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IIntroduction

Today where the products life is shortened due to rapid advancement in research and technology, the major challenge confronted by manufacturing companies is structuring of product development process targeted to reduce the products lead time to market. The word structuring refers to core aspects of transformations needed in product development process suiting to the requirements of customers and other stake holders. There are many research papers describing various techniques and ideas on enhancement of product development process. This present thesis is mainly concentrated on exploring in a more detailed manner on how we can aggravate the product development process using one of the Artificial intelligence (AI) techniques named "Case Based Reasoning (CBR)".

Over the last few years, case based reasoning (CBR) has grown from a rather specific and isolated research area to a field of wide spread interest. This project deals with application of CBR for Roof rack component in cars manufactured by Thule with prime interest on reducing the products lead time to market.

I.I Company Presentation

Thule brand was first established in Sweden in 1942 by a Thulin family, when Erik Thulin an true outdoor lover put the name Thule on pike trap which he designed and started selling to fishermen of Scandinavia. Gradually he started adding more practical things to his company's product range which ensured the growth of his business.

In 1960, the company began to concentrate on car related products and added more product categories by end of 1970's and explored new markets around the world. In 1979 the Thulin family sold Thule to the publicly listed company Eldon but the entrepreneurship and drive has remained and Thule group continued to grow organically and by acquisitions of companies and soon evolved as a Thule Group with new product categories and markets in its portfolio[1].Since then the company is in growth mode.

Headquarters of Thule is in Malmö, Sweden and company presently has almost 50 production facilities all over the world with sales of over 5.7billion Sek (2010) and approximately 3100 employees. The major market for Thule is Automobile industry.

Today Thule is a premium brand used globally for a wide assortment of products with a focus on how to make easier for people around the world to bring their equipments and personal accessories when they are seeking to enjoy their life.

Thule Group mission is to be "the number one choice of consumers around the world that want to transport their equipment safely, easily and in style"[1].

The product and business areas:

Under the motto active life, the Thule Group offers products in four different areas[2]:

Carry Solutions (Laptops, Camera bags, Bag packs, etc.) Vehicle Solutions(Roof racks, Bike racks, Ski boxes, Snow chains, etc.)



Work Solutions (Tool boxes, Ladder racks, etc.)





Towing solutions (Tow bars and Trailers, etc.)



The product roof racks in cars are our main area of interest. KIT (referred to foot with bracket and foot pad) development at Thule is making of new variants of car contact parts (part of existing roof rack system) to fit new cars (new fits) on the market.

The requirements of this product being very high in terms of safety, load bearing capacity and crash testing etc. All the research and development are carried out in the Thule plant Hillerstorp, Jönköping in co-ordination with SP research institute, Borås.

I.2 Thesis Background

This thesis project is a part of ongoing research work on time frame reduction in variant rich products for Roof rack component in cars manufactured by company Thule. The main focus of research is aimed at curtailing the products lead time to market.

The Product roof racks which are mounted on car roofs directly i.e. without the support of rails, as the roof rack consists a foot with bracket and foot pad which is designed based on the geometry of car roof directly. Hence this roof rack has to be adapted to all car models it is supporting. Adaptation process is achieved by modifying two components, the bracket and the foot pad (referred as Kit by engineers). The foot pad is a rubber pad on which track is standing on the roof and the bracket is used to fix the rack by keeping around the roof end. As the company acts in open market competing with car manufacturers, therefore it cannot get nominal data of car roofs. Instead of which they have to gather the geometrical information about car roofs by measuring. Once this information is collected for a particular car model, then foot pad is developed and rack is placed on foot pad as a virtual model[3].



Figure 0.1: The roof rack product is adapted to new car-models by changing the foot pad and the brackets components[3]

Traditionally the drawing of the assembly was created and used to search existing brackets and this was painful task and time consuming for engineers who instead would draw a new one, as list of brackets keep on increasing with models. Two projects one in 2006 and other in 2011 resulted in shortening of lead time by 40%. The system was implemented in two phases. During the first phase, in 2006, it was implemented as stand-alone software with an user interface based on parameter inputs. In 2011 the system was re-implemented as an add-in to the CAD-system presently used at the company. The reasons for re-implementing the system were that, even though speeding the search mechanism, it was time consuming to save new designs into the system, it was error-prone to manually put in parameters representing new brackets, and the engineers felt that the hit rate was poor. When re-implementing the system as an add-in to the CAD-system it became easier to the engineers to store information about the new designs. It also became easier to interpret the information in the system, avoiding errors. Due to these improvements the system is now used on an everyday basis by several engineers in several countries.

Even though the engineers do find re-useable designs it is not the ones that the system presents as top-rated that are re-used. When interviewing some of the

engineers they state that it is seldom that the selected design to re-use is among the top-ten listed by the system. This was achieved by using an Artificial intelligence (AI) technique- Case Based Reasoning (CBR) for searching of brackets and the results obtained after implementation is detailed below.

- Search done in milliseconds instead of hours when done manually.
- Hit rate better than manual.

I.3 Purpose and research

This thesis project concentrates on exploring broader prospects of improving this present technique by enhancing the Kit development process further and also suiting the requirements of designer.

The aim of this thesis work is:

- Categorize the implemented concept with respect to scientific literature.
- How can we inculcate new or modify the Case-based reasoning Algorithm in a way reducing the time frame for reuse of brackets in roof rack products?
- How can we make the process more refined and compatible for the designer?

I.4 Delimitations

The main purpose of this master thesis work is to design and develop a system for reuse of roof rack components for variant rich products by using Case-based reasoning. By which this thesis constrained merely to parameters in design which being geometries of roof rack components. Therefore the effects of the mechanical properties, materials properties, manufacturing aspects and also costs are not taken into consideration in this thesis.

I.5 Outline

This master thesis is divided into following chapters.Chapter1: Introduction in the problem, Chapter 2: Theoretical background about Case Based Reasoning Algorithm (CBR), Chapter 3: Implementation, this chapter describes 'how to implement CBR system to variant-rich products', Chapter 4: The results from the CBR system are presented and discussed, Chapter 5: Conclusion of this thesis work, Chapter 6: Describes the future work.

2 Theoretical background

Theory that is used in this thesis is Case-based reasoning Algorithm (CBR) by which Case-based reasoning support design decision of cases (brackets). Firstly, whole concepts of case-based reasoning are assigned to the system and then using CBR to define reasonable cases to consider in designed cases is the goal of this thesis.

2.1 History of the CBR Algorithm

Case-based reasoning imitates human thinking trying to make a decision based on previous experiences. The roots of case-based reasoning in AI are found in the works of Roger Schank on dynamic memory. The center role that reminding of earlier situation(episodes, case) and situation patterns (scripts, MOPs) have in problem solving and learning[4]. During 1977 to 1993, Case-based reasoning Algorithm (CBR) was rapidly regarded as reasonable high-level model for understanding processes by which it concentrated deeply on problems, for example how humans generate theories about new situations or problems by relying on their previous experiences and how humans learn, understand a new skill to solve problems. The goals of these algorithms were to build decision support systems making work simpler for users. Many CBR model systems were created during this period ,for instance the first system that might be called ' a case based reasoner' was the CYRUS system, developed by Janet Kolodner[5, 6], at Yale University (Schank's group) after that there were successively development many systems based on CBR which being MEDIATOR[7], PERSUADER [8], CHEF[9], JULIA[10], CASEY[11].

Moreover Case-based reasoning is brought to use for the study of analogical reasoning [12] and also from theories of concept formation, problem solving and experiential learning within philosophy and psychology [13-15]. Various CBR workshops were organized in 1988, 1989, and 1991 by the U.S. Defense Advanced Research Projects Agency (DARPA) by which events are provided to create the official discipline of Case-based Reasoning[16]. In addition, other significant artificial intelligence conference such as ECAI (European Conference on Artificial Intelligence) in which CBR system has been part of their usual programs[16]. In 1993, the first European workshop on Case-based Reasoning (EWCBR-93) was created in Kaiserslautern, Germany [17].Thereafter, many international workshops and conference about CBR have been created in different parts of the world.

In recent years, Case-based reasoning has been adapted in many fields. For instance there is Case-based reasoning technology for applying in Product conceptual Design given by Peigang et al. in 2011[18].Case-based reasoning is applied in the functional mode as structural and functional carrier, it is expressed in form of codes which match case parts and then they are evaluated to find the concept to solid parts as shown in the figure2.1 below



Figure 2.1: Using CBR algorithm for applying in Product conceptual Design for prototype machine [19]

2.2 Main Types of Case-based reasoning Methods

Case-based reasoning (CBR) model is supported in cases for organizing, retrieving, utilizing and indexing the knowledge retained in previous cases. Here many cases may be considered as specific experiences or can be utilized as a set of similar cases for retrieving and adapting to new cases. Moreover they may provide directly the solution to modified case if they do not have any differences in correlating two cases. As mentioned before, Case-based reasoning model is used to conceive solutions by comparing cases, adapting solutions and using knowledge from previous cases. This helps humans to learn deeply more about the model, solve problems and helps in designing system. While some cases might not comprise knowledge structure completely based on Case-based reasoning rather it is used only in a specific part of whole structure. Thus it might be concluded that Case-based reasoning model is usually used as interactive system within a whole system.

