design with three FRs and three DPs the design matrix is described as follows:

$$[\mathrm{A}] = \begin{bmatrix} \mathrm{A}_{11} & \mathrm{A}_{12} & \mathrm{A}_{13} \\ \mathrm{A}_{21} & \mathrm{A}_{22} & \mathrm{A}_{23} \\ \mathrm{A}_{31} & \mathrm{A}_{32} & \mathrm{A}_{33} \end{bmatrix} \qquad (2)$$

If the design matrix is diagonal or triangular, the independence axiom will be satisfied. The design is called uncoupled if the design matrix is diagonal. In this situation, each of the FRs is mapped to a single DP. If the design matrix is triangular, the design is called decoupled. In this case, the independence of FRs could be guaranteed if and only if DPs are determined in a proper sequence. Coupled design, corresponds to the other forms of the design matrix which are called "Full matrix". Therefore, based on the first axiom, an axiomatic design must lead to a design matrix which is triangular or diagonal.

Eq.2 is rewritten in the differential form as follows:

$$\{\mathrm{dFR}\} = [\mathrm{A}]\{\mathrm{dDP}\} \qquad (3)$$

Which the elements of the design matrix are calculated by the following equation:

$$\mathrm{A}_{\mathrm{ij}} = \partial \mathrm{FR}_{\mathrm{i}} / \partial \mathrm{DP}_{\mathrm{j}} \qquad (4)$$

2.1. Using the Independence axiom to interpret Flexibility:

Flexibility is defined before as "the ease of changing the system's requirements with a relatively small increase in complexity (and rework)".

Now assume that in the future, one FR_i will change and the system architecture wishes to incorporate flexibility in the system to absorb the change. If flexibility is incorporated in the corresponding DP_i for uncoupled and decoupled designs, other DPs and FRs will not be affected by changing the FR_i (according to Eq.3). Therefore, in the case of satisfying the independence axiom, the GVI index could be optimized.

Assume that each of DPs are associated with one physical part, if not we can aggregate them in one subassembly or module for better imagination of the linkage between FRs or engineering metrics and DPs or related physical parts. This means that our architecture allows us for standardization and modularization. Therefore, as stated in DFV method, reducing the GVI, CI–R, and CI–S of the components helps to these standardization and modularization efforts and by trying to apply independence axiom to our design architecture, it can be possible to prepare it in order to be easily managed to absorb future changes; However it is no longer applicable in the coupled system cases.

If uncertainty increases, where all FRs are uncertain, then the issue of incorporating flexibility becomes more challenging, based on the Jacobean matrix of a coupled system shown in Eq. 4, identifying sensitivities of each FR with respect to corresponding DPs identifies the component's GVI and furthermore can reveal the priorities of DPs which can be candidates for incorporating flexibility. To increase the robustness of the design and to make it uncoupled, a diagonal matrix with the diagonal elements≤ 1 is preferred.

.2.2. Using the information axiom to interpret robustness of the design

The information content is an indicator of complexity in a system; i.e. the higher the information content, the more complex the system. Complexity of a system designates its probability of success. Hence, the probability of success will be reduced when the information content required to satisfy the FRs is enhanced. The total information content of a system is defined as sum of the information contents of the all FRs. Therefore, the system will be complex if the tolerances of FRs for the product are small, due to high accuracy which is required for the corresponding FRs. The other potential case of complexity occurs when the number of components of a system is high. Because increasing the number of components leads to summing up the complexity of these components together and consequently the probability of satisfying the FRs will be reduced. As a result, a physically large system is not necessarily complex if the information content is low. Conversely, even a small system can be complex if the information content is low.

According to the preceding arguments, it is always desired to reduce the information content of systems. The system should be capable of absorbing large variations in the design variables while satisfying the FRs simultaneously. Such design is called a robust design from AD point of view. The more accordance between the design range and the system range, the more robust the system becomes. Two approaches are investigated in this section in order to help the system range to lie in the design range.

2.2.1. Elimination of Bias:

"Bias" is referred to the difference between the target value and the mean value of the system range. The system range is determined by the Probability Distribution Function (PDF) of the system. If the difference between the mean value of PDF and the target value for the system converges to zero, the information content will be reduced. For this purpose, the bias associated with each of the FRs must be minimized in the systems with more than one functional requirement. In such systems if the architecture is coupled, it will be cumbersome to reduce the bias associated with the entire FRs simultaneously. Because changing a FR's bias leads to change in the other FRs' biases due to dependence between them. Therefore, dependent systems are not easily controllable. Conversely, in a decoupled or uncoupled system, making a change in one DP to eliminate the bias, will not lead to change in the bias for the other FRs.

