Structured analysis methodology for reverse engineering of spare parts.

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STRUCTURED ANALYSIS METHODOLOGY FOR REVERSE ENGINEERING OF SPARE PARTS

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ABSTRACT

In today's intensely competitive global market, product enterprises are constantly seeking new ways to shorten products development time and meeting all customer expectations. In general, enterprise developing products had invested in Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) and rapid prototyping (RP), and other technologies that provide business benefits. Reverse Engineering (RE) is considered one of these technologies that provide business solutions for product development. The aim of this study is to develop a framework for reverse engineering of spare parts that includes reverse engineering concepts and procedures. The framework is developed using the Integration Definition for Functional Modeling (IDEF0) technique which is considered one of the modeling techniques that can effectively analyze systems into its detailed components simply. The framework evaluation will be carried out through assessing a success percentage of using the IDEF0 model to produce developed spare parts; where the success percentage is the ratio of all features dimensions of the developed product to that of the part to be replaced. The model has shown that it can describe precisely the information flow and material flow in the measuring planning and the execution of a product.

KEYWORDS

Rapid Prototype; Reverse Engineering; Spare Parts; Integration Definition for Functional Modelling; Hierarchical Modelling

1. INTRODUCTION

Engineering is the process of designing, manufacturing, assembling and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering. Forward engineering is the traditional process of moving from high-level abstraction and logical designs to the physical implementation of a system. In some situations, there may be a physical part/product without any technical details, such as drawings, bills-of-material, or without engineering data.

The process of duplicating an existing part, subassembly, or product, lacking information is known as reverse engineering.

Following are some of the reasons for using reverse engineering:

- The original manufacturer no longer exists, but a customer needs the product.
- The original manufacturer of a product no longer produces the product.
- The original product design documentation incomplete or has been lost or never existed.
- Some bad features of a product need to be eliminated.

IDEF0 is a modeling technique based on combined graphics and text that are presented in an organized and systematic way to gain understanding, support analysis, provide logic for potential changes, specify requirements, or support systems level design and integration activities.

An IDEF0 model is composed of a hierarchical series of diagrams that gradually display increasing levels of detail describing functions and their interfaces within the context of a system.

There are three types of diagrams: graphic, text, and glossary.

- The graphic diagrams define functions and functional relationships via box and arrow syntax and semantics.
- The text and glossary diagrams provide additional information in support of graphic diagrams.

The structural components and features of a language and the rules that define relationships among them are referred to as the language's syntax.

The components of the IDEF0 syntax are boxes and arrows, rules, and diagrams.

- Boxes represent functions, defined as activities, processes or transformations.
- Arrows represent data or objects related to functions.
- Rules define how the components are used
- Diagrams provide a format for depicting models both verbally and graphically

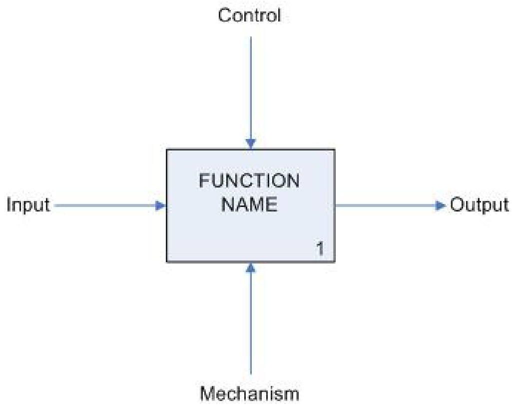

Figure 1 The components of the IDEF0 syntax

2. LITRETURE SURVEY

(Tamas Varady 1996)[1], Ralph R. Martin, Jordan Cox (1996) identified the purpose of reverse engineering and the main application areas, they also outlined the most important algorithmic steps and presented various reconstruction strategies. The limitations of currently known solutions are also described, and areas in which further work is required before reverse engineering of shape becomes a practical were pointed out.