There are many ways for implementing Artificial intelligence systems to help in design or solve problems. These reasons might have some ambiguity about Casebased reasoning, particularly the way it can be adapted in a system. Thus, there is an attempt to clarify the Case-based-reasoning term to distinguish with other separate kinds of case-based reasoning and this is described in topics below.

2.2.1 Exemplar-based reasoning

The term "exemplar-based reasoning" is defined from a classification of different views to concept definition into 'the classical view', 'the probabilistic view', and 'the exemplar view' (see[13]) as shown in figure2 below describing about the concept of birds representing in terms of exemplars. In exemplar view cases are organized based on the view that should be defined extensionally with case being referred to as exemplars. The term is a network structure of categories, semantic relations, case and index pointers by which three types of indices are provided as mentioned below[20]:

- 1. Feature links that point from problem descriptors to a case.
- 2. Case links that point from categories to its associated cases
- 3. Difference links pointing from categories to the closed case that merely differ small features.

These three types of indices is the network background in order to build general domain knowledge to support CBR tasks. A new case will be retained by searching for a matching case by which if a case is found with only small differences between previous case and new one, the new case might not be retained but will combine both cases to retain.



Figure 2.2: An exemplar representation in terms of some of bird's exemplars[13]



2.2.2 Instance-based reasoning

This is specialization of the exemplar-based reasoning to a deeply syntactic Casebased reasoning method. Instance-based reasoning has a duty to reward for lack of guidance of background knowledge from exemplar-based reasoning to get more detailed information in order to close in new instance. This is especially because of approach that they typically consider about nearest neighbor concept for new instances. Thus all information will be attempted to retrieve particularly from background knowledge in order to get most similar instances. On the other hand, exemplar-based reasoning has a target concept depending on only a few of the available details of information.

Basically; instance-based reasoning is a non-generalization approach to the concept learning problem addressed by classical, inductive machine learning methods [21]. The present thesis core concept is also based on this particular approach, where the instances are interpreted as brackets. This resemblance can be contemplated clearly in implementation part described in further topics.

2.2.3 Memory-based reasoning

This method is comprised of memory organization sets by which they will be accessing and searching in the memory to focus of the case-based knowledge. The utilization of parallel processing techniques is a characteristic of these methods, and distinguishes this approach from the others. The access and storage methods may rely on purely syntactic criteria, as in the MBR-Talk system [22].Moreover, CRAIG STANFILL and DAVID WALT [23] mentioned about memory-based reasoning that studying of cognition will be difficult to conceive of thought without memory. Another thing is the inability of Artificial Intelligence to achieve success in any broad domain or to effectively capture the notion of "common sense".

Thus, the goal of memory-based reasoning is to make decisions by looking cases in databases that use similarity based learning. The memory-based reasoning solves and defines cases by using direct reference or databases to memory without using the rules.

This approach has a close resemblance to that of concept implemented in 2006 where the all the data has to be entered manually and the similar brackets is retrieved by comparison of input data exactly with respect to data inherited in memory of system. The similarity of 2006 implemented concept to this approach can related better in implementation part clearly mentioned in further topics below.

2.2.4 Case-based reasoning

Case-based reasoning is used as a generic term in this thesis, it has a particular method that can distinguish based on approach towards solutions, which in casebased reasoning is based on the principle that a new problem-solving case can benefit from the solution of previous cases. The cycle of case-based reasoning comprises four activities [20]:

- 1. Depict the input problem and specify an index.
- 2. Retrieve similar cases to the new problem from the case library.
- 3. Revise or adapt the solution to satisfy the new problem
- 4. Retain the new solution once it has been confirmed or validated under some strategies.

Kolodner[20] describes that " Case-based reasoning as adapting old solutions to meet new demands, using old cases to explain new situations, using old cases to critique new solution, reasoning from precedents to interpret a new situation".

2.2.5 Analogy-based reasoning

Analogical reasoning is based on the idea that problems or experiences outside the circumstances that we are currently dealing with may provide some insight or assistance to find a solution and it is often termed as a synonym to case-based reasoning. Analogy is a way of recognizing something that has not been encountered before by associating it with some related terms. Research on analogy reasoning is therefore a subfield concerned with mechanisms for identification and utilization of cross-domain analogies [3, 24]. The main topic of study has been on the reuse of a past case, called the mapping problem: Finding a way to transfer, or map the solution of an identified analogue (called source or base) to the present problem (called target).

2.3 Case-Based Reasoning Concept

In this context we will explain more deeply about concepts of case-based reasoning and the process involved in application of Case-based-reasoning and the main attributes that defines the working of whole concept.





2.3.1 Indexing construction of existing cases

Case indexing is the process of retrieving similar cases. The main two points that must be considered when creating a case index is firstly, the important feature must be indexed first and the case is then organized ensuring efficient and accurate search of case library. The classification of case index can be categorized according to the attributes that defines whole structuring of case for example a die casting part can be assigned with digits referred as case identification code representing product shape, filling system , functional components (Sliders and lifters), ejector system etc[27].

Secondly, indexing construction might be assigned in a way which engineer prefers designing a particular case i.e., the case index is structured based on preferences of the designer in way providing flexibility in retrieving the cases from case library.

2.3.2 Retrieve

The retrieval of cases in case-based reasoning operation is process to browse and select a relevant design case achieved normally by comparing similar previous design case with new design case.

Recalling databases or previous experience to find the similar cases that is suitable for problem solving. The usage of the term similarity in Case-based reasoning method will focus on similarity as a fuzzy relation between previous and new cases. Then there will be adapting previous case to solve a problem in new cases.

In our thesis, we retrieve cases based on the "weights" that's get assigned to each of case based on nearest neighbor corresponding to the search case parameters[28]. The parameter here is restricted to geometry and some of constraints developed based data collected.

2.3.3 Adapting case histories (Reuse)

Adapting the current case with the retrieved similar case is critical in Case-based reasoning. Normally, new cases rarely match old cases exactly and thus it is necessary to adapt old solution to new case and we define the three general kinds of adaptation to define the suitable solution for the new cases:

- 1. Null adaptation means use an old solution and apply it to current design without adapting it.
- 2. Topological adaptation that separate the main structure of cases (for example the brackets have two kinds which being one with a hole and without hole)
- 3. Parametric adaptation that corresponds to the substitution or adjustment of parameter design (for example the angle of the last part of the bracket and the last bending point of brackets)

In this thesis, our emphasis is more on reducing products design and development time, thus decreasing costs and product lead time to market. Thus adapting case concern merely about the geometries of brackets, they do not need to notice about other properties in design as shown in the three concepts of adaptation above. Worth noticing though, is that type two and type three may cause very different impacts on the adaption process. For instance adding hole (topological change) to an existing design might be much cheaper than changing a wall thickness (parametrical change).

2.3.4 Review (Revise)

Once the adaptation process is finished then next step is reviewing the adapted case to the existing ones in a way making sure that adapted case is confronting to conditions of new case. If the new case matches to one of previous cases completely without any adaptation (Null adaptation), then the further sequential steps after adaptation in Case-based reasoning process is bypassed as pointed by arrow in figure-2.3. As the present adapted case matches to situation in one of the similar previous case, thus the further steps is not necessary to accomplish as it is already matches an existing case in case library.

Review step mainly focuses on evaluation to specification of new product variants and if any discrepancies are found then case is rejected and the whole process is repeated. Thus the cases which are passed by review step is retained in case library as new case.

2.3.5 Retain

After all the process of case-based reasoning (CBR) have done, the new or modified case (brackets) will finally be stored to database for returning back to system again for new case as shown in figure-2.3.

2.4 Models of CBR process

In order to describe CBR process, several general models have been proposed and some of them are explained below.

Kolodner Model:

Kolodner (1993) considered CBR as a process containing the following steps shown in figure-2.4 which portrays case retrieval as primary step, proposing different solutions based on the extracted cases. Next is adaptation where the past solution is modified to fit in new situation, criticism of new solution, its evaluation based on external feedback and lastly storage of verified solution of the present problem in case base [19].

Kolodner emphasizes two main roles for CBR: [19]

<u>Problem Solving:</u>

Adaptation of ball park solution (within the scope) to new solution and then criticized, forms main aspect of CBR. If new solution fails it is adapted again.

• Interpretive Task:

In this task a ball park (within the scope) interpretation is proposed, followed by justification process which tries to create arguments for proposed solution. Justification process compares and contrasts the situation with past cases, looking for similarities between new solution and others that accomplish the desired result.



Figure 2.4 CBR model according to Kolodner (1993)

Aamodt and Plaza (1994) introduced a model which consists the following phases: [19]

- Retrieve the most similar cases
- Reuse the cases
- Revise the proposed solution
- Retain the new solution as part of new case

The model is commonly known as R4 model of CBR, because the process involved in this model can be represented by scheme comprising four REs as shown in figure-2.5. As we can see each step involves more specific steps, for example, retrieve includes identify, search, initially match and select (Aamodt and plaza, 1994).