2.2.2. Reduction of Variance:

Reduction of variance is another method of aiding to the accordance of the target range with the design range. In other words, if the variance converges to zero, the effect of noising factors which affect the system performance are eliminated. Similar to bias, the benefit of variance reduction is helping to satisfaction of the independence axiom. Therefore, it is always beneficial to reduce to variation. The variation could be reduced using several different approaches including reduction of stiffness, designing a system that is immune to variation, fixing the values of extra DPs, minimizing the random variation of DPs and PVs, compensation and increasing the design range [suh].

Table.1 Presents a comparison between applied approaches in DFV method to reduce GVI (or CI) and immediate effect on the two Axioms of AD. As it is illustrated in Table 1 and according to approach 1a, every improvement in configuration of mapping between components and functions is indeed a satisfactory effort to the independence axiom based on AD. In approach 1b, the unsuccessfulness of the approach which may be due to the lack of information is tried to be minimized as much as possible. (Without compromising any customer needs). In approach 2a, the internal coupling is intended to reduce with a reduction of sensitivity of a component. This operation leads to reduction of information content via variance reduction (Based on 2nd AD principle). Finally in approach 2b, the sensitivity of a component with respect to changes is reduced using overdesign. Also, this strategy could be interpreted via the 2nd principle of AD. It means, the variance and information content are reduced with the increase of the design range, which is leading to more probability of successful design.

There are two causes for a component to change over time:

1-external drivers (measured by GVI)- It comes from areas outside the designer’s control (changing customer requirements, regulations, competitor introductions, and so on)

2-Internal drivers (measured by CI-R)- It comes from the interactions between the product components.

Based on the framework of AD, the first one is directly related to 1st axiom, while the second one is more interpretable by the second axiom.

It is important to know that we face to similar situation in interpreting the CI reduction strategies. The only difference is that in GVI case we deal with relationship of Engineering metrics(as FRs) and DPs of component; But in CI case we deal with the inter-component coupling or relationship between DPs of two components (we can assume the receiving specification from one component as functional requirement of supplying specification from the other component as DP). Thus in both of GVI and CI, we have two different strategies, one is removing the relationship between the two related items (relationship between EM and Component in GVI case or relationship between two related components in CI case) and second one is reducing sensitivity of two related items (EM and component in GVI case and two components in CI case).

Therefore, an interpretation of flexibility and the relevant procedures which are based on AD are introduced up to now. Illustration of these indices by means of AD makes these approaches more intuitive to designers. Furthermore, these changes are incorporated into the automotive underbody to make it more robust to future market and design changes. The next section uses an automotive underbody example to illustrate application of the described approaches.

3. Case study: Automotive Underbody

This section covers a detailed application of DFV method to an automotive underbody. Efforts of a design team in order to calculate and reduce the GVI and CI indices for the underbody subsystem of an automotive’s Body in White (BIW) to design a product for future generation are reported in this section. The underbody system is considered as a significant platform system, not only due to its great effect on increasing commonality, but also for its significant role on basic elements of a platform such as product architecture and commonality in manufacturing process and production lines.

According to martin et al [14] Two types of variety should be considered when developing the architecture of a product: variety within the current product line being designed (‘‘spatial’’ variety) and variety across future generations of the product (‘‘generational’’ variety). These concepts are depicted in Fig. 1.

As illustrated in Fig. 1, during the design phase of the 1st generation of a B-Class segment passenger car, all three variants (Sedan, Hatchback, mini SUV) should be considered in such a way that, the platform parts and systems are easily modifiable and reusable in all variants. In other words, the design of a product family using a common platform could be entitled as "Design for Spatial Variety". But if the design is mainly performed based on future uncertainties, for example flexible design for different length, height or even new styles, this approach is named as "Design for Generational Variety". In the automotive industry, with high cost and long development time and considering emerging and competitive markets, both of the above-mentioned strategies are followed.

The Underbody system could be divided to three main parts (modules) as illustrated in Fig. 2. This system, not only, plays an important role in maximizing the commonality of a product family (Design for Spatial Variety), but also has a great influence on product and process architecture. According to Fig. 3, each of these 3 main parts could affect the different functions and attributes in vehicle level.

According to Nam P. Suh [20] complexity is defined as:

“A measure of uncertainty in understanding what it is we want to know or in achieving a functional requirement (FR).”