Kwan H. Lee, H. Woo (2000)[2] proposed a new method that creates a direct link between the reverse engineering (RE) and rapid prototyping (RP) technologies. In RE, an enormous amount of point data is gathered during data acquisition which leads to a huge file size that requires a large execution time .they developed algorithms that greatly reduce point cloud data, and thereby, the data file sizes are decreased considerably.

L. Li, N. Schemenauer, X. Peng, Y. Zeng, P. Gu (2002)[3] present a reverse engineering system for rapid modeling and manufacturing of products with complex surfaces. The system consists of three main components: a 3D optical digitizing system, surface reconstruction software and a rapid prototyping machine. The unique features of the 3D optical digitizing system include the use of white-light source, and cost-effective and quick image acquisition. The modeling software exports models in stereo lithography (STL) format, which are used as input to an FDM 2000 machine to manufacturing products.

Arie Karniel, Yuri Belsky, Yoram Reich (2005)[4] present a practical solution for surface fitting problems with prioritized geometry constraints in reverse engineering. The approach allows prioritizing constraints and uses them for decomposing the problem into a set of sequentially solved, manageable sub-problems. Results on a bench mark problem demonstrate the suitability of the approach to solving large problems with hundreds of surface and constraints.

Zhengyi Yang, Yonghua Chen (2005)[5] presents a new reverse engineering methodology that is based on haptic volume removing. When a physical object is to be digitized, it is first buried in a piece of virtual clay that is generated with the help of a fixture. Now digitizing the physical object is by simply chipping away the virtual clay with a position tracker that is attached to a hepatic device PHANToM. There proposed method has eliminated the need to merge point clouds that are digitized from different views using current digitizers.

You-Min Huang, Hsiang-Yao Lan (2005)[6] initially used dynamic finite element simulation code to simulate photo-polymerization, to determine the distortion of the outer profile of the part and thus reduce the deformation. Then, they applied a reverse distortion correction to the outer profile of the part, and produced a new reverse compensation CAD model which is loaded into a RP machine for practical prototype processing, to increase the accuracy of the process.

Zhenkai Liu, Lihui Wang, Bingheng Lu (2006)[7] presented an integrated system of cross-sectional imaging based on (RE) and (RP) for reproducing complex objects. The system consists of four modules: cross-sectional image measurement, 3D reconstruction, stereo lithography (STL) file generation, and RP slice file generation.

Reverse engineering as necessary phase by rapid product development. The engineering design supported by CAD/CAE techniques allows optimizing the product concept before manufacturing with assistance of CAM, in management for rapid product development and rapid set-up production in advance. The aim of this paper is to present a brief overview of RE as a necessary phase which provide benefits to the design and production processes in advance. (M.Sokovic, J.Kopac – 2006)[8]

Reverse engineering of a symmetric object. (Minho Chang, Sang C. Park – 2007)[9] present a procedure to find an approximate symmetry plane from a point cloud for the reverse engineering of a symmetric object. Even if, the point cloud acquired from a symmetric object does not have exact symmetry planes in the mathematical sense, the data usually carries adequate symmetric information for reverse engineering. This paper proposes a new procedure to extract a symmetry plane, and it includes a registration step, aligning three-dimensional models.

Direct 5-axis tool-path generation from point cloud input using 3D biarc fitting. To simplify the process for getting tool-path information, a simple algorithm is proposed by (k. L. Chui, W. K. Chiu, K. M. Yu – 2008)[10]. The algorithm is used to generate a 5-axis machining tool-path. Instead of implementing any complicated surface fitting techniques, a direct method is proposed for constructing three-dimensional (3D) triangular mesh from the digitizing data with the mesh points considered as the tool contact locations.