Figure 2.5 The model of CBR process (modified Aamodt and Plaza, 1994)

However, these models assume that the case base is readily available "at once" for case retrieval and ignore the fact that case building is also an important task. Finnie and Sun in their work (Finnie and Sun, 2003) have taken in to consideration the preparation of case bases. They extended the model of Aamodt and plaza by adding a new step: "repartition, which builds a satisfactory case base based on utilizing similarity relations to the possible world of problems and solutions (figure-2.6)" [19].



Figure 2.6 CBR process model according to Finnie and Sun (2003)

2.5 Main advantages of Case-based-reasoning:

- <u>Can be applied to broad range of domains</u>: Case based reasoning can be applied to extremely diversified application domains. This is due to limitless number of ways of representing, indexing, retrieving and adapting cases[29].
- <u>Reason with incomplete or imprecise data and concept</u>: The cases retrieved might not be identical to the current query case , but if there exists some defined measure of similarity to query case that's enough as any incompleteness or imprecision can be dealt by case based reasoner. Although this may not relate to exact solution but at least the concept can be derived[29].
- <u>Reason in domains that have not fully understood or modeled</u>: In context where insufficient knowledge exists to build a causal model of a domain, a case based reasoner can still be developed using only a small set of cases from the domain. The underlying theory of domain knowledge need not be quantified[29].

2.6 Drawbacks of Case-based-reasoning:

- Learning, although natural and intuitive, demands some careful considerations as to which cases are added in case library, and how[30].
- Adaptation may be difficult or sometimes impossible for many domains. In others it is done with rules[30].
- Matching process, if complex can add computational cost to CBR system, regardless of how well case library may be designed. In many cases, the distance calculations between the desired solution and actual solution can be difficult to make. This is from a conceptual as well as a computational point of view[30].

2.7 Examples of Algorithms in Case-based reasoning:

Case based reasoning has broad range of domain where it can be applied. Every application can be represented in terms of algorithm and thus we address it as case-based reasoning algorithms. Below we mention a few algorithms applied in different domains.

2.7.1 Indexing and retrieval in case-based process planning for multistage non-axisymmetric deep drawing:

Case based reasoning methodology adopted here is for computer-aided process planning (CAPP) for multistage, non-axisymmetric sheet metal deep drawing. This methodology addresses the indexing and retrieval of process planning cases. Planning cases are done based on feature-based representation of deep drawn parts. Efficient case retrieval is achieved by a feature-based similarity analysis between a new deep drawn part and existing parts in case library[31].

The below figure illustrates the frame work of Case based reasoning system for CAPP for multistage non axisymmetric sheet metal deep drawing. The major modules are case indexer, case retriever, case adapter and case library.

Initially case library consists of few cases retrieved from traditional knowledge based systems or industrial practices. To facilitate case retrieval, each new deep drawn part with its object geometry is described using a feature based representation and it becomes input to the case indexer, which can identify deep drawn parts. Then it is passed to the next step i.e., case retriever, which extracts a case (from case library) that is most similar to the input case and here it employs feature-based similarity analysis. If the retrieved closest case doesn't match the input case then it is passed to case adapter where it is tailors the retrieved case to match the requirements of input case. Finally the output is given to user and case is stored in library as a new historical case [31].

2.7.1.1 Case representation:

A collection of deep drawing features are used here to model a sheet metal deep drawn part. All of these part features is to encapsulate a set of design and manufacturing information including geometric information such as shape, tolerance, surface finish and also includes non-geometric information like material parameters. A commercial CAD system, Solid Edge, is used to support the representation and extraction of feature model for all deep drawn parts in case library.

2.7.1.2 Case library:

The case library consists a number of cases defined in a frame structure that describes design requirements and process planning solution. The design requirements are defined by feature representation and the process planning is defined as a complete process plan for forming a flat blank to final deep drawn part , including all the process sequence with intermediate geometries and process parameters such as initial drawing coefficient , punching force, die profile radii , blank holding force etc.

2.7.1.3 Case Indexing:

It is important criteria in case based reasoning on which the effect of retrieval of most similar case from a large case library. For achieving this it is necessary that the indexing is done in proper way so that system can identify the closest quickly and easily. Here in this case feature geometric parameters and material parameters are used as indices. The feature geometric parameter is main factor that govern the similarity between newly deep drawn part and existing one in case library. The material parameters also influence the similarity match, but are less critical. To avoid any contradictory results the similarity is matched based on weight (importance) of each index.

2.7.1.4 Case Retrieval:

Case retrieval requires a combination of searching and matching. Here in this case similarity match is based on new deep drawn part and the existing parts using the following metric:[31]

$$Sim = (S_{part-geometry} * w_{part-geometry} + S_{material} * w_{material}) / (w_{part-geometry} + w_{material})$$
(1)

where Sim- denotes the similarity metric between two deep drawn parts; $S_{part-geometry}$ and $S_{material}$ respectively denote part geometric and material similarity between two parts; $w_{part-geometry}$ and $w_{material}$ respectively denote weights of part geometry and material.

The material similarity $S_{material}$ between two parts in Eq.1 is defined as inverse of the material resemblance distance between two parts:

 $S_{material} = 1 - D_{material}$ (2)

It can be proven that $D_{material}$ ranges from 0.0 to 1.0 i.e., $D_{material} \in [0.0, 1.0]$, hence $S_{material} \in [0.0, 1.0]$. For similarity value 0.0 indicates "most dissimilar" and 1.0 indicates "most similar". For resemblance distance value, 0.0 indicates "closest" and 1.0 indicates "most distant". This notation applies all through this concept.

The part geometric similarity mentioned in Eq.1 is defined as aggregation of all the feature geometric corresponding deep drawing feature pairs in the new and old existing parts as shown below.

$$S_{part-geometry} = 2 * \underbrace{\sum_{i=1}^{m} S_{feature-geometry}^{i}}_{2m+n}$$
(3)

Where $S_{feature-geometry}^{i}$ – feature geometric similarity between the ith matched feature pair in new and existing parts.

m – matched feature pairs applying to both new and existing parts(numerator is multiplied by 2)

n – number of unmatched deep drawing features either in new or existing parts.

Further, $S_{feature-geometry}^{i}$ is defined as the inverse of the geometry resemblance distance between the ith matched feature pair, and shown below:

$$S_{feature-geometry}^{i} = 1 - D_{feature-geometry}^{i}$$
⁽⁴⁾

 $D_{feature-geometry}^{i}$ – Geometry resemblance distance between ith matched feature pair, which is expressed as a normalized Euclidean distance between corresponding features (shape, tolerance and finish).

The shape parameters are expressed as $\frac{D_{mi}^F}{D_{ma}^F}$, $\frac{D_{ma}}{D_{ma}}$, $\frac{D_{mi}}{D_{ma}}$, $\frac{D_{mi}}{R_{ma}}$, $\frac{D_{mi}}{R_{ma}}$, $\frac{D_{mi}}{R_{ma}}$, $\frac{D_{mi}}{R_{ma}}$, $\frac{R_1}{R_{ma}}$, $\frac{R_2}{T}$, $\frac{R_3}{T}$ and θ , where D_{ma}^F and D_{mi}^F denotes diameter of the flange along the major and minor axes; D_{ma} and D_{mi} denote diameters of the drawn cup along the major and minor axes; R_{ma} and R_{mi} denote the curve radii of the drawn cup along major and minor axes; H- height of drawn cup and θ – taper angle of drawn cup;

T- thickness of the sheet metal as shown in figure-3.1

 R_1, R_2, R_3 – Several important fillet radii.





Figure 2.7 Feature shape parameters of an extracted deep drawn part [31]



Figure 2.8 Flow chart of the case retrieval algorithm for similarity analysis [31]







Figure 2.10 Similarity metric calculation chart between case#025 and new case [31]

In summary, to calculate the similarity metric the shape resemblance distance $D_{shape}^{i} \in [0.0, 1.0]$ between the ith matched feature pair is calculated first with Eq.5 which is then substituted into Eq.4 to calculate the feature geometric similarity $S_{feature-geometry}^{i} \in [0.0, 1.0]$ between the ith matched feature pair. $S_{part-geometry} \in [0.0, 1.0]$ between two parts is calculated by substituting $S_{feature-geometry}^{i}$ into Eq.3. The material similarity is calculated $S_{material} \in [0.0, 1.0]$ between two parts is calculated by substituting $S_{feature-geometry}^{i}$ into Eq.3. The material similarity is calculated $S_{material} \in [0.0, 1.0]$ between two parts is calculated $S_{material} \in [0.0, 1.0]$.

Note that all the weights in these equations are determined by experience.

2.7.2 A case based reasoning approach for generating new product ideas:

In this approach a product is represented by a vector, which involves a number of product attributes. These attributes are defined based on user-centered design (UCD) paradigm i.e., the context of use and an interaction with users for the product is described by these attributes. By the product representation, a product database can be established and for a benchmarking product we use case-based reasoning technique to retrieve those products which are "sufficiently relevant" to the benchmarking one, from the database [32]. The functions of the retrieved products are the candidate for new ideas to be added onto the benchmarking product. All the retrieved products are screened manually for identification of creative and valuable ideas.