In this section, the CI and GVI indices of a complex under body system is studied. Finally, the design team applies these two indices to develop a decoupled architecture that requires less design effort for follow-on products.

3.1. Investigation of the floor panel according to GVI indices

In order to calculate the GVI according to DFV method, the relation between customer needs and engineering indices (QFD Phase I) and then the relation between system parts and engineering indices (QFD Phase II) must be known. Then, it is possible to identify and prioritize the parts which are potential candidates of modification due to the future uncertainties of customer needs.

In fig. 4, some of the engineering indices or Design Parameters (DPs) which have influence on GVI calculation are presented. The total length of the car which is a function of wheelbase, L1, L2 and also the suspension and power train mounting points (which has to be fixed in all variants of a product family) are some samples of engineering indices as illustrated in Fig. 4.

Also, the probability of changes in customer needs could be propagated into the phase II of QFD (in system level) and lead to probable changes to each part of the under body system.

As shown in fig 5, QFD phase I lists the customer needs and their relationship to engineering metrics. The last column is estimating qualitatively (high/medium/low) the range of changes for the customer requirements. These changes which are considered as risks of the future changes over platform are determined or judged by different methods such as conjoint analysis, trend analysis and market analysis.

As shown in Fig. 6, QFD phase II maps the engineering metrics (EMs) to the main parts of underbody, used in the current design. The GVI matrix is found based on the QFD phase II matrix considering the future target values of the EMs. The GVI matrix uses a 9/6/3/1 rating system for these estimations (the legend table in Fig. 7). For each EM/component node in the matrix according to Fig. 7, the team estimates the component redesign costs (including design effort, tooling, and testing) required to meet the future target value for the corresponding engineering metric. For the conventional automotive underbody, the front end (GVI=54) and the rear floor (GVI=54) are the main subassemblies that have higher percentage levels of redesign required to meet the future specifications.

3.2 Investigation of the floor pan according to CI indices

Developing the coupling index is carried out by considering the ‘‘specification flows’’ among components. These specification flows are defined as the design information that must be passed between designers to design their respective components. As a realistic approach and in order to simplify the complexity of the specifications flows, the main focus is on the geometrical parameters, and other parameters like material which could be easily selected and decoupled are not considered. Figure 8 shows the specification flows between the front body, front floor, and rear floor. For example, the design team has determined that changes in the ‘‘X/Y/Z-dimensions’’ specifications for the front floor can cause changes in the design of the rear floor. Fig 9 shows a graphical representation of the specification flows between main parts of automotive underbody.

Then, the team estimates sensitivity of each component to a small change in that Specification. If a minor change in the specification requires a modification in the component, then the component sensitivity is considered as high. If the specification requires major change to create a change in the receiving component, then it is considered as low sensitivity. The high sensitivity specifications are given a rating of 9, and the low sensitivity specifications are given a rating of 1 as shown in Fig. 10. Based on mentioned rating system, For each column and row, the sensitivities are summed for the conventional architecture of automotive underbody. The CI-R and CI-S for each of the modules are high, which means that the design has a relatively strong coupling between all modules in this matrix. Thus, we can conclude that each of the mentioned modules has high potential for standardization and modularization, because the calculated GVI and CI of main parts show that those modules are most likely to cause major redesign effort in later generations.

As mentioned before, by calculation of GVI index for a conventional underbody, the probable risk of changes of the main parts due to the future uncertainties was investigated. Also, the information strength between main parts of the underbody was also studied by calculation of CI index for a conventional underbody. Up to now, it could be guessed that the conventional architecture has a great potential for improvement in terms of DFV. As shown, mechanism of developing the generational variety index (GVI) and coupling index (CI) are themselves significant processes, which give the project team a more explicit understanding of the external drivers of change and of how changes may propagate throughout the design. The next section describes how these indices are further applied to develop a product platform architecture that is more robust to changes from the external or internal drivers.

3.3. Implementing GVI and CI reduction approaches on the underbody

In this section, the main goal is to implement the GVI and CI reduction approaches (as interpreted based on AD) on a conventional underbody system in order to redesign the current architecture to protect the design against future probable changes.