Z. – C. Lin and C. – Z. Lin (2000) and Z. – C. Lin and J. – J. Chow (2001)[11,12] used An IDEF0 model to plan and analyze the measuring sequence and operation of a coordinate measuring system for a work piece machined by a machining centre. The IDEF0 model to analyze the measuring function requirements for solving the problem of ambiguous internal information flow and material flow during the measuring process, and developed a data module for the CMM measuring system using the EXPRESS language in STEP, to support the IDEF0 function process module. An information flow design model was also established, which integrated the IDEF0 process requirement analysis model and the EXPRESS data module.

3. NODE INDEX

A-0 RE process decomposition and Assessment of a Reverse Engineering Model for Spare Parts

A0 Re-engineer Spare Parts

- A1 Disassembly
  - A11 Disassembly
  - A12 List Components
  - A13 Numbering
  - A14 Define Features to Measure
- A2 Measure and Test
  - A21 Classify components into category
  - A22 Define Measuring Tools
  - A23 Measuring
  - A24 Material composition test
  - A25 Data Collection
- A3 Design recovery
  - A31 Evaluation
  - A32 Point cloud
  - A33 Optimization and Recovery
  - A34 Improvement and Development
- A4 Manufacturing Design
  - A41 Define Raw Materials
  - A42 Define Manufacturing Processes
  - A43 Sorting Manufacturing Processes
  - A44 Define Manufacturing Processes Conditions
  - A45 CAD/CAM File Converter
- A5 Prototype and test
  - A51 Traditional Machining
  - A52 Non-Traditional Machining
  - A53 Test and Inspection

A6 RE product

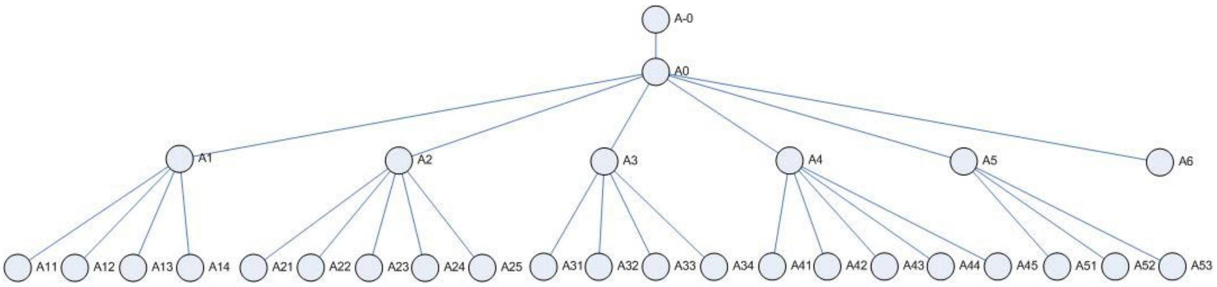

Figure 2 Schematic diagram of nodes for reverse engineering process decomposition

4. ESTABLISHMENT OF THE INITIAL LAYER OF THE IDEF0 REVERSE ENGINEERING MODEL

The first layer in establishing the R-engineer spare parts model is called the A-0 layer, which is the initial layer of the entire model. All system analysis activities are decomposed from this initial layer. The A-0 layer contains an initial activity model of the system called the"A0 activity box". The system starts from the A0 activity box to carry out decomposition analysis. Therefore, the input into the A0 activity box is the initial input into the system, and its output is the final output.

This article explores the sequence to go through in developing a product. At the beginning, it is necessary to understand the entire product perfectly and transform the raw material into a developed one similar to the original to satisfy customer requirements.

In this section "Re-engineering spare parts" is the functional activity of the initial layer, while "raw materials" and "product" are the initial input.

Figure 3 shows the IDEF0 initial model of production. Figure 4 shows the IDEF0 model after decomposition of the A0 node.

In figure 4, technicians proceed with product "Disassembly" (A1 node) using jigs & tools and then measure (A2 node) the disassembled product according to its initial identification in a stable environment using measuring equipments such as (Co-ordinate Measuring Machine CMM, Talyrond, Calipers, etc).the next function is design recovery (A5 node) for the data collected from (A2 node) using computer aided design(CAD) system, in this function consideration of quality standards must be taken to satisfy customer's needs.