UCD is defined as "philosophy based on needs and interests of the user, with an emphasis on making products usable and understandable" [33]. The ISO 13407 standard also provides a frame work for applying UCD [34]. According to this standard UCD activities need to start at the earliest stages of product development: (1) understand and specify the context of use, (2) specify the user and organizational requirements (3) produce design solutions and (4) evaluate designs against requirements. UCD has been widely used in industry [35, 36] and some example applications are design of modern microelectronic products [37], design of a website [38], the design of a user interface of welding machine [39] and the design of new product concept [40].

2.7.2.1 Product Representation:

As mentioned above the product is modeled by a vector consisting of a number of product attributes. According to paradigm of UCD these product attributes are developed from five dimensions[32]:

1) Interface modality:

This dimension is used to identify the medium through which the product interacts with user. Here medium denotes a particular portion of the user's body. Here it is put into three subdivisions sensory modality, response modality and positioning location. *Sensory modality* represents medium or Sensors through which the user receives messages sent from product for example sensory modality of a watch is visual and of a radio is audio. Next, *response modality* denotes the medium through which the user responds or manipulates the product; some of its attributes are face, neck, hand, foot etc. For example a pair of glasses involves two response modality attributes face and eyes. Finally the *positioning location* denotes the medium through which the user carries the product and related attributes are head, chest, hand, back etc. For example a pocket watch involves chest-waist.

2) Task:

The second dimension- task is to model the tasks to be performed by the user through using the product. According to users these are also categorised into seven groups they are eating, clothing, living, transportation, education/entertainment, working and healthcare. All these groups describe the tasks relevant to the definitions described by their names. For example *cooking pot* is for the processing of food- related to eating group, a *washing machine* is for cleaning purpose-related to clothing group, GPS is used for navigation purpose-related to transportation , email and tape recorder systems where one is for entertainment and education – related to education/entertainment, telephone and thermometer where one is used for communication and other is for inspection – related to working group and finally soap, wheel chair in which one is used for daily maintenance purpose and other rehabilitation purpose.

3) Physical feature:

This dimension is characterized by three features physical size, movability and scalability. The best example this group is notebook medium in size, portable and medium level in scalability.

4) Environment:

This dimension describes about the environment where the product is used. This is further characterized into three subdivisions which are number of users, indoor/outdoor place and the harshness of the environment. Numbers of users constitute for products usage example a television is for group and where as personal digital assistant is for single user. Similarly for indoor/outdoor we can cite an example such as printer which is only indoor use and walkie-talkie serves both indoor and outdoor and finally for harshness of environment the example is industrial computer which can be used in high temperature and high noise environment.

5) Users:

The final dimension users are characterized by the following demographic features; gender, age group, working industry and job position. The gender denotes to population of users in terms of gender, age group represents young, adult, child, infant and aged, working industry denotes to type of industry like agriculture, manufacturing, trade, service/education and government,

finally job position is clustered as middle management, top management, office clerk etc.

Thus based on the representation scheme mentioned above a product can be modelled by a vector consisting 87 attribute values. Each attribute of a product can be valued in five scale points; extreme relevance (1.0), relevance (0.5), low relevance (0.25), no relevance (0). Below figure-3.5 shows the vector representation of two products, cell phone and ball pen.

ID	Dimension	Group	Attribute	Cell phone	Ball pen
1	Interface Modality	sensory modality	visualization (or sight)	0.5	1.0
2			audio/hearing	1.0	0
3			gustatory (or tasting)	0	0
4			olfactory (or smelling)	0	0
5			tactile	0.5	0.5
6		response modality	eye	0.5	1.0
7			mouth	1.0	0
8			face	0.5	0.5
9			neck	0.5	0
10			hand	1.0	1.0
11			foot	0	0
12			finger	0.5	0.5
13		positioning location	head	0	0.25
14			neck-shoulder	0.25	0
15			chest-waist	1.0	1.0
16			back	0	0
17			hand	0.5	0.5
18			foot	0	0
19	Tasks	eating	preparation	0	0
20			processing	0	0
21			serving	0	0
22			cleaning	0	0
23		clothing	preparation	0	0
24			modification	0	0
25			cleaning	0	0
26		living	cleaning	0	0
27			maintenance	0	0
28			monitoring	0	0
29			decorating	0	0
30		transportation	planning	0.5	1.0
31			navigating	0	0
32			monitoring	0	0
33			emergency handling	1.0	0
34			vehicle	0	0
35		education/entertainment	searching	0.5	0
36			understanding/integrating	0	0
37			creating	0.5	1.0
38			Storing	0.25	0
39			distributing	0.25	0.75
40		working	planning	0.25	1.0
41			execution	0.5	0.25
42			inspection/review	0	0.5
43			decision	0.25	0
44			communication	1	0.25
45		health care	daily maintenance	0	0
46			detection/diagnosis	0	0
47			remedy	0	0
48			rehabilitation	0	0

1D Dimension	Group	Attribute	Cell phone	Ball pen
49 Physical Feature	physical size	mini	0.25	0.25
50		small	0.75	0.75
51		medium	0	0
52		large	0	0
53		extra-large	0	0
54	movability	portable	1.0	1.0
55		stationary	0	0
56	scaleability	small	0	0.5
57		medium	1.0	0.5
58		large	0	0
59 Environment	number of users	single user	1.0	1.0
60		group of users	0	0
61	indoor/outdoorplace	indoor	0.5	0.5
62	-	outdoor	0.5	0.5
63	the harshness of environment	illumination	0.75	0.75
64		temperature	0.5	0.5
65		humidity	0.5	0.5
66		noise/vibration	0.25	0.5
67		dust	0.5	0.5
68		pressure	0.5	0.5
69 Users	gender	male	0.5	0.5
70		female	0.5	0.5
71	age group	infant	0	0
12		child	0.25	0
73		teenager	0.5	0.25
/4		young adult	0.5	0.5
75		adult	0.5	0.5
76		the aged	0.25	0.25
77	workingindustry	agriculture	0.5	0.5
78		manufacturing	0.5	0.5
79		trade	0.5	0.5
80		service/education	0.5	0.5
81		government	0.5	0.5
82	job position	top management	0.5	0.5
83		middle management	0.5	0.5
84		supervisor	0.5	0.5
05		engineer	0.5	0.5
80		engineer	410	
85 86		office clerk	0.5	0.5



2.7.2.2 Generation of New product ideas:

Based on the proposed product representation scheme, here they case based reasoning technique for generating new product ideas. The idea generation mechanism starts with bench marking the product, an existing product on which new functions are to be added. For this purpose we use the high value attributes (≥ 0.75) as keys to retrieve other products that are "sufficiently relevant" to the benchmarking product. All the retrieved products are screened and subsequently rated manually to determine the quality of the new ideas (i.e., how creative and valuable it is). Computing the relevance metric:[32]

If we take an already established product database, involving a large amount of products and each product is modelled according to proposed scheme –vector form.

Let $P = \{p_i, i = 1, ..., k\}$ represent the database, where

 $P_i = [p_{ij}] \ 1 \le j \le 87$ denotes the ith product and p_{ij} is the value of jth attribute.

Let $B = [b_j] 1 \le j \le 87$ denote the benchmarking product.

Let $AR(b_{j}, p_{ij})$ represent the relevance metric of the j-th attribute of the product B and P_i . $AR(b_j, p_{ij})$ is defined below;

$$AR(b_{j},p_{ij}) = 1 - |b_j - p_{ij}| \quad (1)$$

Let $S = \{j \mid b_j \le 0.75\}$ represent a set of high value attributes of product B. Some attributes in S is selected to from a key set, which are used to retrieve "sufficiently relevant" products. Define T c S as the key set. Let PR_i^T represents the product relevance metric between products P_i and B, with respect to set of attributes T. PR_i^T is defined below, where $W_j \in [0,1]$ denotes the weighting factor of j-th attribute given by users i.e. users can intentionally gives preference on attributes in T

$$PR_{i}^{T} = \sqrt{\sum_{j \in T} \frac{\left[b_{j} \cdot AR(b_{j}, p_{ij}) \cdot W_{j}\right]^{2}}{\left[b_{j} \cdot W_{j}\right]^{2}}}$$

Procedure of CBR: $[b_j.AR(b_j, p_{ij}).W_j]^2$

The concept above can be used to develop a product innovation retrieval system, called PIRS. The procedure for using the PIRS to generate new product ideas is given below[32]

- Step-1 : Initialization
 - Assign $R_set = \emptyset$, $A_set = \emptyset$
 - Ask user to determine the benchmarking product B
- Step-2: Determine $S = \{j \mid b_j \le 0.75\}$, the set of important attributes for product B.
- Step-3: Ask the users to select attributes in S to form several key sets T_k (k = 1, ..., n) and give W_j for each attribute in T_k .
- Step-4: Retrieve "sufficiently relevant" products from the products database

- Ask the users to determine a relevance threshold $h \in [0,1]$
- Retrieve and place the "sufficiently relevant" products in R_set that is $R_set = \bigcup_{k=1}^{n} \{ p_i \mid PR_i^T \ge h \text{ for } i \in T_k \}$
- Step-5: Ask the users to select creative and valuable product ideas R_set and place them in A_set.