3.3.1. An example of GVI reduction applied to the Front End

The specification which links the front end and front overhang magnitude, is "L1" or longitudinal dimension of engine compartment (by different L1 values we can create different variants with different overhang sizes or different overall lengths of car). Removing this specification link (using approach 1a) would be possible by using a modular crash can. It is possible to achieve different overhang lengths by adjustment of the crash can length, so that changing the vehicle front overhang doesn't require major redesign or retooling (incorporating flexibility in product or process respectively). One possible design to separate a change in the crash can area from larger modifications to entire of the engine compartment or front end, is to have an engine compartment with Considering modular crash can in front bumper reinforcement. This architecture design is shown in Fig. 11. It allows upgrading (The front end and the front overhang specs are separated using the crash can) without a major design change, which leads to reduction of the GVI. But in this case, it is impossible to use the approach 1b, because it is difficult to freeze this specification that is tightly linked with customer needs (different lengths of car, different performances of cooling pack because of using different power trains with various performances and so on). Approach 2a is not applicable here since we applied approach 1a before and the proposed solution disconnects the relation between the spec and the component. Thus, it is not effective to reduce sensitivity of components by reduction of the internal coupling. Design to meet most stringent future overhang spec (approach 2b) is an expensive and inefficient way in this case.

Change in the customer requirements for vehicle height (eg: mini SUV derivation based on B-segment platform) is heavily linked to the suspension height or even the tire size. In traditional architecture, a change in the overall height of vehicle requires changing of the entire sub-frame (cradle) and also requires extra space for bigger tire envelop which may lead all neighbor parts of wheelhouse and even side frame to be changed. The achievable possibility is to decrease the internal coupling of the front end (approach 2a) so that it can be updated without major redesign and retooling costs.

Again, although this approach does not standardize the component, it helps to alleviate some of the effects of the change. The internal coupling may be reduced by modularization of the front end. So it can be down-sized by removing the spacer. For instance, the height of the vehicle could be modularized by placing an extender or spacer between the front end (sub-frame) and the suspension system (Fig. 12).

On the other hand, the design of the longitudinal frame should be in such a way that the bigger tire could be packaged, so this means considering headroom or the approach 2b. Thus, if the low end variant with 14 inch rim and high end variant with 17 inch rim are supposed to be produced, the design of the front end must guarantee the space required for bigger tire. So, the front end design must protect higher levels of specifications.

But, another engineering metric in body design of a vehicle is the level of common production processes in different body forms of a product family. So, it is required to use common positioning points of different variants as illustrated in Fig. 13. So, the approach 1b or freezing the positioning point coordinates is used in designing of the all common family products.

Of course, if there is possibility of change in the positioning points of a product family, another method is to consider flexibility in the process domain (not the product domain). It means implementing the approach 2b or considering modular fixtures in design of the production fixtures.

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A summary of these possible architecture changes for the front end subassembly is shown in Table 2.In design of a platform and a product family, the freezing contractual concept of some specifications in all variants of the product family is mostly used. As an example, the engine mount location points or suspension-body connecting points are mostly considered as design hard points. (due to maximizing the commonality). In this specific example, the engine bay width and even the vehicle track are freeze in all variants.

In table 2, a summary of applied approaches for front end GVI reduction and the solutions for product architecture changes are shown. It should be noted that these solutions are created after the brainstorming session among the design team members.

3.3.2. Examples of GVI reduction applied to the Front floor and the rear floor

The most important engineering metric which is potentially changeable due to either generational variety or spatial variety is the vehicle length. So the requirement of producing different variants of a vehicle with different wheelbase lengths, leads to front floor changes in the variants. Therefore, in order to have a robust design of this parameter while the wheelbase is not supposed to be frozen for a product family on a specific platform (most OEMs are acting like this in the recent years), two solutions could be considered. The first one is to use the approach 1a (removing the specification). Hence, it is enough to design the modular cross member by using small or big parts on the front floor and the smaller or bigger wheelbase could be achieved (According to 1a approach as depicted in Fig. 14). In this case, by using a medium cross member, the relation between the length of the vehicle and the front floor is removed, but the other solution is to use approach 1b by which the sensitivity of the front floor to the length variation is reduced in such a way that, the front floor is not changed in order to reach different wheelbase lengths.

So design of the front floor panel should be carried out according to the bigger wheelbase and in order to have smaller wheelbase, the bigger part could be trimmed without any modifications on the drawing operation. So, by considering a trimming operation, different wheelbase values are achieved. These two approaches are shown in Fig. 14.

It is possible to suggest new attractive solutions for modification of the floor panel architecture (just like front end) by brain storming among the design team members. Also regarding the rear floor and rear overhang, the 1a approach could be used. It means that using an extension could decouple the relation between rear overhang and rear floor. Therefore, it is possible to achieve different rear overhang sizes, while having a common rear floor panel is simultaneously (Fig. 15). For this system, freezing some specifications of the product family is used. Fig. 16 illustrates all of the vehicle architecture specifications used in this paper.