Manufacturing design (A4 node) takes place after the design recovery, the production engineer specify all conditions and sequences of production according to the CAD file. In this process computer aided manufacturing (CAM) system had been used, after then the CAD, CAM files are used to produce a prototype (A5 node). Two different systems could be used, computerized numerical control (CNC) machining and traditional machining systems depend on the quality standards needed which was specified before in the design, then inspection of the developed prototype will take place to compare it with the original one using computer aided inspection (CAI) system with its supporters such as measuring equipments.

Finally the production process of the developed product takes place after taking the acceptance of the prototype test.

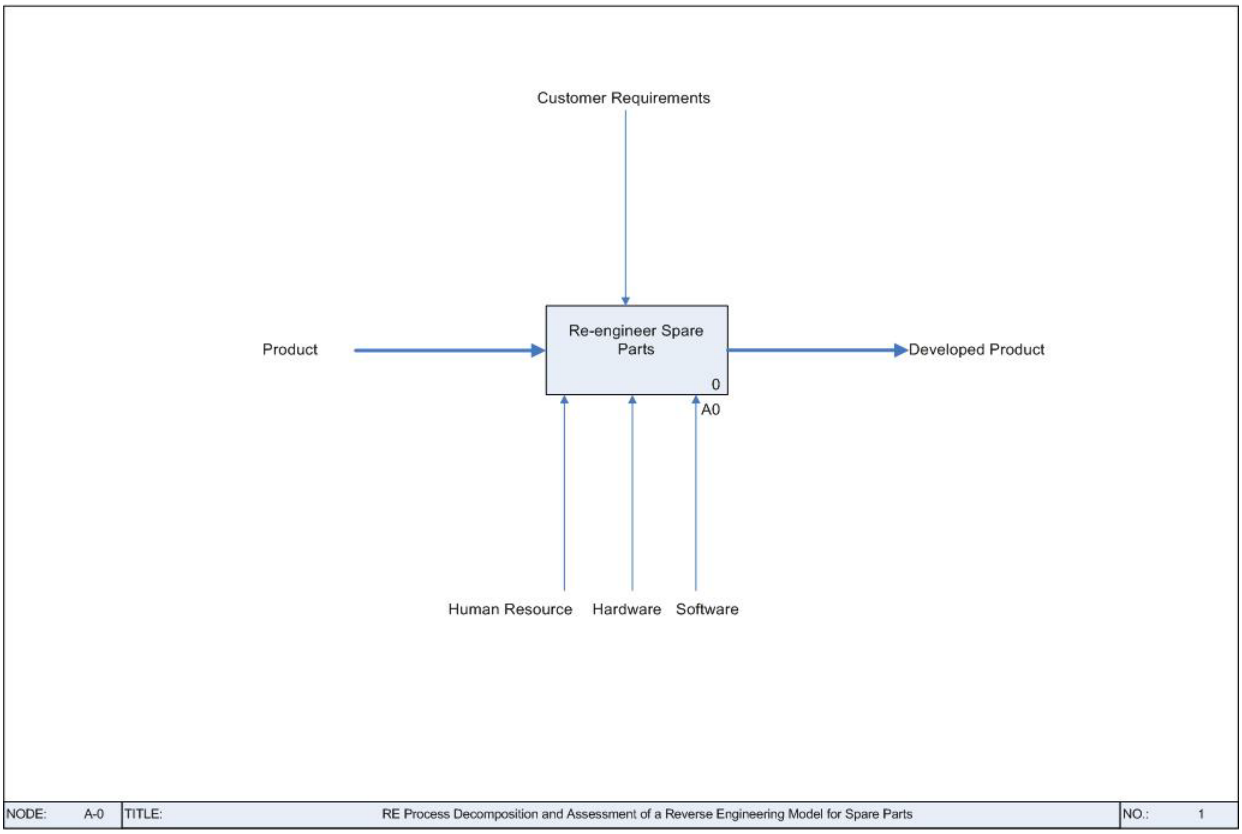

Figure 3 shows the IDEF0 initial model of production

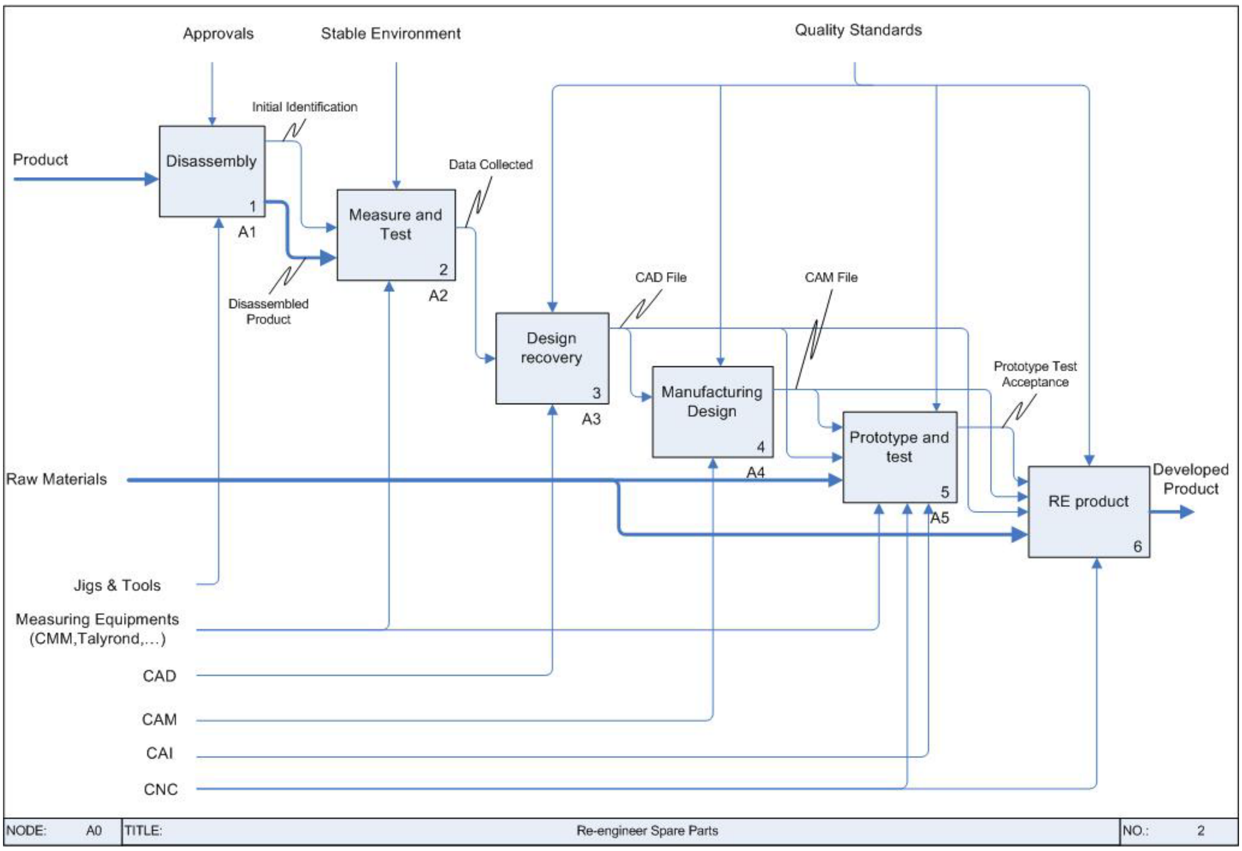

Figure 4 Re-engineer Spare Parts process decomposition

Figure 5 shows the disassembly process, after product had been disassembled a list of components takes place which define each components of the product according to its type and quantity, then each component takes a unique number to be define with, after then all features for each component could be measured or test be defined.
Figure 6 shows "Measure and Test" node after decomposition.
First of all the product components been classified into category according to its type & quantity and features to be measured using a coding system then defining the suitable available measuring tools which will be used in measuring the product components features that was defined early.
The disassembled product goes then through the measuring process which needs special labs prepared well for measuring. The measuring process could be done using two techniques contact or non-contact measuring equipments or both according to the features and accuracy needed.
All measuring data will be then collected in a measuring report.
The disassembled product will go then to the material composition test to understand each component structure and mechanics. This test will be done through two ways, destructive and non-destructive tests, after those tests a material composition report will be established.
Finally the two reports of measuring and material composition will be collected together to be analyzed using special software.
Figure 7 shows the decomposition of the design recovery process (A3 node)
Using a special software an evaluation of the collected data will be done to help in producing point cloud for the disassembled product which discuss an initial imagination design for it, after then a CAD file will be produced to be feed into the optimization and recovery process which repair and specify the dimensions of the product clearly, this CAD file go then to take the final design which will be produced after putting some development on the design to improve its functions.