In summary, here we have seen the approach of case based reasoning in generating new product ideas. A product is modelled by 87 attributes based on user centered design (UCD) paradigm. For each attribute, a product is assigned a 0-1 value and higher the value, the more important is the attribute. For a bench marking product, some of its important attributes are manually selected as keys for retrieving from database the products that are "sufficiently relevant" to the bench marking product. The main functions of these retrieved products are taken as candidate new functions of the benchmarking product.



3 Methods of Implementation:

3.1 Introduction:

The approach applied here is a simple one where we used the knowledge gained through literature study and utilized it in finding a suitable concept that is feasible to adapt to our thesis requirements. Case based reasoning concept on a whole is interpreted in terms of algorithms that define the way the application works. In the following topics we discuss in detail about different algorithms with respect to different contexts and also about concepts pertaining to our thesis.

The main intention behind citing this example of Case-based reasoning applications is to understand how diversified the concept of case-based reasoning can be implemented in different contexts.

3.2 Reuse concepts for bracket

3.2.1 First concept of searching bracket system (2006)

At the beginning before the development of present searching bracket system, there was a concept for search bracket system which was implemented as standalone software with an user interface based on parameter inputs. Searched brackets will be displayed in a table with all the parameters as shown in figure-3.6.

Thule Bracket System v1.1																		
Arkiv Visa Verktyg Hjälp																		
Sökresultat Blecktyper Antal bleck: 476 st																		
Sökträff ArtikelNr Grupp P1x P1y P2x P2y P3x P3y P4x P4y P5x P5y Tx Ty Lx Ly V L																		
	853-2215-866	Internal Rain Gutter	0	61	-17.3	72.9							-14.2	87.6	-6.7	88.1	93.8	7
	853-2215-871	Internal Rain Gutter	0	55	-3.5	57.5	-7.8	69.4					-1.7	71.6	-0.7	68.8	19.7	3
													-6.8			104		1
	853-2215-907	Plus Bracket	0	62	13	69							17	82.3	43.6	92.5	111	2
	853-2215-918	Minus Bracket	0	61	-17.5	74.5							-15	95.5	0.5	102.6	114.6	1
	853-2215-919	Minus Bracket	0	60.8	-21	83							-18	101.2	-4	107.5	114.2	1
	853-2215-920	Plus Bracket	0	64	-3	65.2							-1.8	84.7	9.6	86.9	100.9	1
	853-2215-979	Plus Bracket	0	61.8	4	69							4.4	81.2	23	83.8	98	1
	853-2215-990	Minus Bracket	0	61	-4.1	72							-4.1	80.5	9.1	87.6	118.3	1
	853-2215-991	Minus Bracket	0	60.4	-3	65.4							-4	74.1	10.3	81.1	116.1	1
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Figure 3.1 First version of search bracket system

The system was re-implemented in 2011, the reason was even though speeding the search mechanism, it was time consuming to save new designs into the system, it was error-prone to manually put in parameters representing new brackets, and the engineers felt that the hit rate was poor.

3.2.2 Second concept for searching bracket system (2011)

The development of new bracket system was to overcome the draw backs in previous implemented system. Therefore this developed system was implemented with an add in to CAD system and thus it became easier for engineers to interpret the results in more effective manner.

The implemented system uses Case-based reasoning an artificial intelligence technique for obtaining the desired results. The effectiveness of this is described in thesis background topic mentioned above.

The system implemented is shown in below figure-3.7 and the detailed description of functioning of system will be described in further topics.



Figure 3.2 Latest version of search bracket system

3.2.2.1 Fuzzy set approach in Case-Based System

Implemented system uses a "Fuzzy set approach" in Case-based reasoning process. This concept means a set of primary objectives that are presented and model the meaning of ambiguous terms such as length, thickness, and process multiple memberships in classification[41]. By which this approach provides detailed attributes in working system. First, it allows numerical features to be converted into fuzzy terms to simplify the matching old brackets. Second, it permits old brackets in the different domain (dimensions) to be comparable with search bracket [41]. So using this concept into CBR algorithm to search similar brackets is detailed below:

p is the number of parameters (Points, Angle, and etc.)

n is the number of brackets

i = 1....n

j = 1....p

S is the search bracket.

B is the old brackets in the database.

Bi is one bracket in the database.

To start with the distance between search bracket and each old bracket are calculated. The calculated difference in distances is assigned weights based on the gap between search bracket and each bracket in case library.

$$d_i = |S - B_i| \tag{1}$$

$$\Delta = maxB - minB \tag{2}$$

$$\overline{d_{ij}} = \frac{d_{ij}}{\Delta_j} \tag{3}$$

Next, the sums of all distances are calculated:

$$D = \sum_{i=1}^{n} \overline{d_i} \tag{4}$$

And then the weighted total-distance matrix of the brackets is gathered to:

$$A = \sum_{j=1}^{p} D_j \tag{5}$$

A is the total accumulated distance of all brackets derived from the search bracket and old bracket and then it is used to assign for search weight equation:

$$w_j = 1 - \frac{D_j}{A} \tag{6}$$

By which the weights is mainly values, it is specified the important dimensions from seeing how much weights distribute for search bracket dimension.

After that values to compare the bracket are calculated and combining the weight function in the equation

$$h_{ij} = \frac{\bar{d}_{ij}}{D_j} \tag{7}$$

$$H_i = \sum_{j=1}^p w_j \cdot h_{ij} \tag{8}$$

Finally, the best suitable bracket is the one with the minimal H value.

After forming the Case-based reasoning algorithm concept as mentioned before, the system then uses typical Case-based reasoning approach for encouraged system work. It is adapted CBR concept into the system as described below:

3.2.2.2 Case Indexing:

The case indexing in this system is based on geometry that designer sketches in CAD software (Solid works) as shown in figure-3.8 below. Here the engineer first draws the sketch in CAD and then imports it into system and thus all the necessary parameters defined in algorithm is inherited into the system. Then the case is stored in case library.



Figure 3.3 Indexing the bracket into the system that is generated from Solid works

3.2.2.3 Implemented concept in Retrieve

In this step, all of attributes (distance) are assigned in the fuzzy equation as mentioned above in description of algorithm. The search criteria bracket once sketched and stored in database(marked with blue), it is then used for retrieving the similar brackets which are placed in order of the weights assigned to it in the list view below as shown in figure-3.4.

🖳 Form2		
Helpers		
Kits Brackets Settings Master2012		
In Work Brackets		
Name Created		
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653-2215-007 29/92. 653-2215-007 29/92. 653-2215-010 29/92. 653-2215-011 29/92. 653-2215-011 29/92. 653-2215-011 29/92. 653-2215-011 29/92. 653-2215-011 29/92. 653-2215-013 29/92. 653-215-013 29/92. 653-215-015-015-015-015-015-015-015-	Angle Angle Angle Angle Angle Angle Angle Angle CADFile DateCreated FlangeCurvature FromPoints LastModified Name Manue M	36.624652361292248 C:\Temp\TRacks_Test\Brackets\We 10/5/2012 18:26 0 10/5/2012 18:26 853-2215-9999 ▼
Similar Brackets 803-22 (5-9999		
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Figure 3.4 All the similar brackets in the system that transforms the retrieve system.

The below figure 3.5 illustrates the ranking of the retrieved similar brackets and the top most bracket highlighted in blue portrays the most nearest similar bracket.

Form2				- 0 ×
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853-2215-0109 29/9/2			CADFile	C:\Temp\TRacks_Test\Brackets\Nk
853-2215-0110 29/9/2			DateCreated	10/5/2012 18:26
853-2215-0111 29/9/2			FlangeCurvature	0
853-2215-0113 29/9/2			LastModified	10/5/2012 18:26
853-2215-0114 29/9/2			Name	853-2215-9999
853-2215-0115 29/9/2			NumberOfPoints	6
853-2215-0117 29/9/2			I	Palas 🛁
853-2215-5678 2/5/20			Defines the name of the bracket	
853-2215-1234 9/5/20 853-2215-9999 10/5/2				
C. 1. D. 1. 1. 070 0015 0000				
Similar Brackets 853-2215-3330				
Name HR (953,2215-2214 0,01902	Angle X T Pin	JW T		^^
853 2215-0100 0.02494	0.02912 0.02534 0.00165 False	2		E
853-2215-0114 0.02614	0.03038 0.00671 0.03769 False	2		
653-2215-0095 0.02625 653-2215-0112 0.02973	0.02241 0.04753 0.00925 False	2	— Ranking of similar bi	rackets
\$53-2215-0075 0.02989	0.03091 0.02460 0.03373 False	2		
853 2215-0113 0.03014	0.03234 0.02311 0.03075 False	2		
853-2215-5678 0.03086 853-2215-0029 0.03109	0.02376 0.06356 0.01124 False	0		
1 over 10 mor 0.03103	0.02370 Palse	1.4		

Figure 3.5 Ranking of the similar brackets generated from the system

3.2.2.4 Case Revise/Adapt:

In revise step, when the search bracket is not matched exactly with old brackets, the result must be adapted. Here the choice of choosing a bracket for adaption form obtained list of brackets is completely based on designer. The implemented system only presents him the nearest solution to desired one. The process is shown in the figure-3.6.