According to the previously-mentioned items, Fig. 17 illustrates a new architecture after applying DFV method on a conventional architecture of an underbody system. It should be noted, this example contains simplifying assumptions and in every product development project, and due to the project requirements, another approach may be used for adding flexibility to a conventional architecture. Main approaches used for each system are described briefly in Fig. 18.

After applying the design changes to the automotive underbody, the design team reviews the GVI and CI matrices to investigate if more changes should be applied to the architecture. They need to consider whether the GVI of the remaining components leads to significant redesign costs for those components, or if the changes are propagated, significant redesign of other components is required. For the automotive underbody, standardizing the front end, front floor and the rear end causes a significant reduction in the expected future redesign costs. It is obvious, after rearranging of a new architecture and informational disconnection between main components, CI factor will be reduced. Fig. 19 suggests the reduction of CI index in old and new architectures; also GVI calculation for a new architecture is illustrated in Fig.20 and in Fig. 21. A comparison of GVI reduction in old and new architectures is presented. So the above items state the robustness of the new architecture with respect to the changes initiated from internal and external sources of change.

CONCLUSIONS

Designing a suitable architecture for a platform is an essential step towards cheaper and faster development of a product family, so if this common platform is to be protected against future probable changes, the lifetime of the platform and its derived products will be increased considerably. In this paper, a new interpretation of the axiomatic design is presented. As a result of this argument, the axiomatic design framework is introduced to be a method which leads the system to be designed with high flexibility; i.e. such a system would be able to cover the future uncertainties with the minimal cost and time consumption. For this purpose, the two axioms are interpreted separately as elements of Design for variety.

The underbody of a new developing platform, which has a great role in platform architecture construction, is considered as a case study to implement the DFV method by reduction of CI and GVI indices. In this way, the indices are first calculated and then a sequence of solutions is proposed by the design team to reduce the value of these indices remarkably. As a result, the flexibility of the platform against future uncertainties is enhanced. Therefore, robustness of the new architecture to the internal and external sources of change is increased.

There are a number of sources of limitations in this work. These limitations are initiated from the data of a specific platform and a specific segment and are based on the assets of a specific OEM and also the brain storming of the design team who are involved in this case study. But development of this index and translating it into different domains based on AD logic could be a base for future investigations. Applying this method to the other system architectures like sub frame or other important platform parts could be studied as well.

REFERENCES

1. Ying-Ming Wang, Kwai-Sang Chi: A neutral DEA model for cross-efficiency evaluation and its extension, in Expert Systems with Applications, An International Journal (2010),ref 3666–3675

2. Salah R. Agha, Ibrahim Kuhail, Nader Abdelnabi, Mahmoud Salem, Ahmed Ghanim: Assessment of academic departments efficiency using data envelopment analysis. Journal of Industrial Engineering and Management (2011), p301-325.

3. GU¨LSER KO¨KSAL & BURAK NALC¸ACI," The relative efficiency of departments at a Turkish engineering college: A data envelopment analysis ", International Journal of Operations & Production Management (2006) 51: 173–189

4. Rita Markovits-Somogyi," ranking efficient and inefficient decision making Units in data envelopment analysis ", Industrial Management & Data Systems, (2011)pp. 446 – 456

5. Abbott, M., & Doucouliagos, C. The Efficiency of Australian Universities: A Data Envelopment Analysis. Economics of Education Review, 22(1),(2003), 89-97..

6. Lopes, A., Lanzer, E. Data Envelopment Analysis-DEA And Fuzzy Sets to Assess The Performance of Academic Departments: A Study at Federal University Of Santa Catrina-UFSC. Pesquisa Operacional, 22(2), (2002), 217-230.

7. Moreno, A. & Tadepalli, R.. Assessing Academic Department Efficiency a Public University. Managerial and Decision Economics, 23(7), 385-397.8. Janusz Bucki Yvon Pesqueux, (2000),"Flexible workshop: about the concept of flexibility", International Journal of Agile Management Systems, Vol. 2 Iss 1, (2002) pp. 62 – 70

9. Tom Davis (1993) ,"Effective Supply Chain Management",Sloan Management Review, Summer 1993 edition.

10. Nand Kumar, Ranganath.M.S, Chandrashekhar, "Sustainability Analysis of Banking Sector in India using DEA", in National Conference on Inclusive & Sustainable Growth - IMT Nagpur

11. www.emeraldinsight.com

12. Banxia Frontier Analyst 4 Demo version.