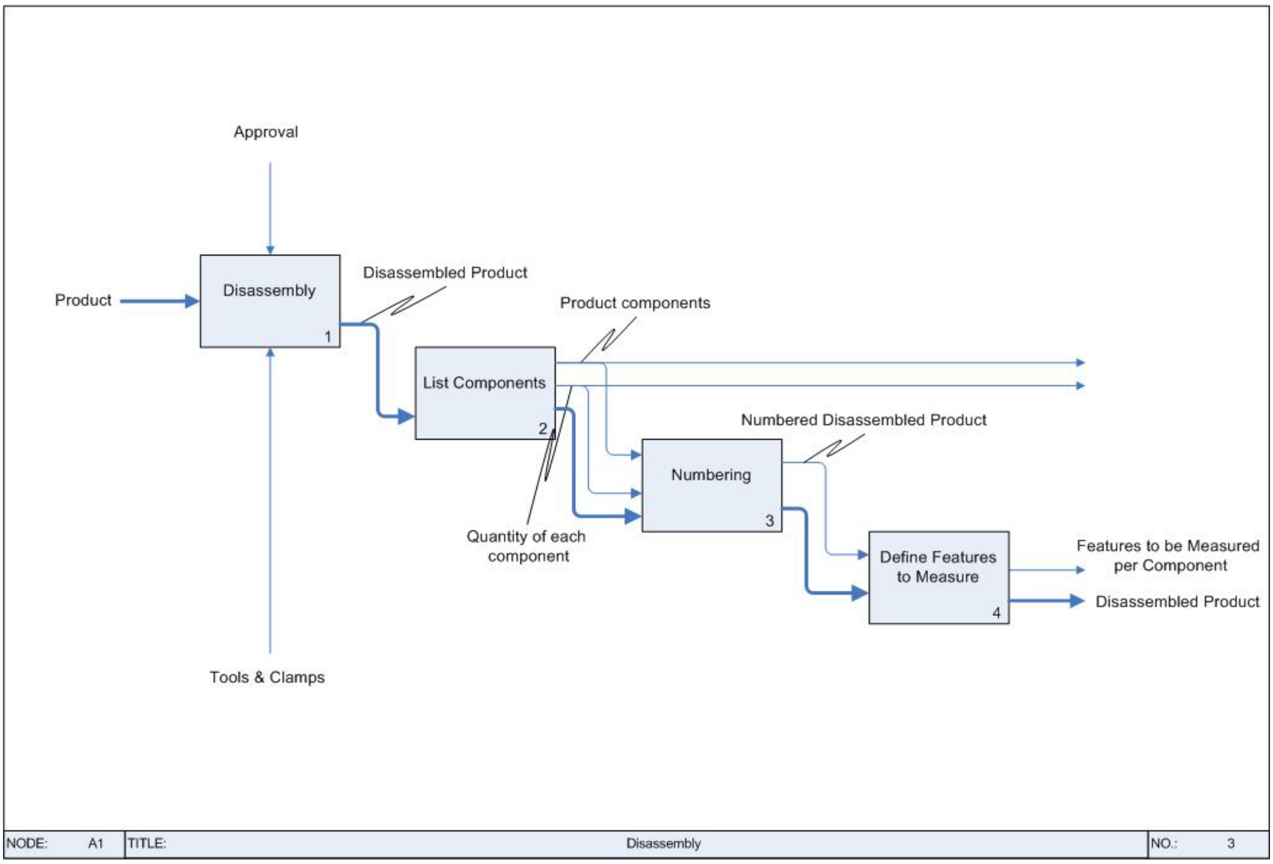

Figure 5 Disassembly process decomposition