Figure 3.6 Comparison between the search bracket and old brackets.

3.2.2.5 Case Review

Here in the present system the review part has no importance as compared to that mentioned in theoretical background. The main reason being the adaptation step here is done manually by designer according to required specifications and thus the tasks that define review step is already done in adaptation step by designer.

3.2.2.6 Case Retain

The bracket once adapted by the designer it is then stored in case library as shown in figure-3.7.

🖳 Form2		
Helpers		
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	Release Add as Front to	
Existing f	Add as Rear to Draw Bracket(s)	
Name 853-2215-	Generate CAD-model Get From Selected Curve	
853-2215- 853-2215- 853-2215-0075 853-2215-0076	Add Bracket From CAD file 29/9/2 29/9/2	

Figure 3.7 Release the new design bracket in order to be the database for next search brackets

3.3 Our concept

Here in our thesis we aim at developing a better system when compared to previous one. According to information provided after interviewing design engineer in the company, foundation of our concept for improvement of system further was laid based on this information. For example, when engineers use previous search bracket programme, the brackets come up at the list of similar brackets but it's not yet clear for designer from results which one is most suitable bracket. Engineer just attempt to use most top ten brackets in the list of the programme and check it with respect to required search bracket criteria.

Here we come up with our concept where in new system we try to give the designer the best result by using different concepts (including previous one). The designer in our system has an option of choosing the type of bracket required and also the wall thickness. These two additional criteria that we embedded into system helps in reducing the search list based on the chosen criteria, as brackets are categorized based on these criteria in database. This is shown in figure-3.8 below.

Besides, in the new system we use two search criteria to be implemented for finding similar bracket. The first criterion is based on the algorithm and weight concept that we use to generate the most similar bracket. Second criteria use the same algorithm but with addition of more constraints i.e., assigning weights based on wall thickness chosen. It will be explained more in the retrieve concept below.

Helpers					
Kite Brackete Settinge M	laster2012				
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Used Function					
Pin					
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Thickness					
15mm					
2 mm		First Search		Panat	
None		criteria		ICSCI	
1					
,					
First search similar brackets] !	Second search simil	ar brackets Thir	rd search similar b	rackets Top of	of all search brackets
First search similar brackets	Second search simil	ar brackets Thir	rd search similar b	vrackets Top of	of all search brackets
First search similar brackets 1 Name X 853-2215-0082 0.94758954	Second search simil	ar brackets Thir X1 0.94893504	rd search similar b Y1 0.94901911	rackets Top of Ht_rate 0.94075169	of all search brackets
First search similar brackets 3 Name X 853-2215-0082 0.94758954 853-2215-0087 0.92798272	Second search simil Y 0.94960764 0.92890701	ar brackets Thir X1 0.94893504 0.92913121	rd search similar b Y1 0.94901911 0.92649685	rackets Top of Ht_rate 0.94075169 0.92859874	of all search brackets
X X Name X 853-2215-0082 0.94758954 853-2215-0076 0.92798272 853-2215-0076 0.92798272	Second search simil Y0.94960764 0.92890701 0.92887899	ar brackets Thir X1 0.94893504 0.92913121 0.92963567	rd search similar b 	rackets Top of Ht_rate 0.94075169 0.92859874 0.92831848	of all search brackets
Name X 853-2215-0082 0.94758954 853-2215-0070 0.9278207 853-2215-0076 0.92785669 853-2215-0075 0.927712002 853-2215-0075 0.927712002	Second search simil Y0.94960764 0.92890701 0.92887899 0.92859874	ar brackets Thir X1 0.94893504 0.92913121 0.92963567 0.9293552 0.9293552	rd search similar b Y1 0.94901911 0.92649685 0.92523571 0.92551597 0.9249496	rackets Top of Ht_rate 0.94075169 0.92859874 0.92831848 0.92243320 0.92243320	of all search brackets
Name X 853-2215-0082 0.94758954 853-2215-0076 0.9278272 853-2215-0076 0.92785609 853-2215-0075 0.92778450 853-2215-0075 0.92777445 853-2215-0175 0.92777745	Second search simil Y 0.94960764 0.92890701 0.92859874 0.92938344 0.92938344	ar brackets Thir X1 0.94893504 0.92913121 0.92963567 0.9295542 0.92915924 0.92915924	rd search similar b Y1 0.94901911 0.92649685 0.92523571 0.92551597 0.92439496 0.921219	rackets Top of Hit_rate 0.94075169 0.92859874 0.92831848 0.92243320 0.92117206 0.9231383	of all search brackets
/ Name X 853-2215-0082 0.94758954 853-2215-0087 0.92768059 853-2215-0076 0.92768050 853-2215-0076 0.92768050 853-2215-0075 0.9271002 853-2215-0015 0.9271020 853-2215-0015 0.92710402 853-2215-0115 0.92710402 853-2215-0117 0.9291020 92801686 92801687	Second search simil Y 0.94960764 0.92890701 0.9287899 0.92858874 0.92938344 0.92787008 0.92787008 0.92781403	ar brackets Thir X1 0.94893504 0.92913121 0.92963567 0.92935542 0.92915924 0.92859874 0.92859874	rd search similar b Y1 0.94901911 0.92649685 0.92523571 0.92551597 0.92551597 0.92439496 0.92131219 0.9293937	vackets Top of <u>Ht_rate</u> 0.94075169 0.92859874 0.92831848 0.9224320 0.92217206 0.9231383 0.91542690	of all search brackets
Number X 853.2215.0082 0.9475854 853.2215.0082 0.9475854 853.2215.007 0.9278569 853.2215.007 0.9278569 853.2215.0075 0.9276509 853.2215.015 0.9277145 853.2215.015 0.9280659 853.2215.015 0.9280659 853.2215.010 0.9280659	Second search simil Y 0.34960764 0.322897071 0.32887899 0.32858874 0.32938344 0.32781403 0.32781403 0.32781021	ar brackets Thir X1 0.94893504 0.92913121 0.92963567 0.92915924 0.92915924 0.92859874 0.92859874 0.92823441 0.92744970	rd search similar b Y1 0.94901911 0.92649685 0.92523571 0.92551597 0.92551597 0.92439496 0.92131219 0.92929937 0.92627710	vackets Top of <u>Ht_rate</u> 0.94075169 0.92859874 0.92831848 0.9224320 0.9217206 0.92131383 0.91542690 0.91150338	of all search brackets
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Nume X 653.215.0082 0.9476895 853.2215.0082 0.9476895 853.2215.0087 0.92768627 853.2215.0075 0.92768627 853.2215.015 0.92768627 853.2215.015 0.92778427 853.2215.0115 0.9270445 853.2215.0115 0.9280059 853.2215.0115 0.9280059 853.2215.0101 0.9280059 853.2215.0101 0.9280059 853.2215.0101 0.9280059 853.2215.0102 0.9255043	Second search simil Y 0.92830701. 0.928590701. 0.92859874. 0.92938344. 0.92938344. 0.92787008. 0.92787008. 0.92781403. 0.922781203. 0.9261021. 0.92620072. 0.92620072. 0.92620072. 0.92620072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.9262072. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.927200. 0.	ar brackets Thir X1 0.9293504 0.9293567 0.92935542 0.92935542 0.92895874 0.9289874 0.92823441 0.92823441 0.92744970 0.92728155 0.9276180	d search similar b Y1 0.94901911 0.92649685 0.92523571 0.9251597 0.92439496 0.92131219 0.92293937 0.9229307 0.92259307	rackets Top of Ht_rate 0.94075169 0.92859874 0.922831848 0.92243320 0.92117206 0.9213383 0.91542690 0.91542690 0.9154539 0.91318489	of all search brackets
No. No. First search similar brackets No. Name X 853-2215-0082 0.94758954 853-2215-0075 0.92768605 853-2215-0075 0.92768605 853-2215-0015 0.92764605 853-2215-0115 0.92704405 853-2215-0115 0.92904052 853-2215-0115 0.92904052 853-2215-0108 0.92802561 853-2215-0117 0.92505043	Second search simi V 0.34960764 0.92897890 0.92858974 0.92258974 0.92258974 0.922787008 0.92787008 0.922815033 0.922612033 0.922612033	ar brackets This X1 0.9493504 0.92913121 0.92935542 0.92935542 0.929359874 0.9289874 0.9289874 0.92823441 0.92728155 0.92756180	d search similar b 91 92 92 92 92 92 92 92 92 92 92	wackets Top of Ht_rate 0.94075169 0.92859874 0.92831848 0.92831848 0.9224320 0.92117206 0.9213383 0.9213383 0.91542690 0.91542690 0.91160338 0.91318489 0.91318489	of all search brackets
Name X B53-2215-0082 0.94758954 B53-2215-007 0.92788572 B53-2215-007 0.92788572 B53-2215-007 0.92781202 B53-2215-0071 0.92781202 B53-2215-0113 0.92771404 B53-2215-0113 0.9277144 B53-2215-0110 0.9280505 B53-2215-0111 0.9280505 B53-2215-0117 0.9280505 B53-2215-0117 0.9255043	Second search simi V 0.34960764 0.32897890 0.32887899 0.32859874 0.32283344 0.32781403 0.32781403 0.322815033 0.322815033 0.32261207	ar brackets Thi: X1 0.94893504 0.92913121 0.9293562 0.92935542 0.92935542 0.92859874 0.9282941 0.92728155 0.92728155 0.92756180	rd search similar b 94 92649685 0.92649685 0.92523571 0.9251597 0.92439496 0.92131219 0.92293937 0.92293937 0.92229307 0.92259559	rackets Top of <u>Ht_rate</u> 0.94075169 0.92859874 0.922831848 0.92217206 0.92213383 0.92117206 0.9213383 0.91542690 0.91542690 0.91542690 0.91374539 0.91318489	of all search brackets

Figure 3.8 Current version for the searching bracket system

In previous concept, there was use of fuzzy set approach into CBR and here in our concept we tried to use a different approach i.e., iterative closest point (ICP). Here we use the same frame work that was used in previous concept but the weight generating equation uses ICP concept.

ICP algorithm is the dominant method for comparison of aligning dimension models based purely on the geometry regarded the points on the models. They used four stages for this algorithm.[Faugeras 1986,Stein 1992].

- 1. Selection of some set of points on pairs
- 2. Matching these points respected the distance of pairs
- 3. Weighting the corresponding pairs appropriately
- 4. Optimizing the rang of pairs

This concept utilizes standard deviation as main criteria for Rejection of pairs whose point-to-point distance is larger than some multiple of the standard deviation of distances[42].

The standard deviation of a random variable (search brackets) is shown how much variation for search brackets from average distance value. A low standard deviation illustrates that the data points tend to be very close to the mean, while high standard deviation illustrates that the data points are spread out over a large range of values as shown in the figure-3.9.





Consequently we try to adapt standard deviation into the typical system that we improved from the previous version.

p is the number of parameters in search bracket

n is the number of brackets

t is the number of points of search bracket

j = 1....n

 $k = 1 \dots t$

S.D = standard deviation of search bracket

M = a mean number of search bracket

S is the search bracket.

 D_{max} = maximum distance between search bracket and old bracket

Bi is one bracket in the database.

To begin with calculation of the distance between search bracket and old bracket are indicated in the equation below.

$$d_i = |S - B_i| \tag{1}$$

Then using the different distance put in the mean:

$$M = \frac{\sum_{i=1}^{p} d_i}{\sum_{k=1}^{t} k}$$
(2)

After that get the standard deviation of search brackets to assign into the weight function.

$$S.D = \sqrt{\frac{\sum_{i=1}^{p} (d_i - M)^2}{\sum_{k=1}^{t} k}}$$
(3)

Next, the standard deviation is assigned to provide speculated maximum distance of search bracket and old bracket .Moreover there is use the error function as multiplying 2.5 for 99.9 % of correct value:

$$D_{max} = 2.5 * S.D \tag{4}$$

And then the weighted distance is generated from each case distance dividing maximum distance[43]:

$$w_i = 1 - \frac{d_i}{D_{max}} \tag{6}$$

Finally, after we get each weight for each parameter of search bracket, the weights are combined for getting averaged weight for considering search brackets.

$$H_j = \frac{\sum_{i=1}^p w_i}{\sum_{i=1}^p i} \tag{8}$$

The best proper bracket is the one with the maximum H value.

After the equations are provided for inputting in CBR algorithm, the system of searching bracket system is attempted to handle CBR algorithm into the system for improving usage of the system. There are separate step that the CBR concept put in the system as described below.

3.3.1 Implemented concept in Indexing construction of existing cases

Indexing cases (brackets) here is similar to the one adopted in previous version, where the desired bracket sketch is drawn in CAD and all the data required is inherited into the system. The below figure-3.10 shows the place where the bracket is portrayed in system.



Figure 3.10 Import the new bracket from the sketch

3.3.2 Implemented concept in Retrieve

Case retrieval in our concept is based two aspects geometry and criteria chosen by designer. The following is the description of case retrieval procedure in our concept:

- 1. If the number of rear points of search brackets = the number of rear points of old brackets then the differences in distances of the rear points of search bracket and old bracket in both X, Y direction is adapted in algorithm mentioned above and the results are thus retrieved.
- 2. If the number of rear point of search bracket and old brackets are not equal then results are based on difference in the distance of each rear point of old bracket regarding X and Y axis.
- 3. Get the distance between the angle at bending point of search bracket and old bracket.

Then the system will retrieve the brackets through all of the constraints above and using the iterative closest point approach as mentioned before. After that the system will compute in order to get the similar brackets as shown in the figure-3.11.

First search simil	Tist search similar brackets Second search similar brackets Top of all search brackets									
Name	X	Y	X1	Y1	Hit_rate		*			
853-2215-0082	0.94744397	0.94958395	0.94887072	0.94895988	0.94019317	The best proper bracket				
853-2215-0087	0.92786090	0.92884101	0.92907875	0.92628529	0.92851411					
853-2215-0076	0.92772725	0.92881129	0.92961367	0.92494800	0.92821694		Ξ.			
853-2215-0075	0.92694609	0.92851411	0.92931649	0.92524517	0.92197623					
853-2215-0113	0.92764005	0.92934621	0.92910847	0.92405647	0.92063894		٠.			
853-2215-0115	0.92937360	0.92774145	0.92851411	0.92078753	0.92271917					
853-2215-0107	0.92883419	0.92768202	0.92812778	0.92925705	0.91454682					
853-2215-0101	0.92979491	0.92789004	0.92729569	0.92658247	0.91038635					
853-2215-0088	0.92875469	0.92803863	0.92711738	0.92182764	0.91276376					
853-2215-0117	0.92532413	0.92536404	0.92741456	0.92479941	0.91216941		٣			
							_			

Figure 3.11 Similar brackets are provided from CBR algorithm

3.3.3 Implemented concept in Adapting case histories

In the adaptation or reuse step, there must be criteria established for defining a suitable bracket and make a group for seeking exactly same bracket from the library. As mentioned in theoretical background following the three general kinds of adaptation to define the proper brackets below:

- 1. Null adaptation means when the system try to seek the proper brackets and the result obtained exactly matches the old bracket (here it is only with respect to geometry).
- 2. Topological adaptation segregates the brackets into groups which provide choices for selecting a group of brackets like bracket with pin, without pin, and wall thickness. And there also is "none" option provided just in case that engineer want to use all of the brackets in the library without considering any of the criteria as show in the figure-3.12

Optimizing option		
Used Function Pin Without_Pin None	Second Search criteria Criteria Top of all	Used function for
Thickness		brackets in the library
2 mm	First Search Reset	

Figure 3.12 Used function for separated group of brackets

3. Parametric adaptation, in this case, there can be adjustment for parameter design such as changing the parameters(distance or angle) between the search bracket and old bracket to get suitable bracket as shown in the figure-3.13



Figure 3.13 Comparing the search bracket with old bracket that are similar and only adapt a bending point and angle of bracket

Moreover, we try to generate the best top three brackets from the three criteria that has been implemented from the previous system, our system, and another algorithm (three buttons in interface). Another algorithm is nothing but our concept with addition of more constraints. Here we consider the weight function with respect to the wall thickness of the bracket as:

- 1. If the wall thickness = 1.5 mm then the function should added more percentage of the weight at 5%
- 2. If the wall thickness = 2 mm then the function should added more percentage of the weight at 3%
- 3. If the wall thickness >2mm then the function should added more percentage of the weight at 2%

The above concept of assigning weights is not based on any data, it's purely conceptual. According to information collected we have inferred that wall thickness of brackets has only two variants and thus we adopted the criteria. The weights are based on concept that wall thickness=1.5mm uses less material than the one with 2.0mm the weightage is more for first than for later one. Finally the weight for none is higher than other two because of increase in range of selection.

Finally we have portrayed the results all different versions of results from different search algorithm into one list view as shown below in the figure-3.14.



Figure 3.14 Top three brackets that are generated from the three criteria.

3.3.4 Implemented concept in Review

After the adaptation step has been done, next step is the review where search criteria brackets are compared with the results retrieve. Here in our concept the review part is taken up by the designer and if he finds the adapted result is good enough then it is stored in case library. If the results adapted is not suitable then the process repeats and will check for other similar brackets. The comparison is shown in figure 3.15 below



Figure 3.15 Comparing the search bracket with old brackets in case of the search bracket are not matched with old brackets

3.3.5 Implemented concept in Retain

In this step, after all the process for search bracket has done then the new modified bracket will be used for the design task and added into the library of the bracket as shown step in the figure-3.16.

Helpe	ers								
Kits	Bracke	ets	Settings Master2012						
In We	ork Brac	kets	I						
Name	e		Created						
New	test brac		View	►					
			New Bracket						
			Delete						
			Release						
			Add as Front to						
			Add as Rear to						
			Draw Bracket(s)						
Exist	ing Brad		Generate CAD-model						
853-2	e 215-008		Get From Selected Curve						
853-2	215-008		Add Bracket From CAD file	•					
853-2	215-010	0 2	8/9/2						

Figure 3.16 Collect the new design bracket in order to be the database for next search brackets

4 Finding and analysis

4.1 Comparison with previous concepts

As the concepts that are described from methods of implementation topic, it can be obviously seen the progression of development of the search bracket system. The system has been successively adapted in order to obtain the best solution for selecting the proper bracket in the design task.