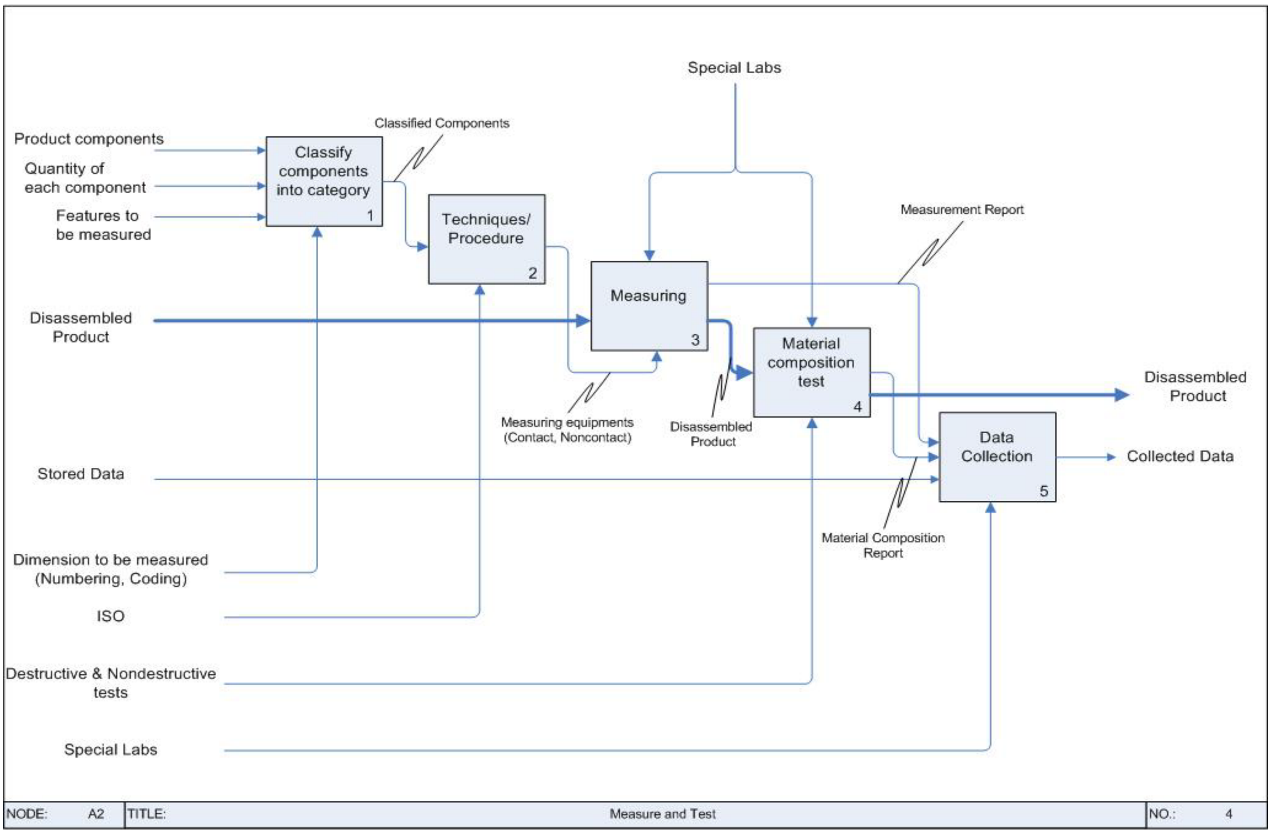

Figure 6 Measure and Test process decomposition