4.1.1 Comparing second developed system with new developed system

When comparing between the new and previous version of developed system, they work on same platform, but we try to explore more criteria inherited in system compared to previous system. The new version has all the aspects considered with respect to designer and utilizing the criteria inherited in system. Firstly, the iterative closest point approach used in the Case-based reasoning algorithm along with standard deviation principle employed for generating hit rate has given better results when compared to previous version.

Another development is interface of the new version. The categorization of brackets into groups as pin and without pin reduced the brackets search list. In addition to that we have wall thickness also as one of group reducing the search list of brackets further. While the previous version, there are no choices for with respect to segregation of brackets. It normally works by searching all similar brackets and gets them into the list of the system.

Moreover, the parameters which are considered in the Case based reasoning algorithm have been increased from the previous version for approached most similar brackets. The new version compares the distances between search bracket and old bracket with respect to each point on the brackets and the distance of angles .That means the search bracket can be accessed the most similar brackets, meanwhile in the previous system the comparison between the distances is based on two points which are the last two points on the bracket for retrieving similar brackets. The figure-4.1 distinguishes clearly the parameters considered by new version (marked as bracket from new concept) and previous version (marked as bracket from old concept)with respect to search bracket.





4.2 Results

In this thesis, the results are portrayed in two different forms one is geometrically in CAD program as shown in figure 4.2 in which the comparison between the required search bracket (in color red) and other two are the results from old concept(blue in color) and new concept(green in color) is clearly displayed. There is one more result shown (pink in color) which represents the similar bracket retrieved using criteria.





The second being the interface itself which was modified based on discussions held with design engineers and outcome of this is shown below in figure where we have options to select from i.e., pin and wall thickness which according to engineers are two main aspects segregating brackets in to groups. The other buttons are related to the search algorithms and each button signifies a different search algorithm that is used to retrieve the search bracket with different criteria.

🚽 Form2						
Helpers						
Kits Brackets	Settings Mas	ter2012				
Creating bracket	5					
Optimizing option	n					
Used Function						
Pin Without_Pin None			Second Search criteria	h Third cr	I Search iteria	Top of all
Thickness						
[15mm						
2 mm		_	First Search		Reset	
None None		-	criteria			
First search similar brackets Second search similar brackets Top of all search brackets						
Name	Х	Y	X1	Y1	Hit_rate	
853-2215-0082	0.94758954	0.94960764	0.94893504	0.94901911	0.94075169	
853-2215-0076	0.92785669	0.92887899	0.92963567	0.92523571	0.92831848	E
853-2215-0075	0.92712002	0.92859874	0.92935542	0.92551597	0.92243320	
853-2215-0113	0.92///445	0.92938344	0.92915924	0.92439496	0.9211/206	
853-2215-0107	0.92890058	0.92781403	0.92823441	0.92929937	0.91542690	
853-2215-0101	0.92980659	0.92801021	0.92744970	0.92677710	0.91150338	
853-2215-0088	0.92559043	0.92815033	0.92728155	0.92229307	0.913/4539	-

Figure 4.3 Interface for searching the brackets new concept

4.3 Analysis:

The concepts implemented were based completely on knowledge gained from the literature on various case based reasoning techniques and discussions with design engineer handling the system with previous concept.

Initially we started the process of development by framing the purpose and research questions and constrained our work in accordance to it. In 2011 a completely new system was programmed based on case-based reasoning technique with an add-in feature with CAD software for analysing the solutions in a better manner. This present system was appreciated and is presently being under implementation. Our thesis topic of interest starts from here and basis of thesis was how can we improve the system further and have a better concept. For answering this we needed to understand the existing concept in detail and thus we needed to categorise the existing concept in accordance to literature for exploring new and better concepts. We found the existing concept to be related to a fuzzy set approach.

Further for improving the algorithm our idea was to construct a concept that resembles closely to the required search criteria. We went through lot of literatures understanding new concepts (few examples are cited above) and searching for suitable methods that can adapted to our conceptualized idea. Before getting into algorithm, firstly when discussing with design engineers about feedback on already implemented method and also about what according to them can be changed or has scope of improvement for enhancing the present method. Thus, we came up with modified interface with all the new criteria as shown in figure where we introduced pin and wall thickness the two aspects that categorises the criteria for search, thus reducing the search list and giving more valued result. Interface also consists of several other buttons which are used for differentiating the search algorithms. Finally the algorithm which we constructed is mainly built on calculating the differences between the distances of search criteria and existing brackets list and assigning lower weights to pairs with greater point to point distance. As mentioned above our idea was to bring the closest match and from results we clearly see the improvement from previous concept.

5 Discussions and Conclusion

5.1 Discussion on methods

Initially the methods that is assigned into the searching bracket system is based on the CBR theory as mention in literature review. In order to fulfil the purpose of the thesis, there is typically using iterative closest point approach into CBR algorithm in the system to respond main requirements in the design. That are reducing the time frame for reuse of brackets and accessing the most similar bracket to make the design process conveniently. As mentioned in the concept comparison, the new system as created has inherent strengths with regard to specification of groups for the brackets and comparing the most similar bracket according to three criteria which provide top three brackets for engineer consideration. The detailed steps are clearly portrayed in below figure 5.1.

In the other hand, we found some barriers for designing system that are lacking constraints of design information which should be considered into the system. For instance the manufacturing information that might be affected for considering in design task .Moreover they really need to specify the weight regarding wall thickness because presently there are only two dimensions regarding the length and the bending points that are certainly constraints of the weight system. But we try to put the weight regarding wall thickness without any supported information for designers by giving the weighted percentage because we recognize that in real design situation, searching similar bracket should consider the parameters in the three dimensions to really access the most similar bracket.

Finally the new system that is developed indicates that it is in line with the purpose of the thesis, but as its limited only to geometry the scope would be limited and we should consider to broaden the scope in the future for better results. The new system has been an attempt to answer the designer requirements for bracket design task based on CBR theory.



Figure 5.1 Flowchart illustration the searching process for the brackets

5.2 Discussion on findings

In our thesis the findings is stated in different forms (detailed in finding and analysis part) as the basic purpose of the thesis is to develop a system that reduces the time frame for reuse of components in variant rich products. After a thorough discussion in design engineers in company and considering all aspects of information given by them, we interpreted those as our purpose and research questions as mentioned below.

- 1) Categorize the implemented concept with respect to scientific literature.
- 2) How can we inculcate new or modify the CBR Algorithm in a way reducing the time frame for reuse of brackets in roof rack products?
- 3) How can we make the process more refined and compatible for the designer?



From the findings we have seen that already implemented concept is a fuzzy set related concept and its application has been clearly explained in methods of implementation. The basic purpose behind the formulation of this question is to really understand the existing concept and categorize according to the scientific literature for a better contemplation of the implemented concept. This forms a strong foundation for building up a new concept which would be better than the implemented one.

The next question being how can we build a new concept or modify the existing one in better way for achieving the main purpose of our thesis. This we achieved by going through all the literature related case based reasoning algorithms and finding a feasible concept that can be adapted to our thesis. Then we came up with a conceptual idea that we use distances between the points (search criteria and existing list) and assign weights according to point to point distance that is lower weights to greater point to point distance(iterative closest point approach). The result after implementation of this concept is better than previous concept (as shown in figure-4.2) and thus providing solution for our framed research question.

Finally the last research question, which is related to modification of the interface and formulation of this also, came up during discussions with design engineer. The modification made in the interface is shown in figure where when compared with implemented interface there is addition of new criteria pin and wall thickness which categorizes the brackets search and thus reducing the search list. Thus having found a solution to all our research questions, the effectiveness of the concept is still under study.

5.3 Conclusion

Finally from the discussions and findings we can conclude our thesis in brief as mentioned below.

- Case based reasoning theory if adapted in a proper way with by clarifying all aspects constituting its formation; we achieve good results that enhance the overall performance of the system.
- Implementation methods adopted here is an adaptation of existing concept linked with new ideas and criteria in a way enhancing the implemented system to function in a better manner, such that finding the solution becomes simpler and easier.
- Categorization of brackets reduces the search list of brackets, thus reducing the time frame for searching the similar brackets.
- Comparison of top rated results from all different search criteria helps designer in choosing the right bracket and reducing the work load of checking out all the brackets.
- The concept developed here is based on information provided by company and it was restricted to only geometrical aspects to be considered in our thesis. The scope of thesis is limited and the possibility of finding the best result is thus constrained.

Future Work:

- The weight function linked to parameters forms the crux of the algorithm and it should be properly defined. Here for parameters like wall thickness the importance or weightage criteria is not yet clear and thus needs further study on how we can assign the weights.
- There should be more categorization of the bracket for convenient and fast processing in selection of the similar bracket because now there are only the wall thickness and pin as categories.
- The selection of bracket can be enhanced further by using knowledge based engineering approach, so that the interpretation of selection of bracket is clear and contemplation of concept is clarified.
- Further research can be adapted for other variety of brackets like for the one whose front and rear points are not matching.

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