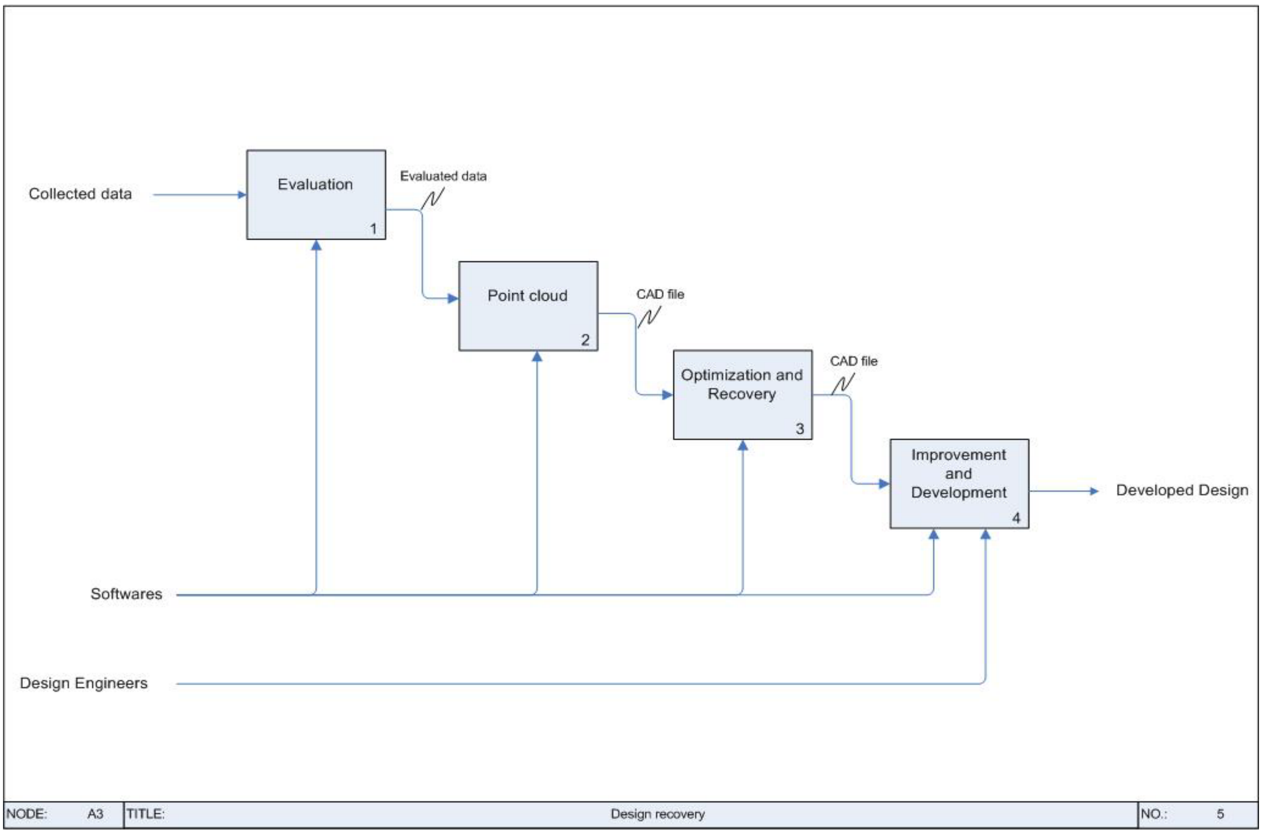

Figure 7 Design recovery process decomposition

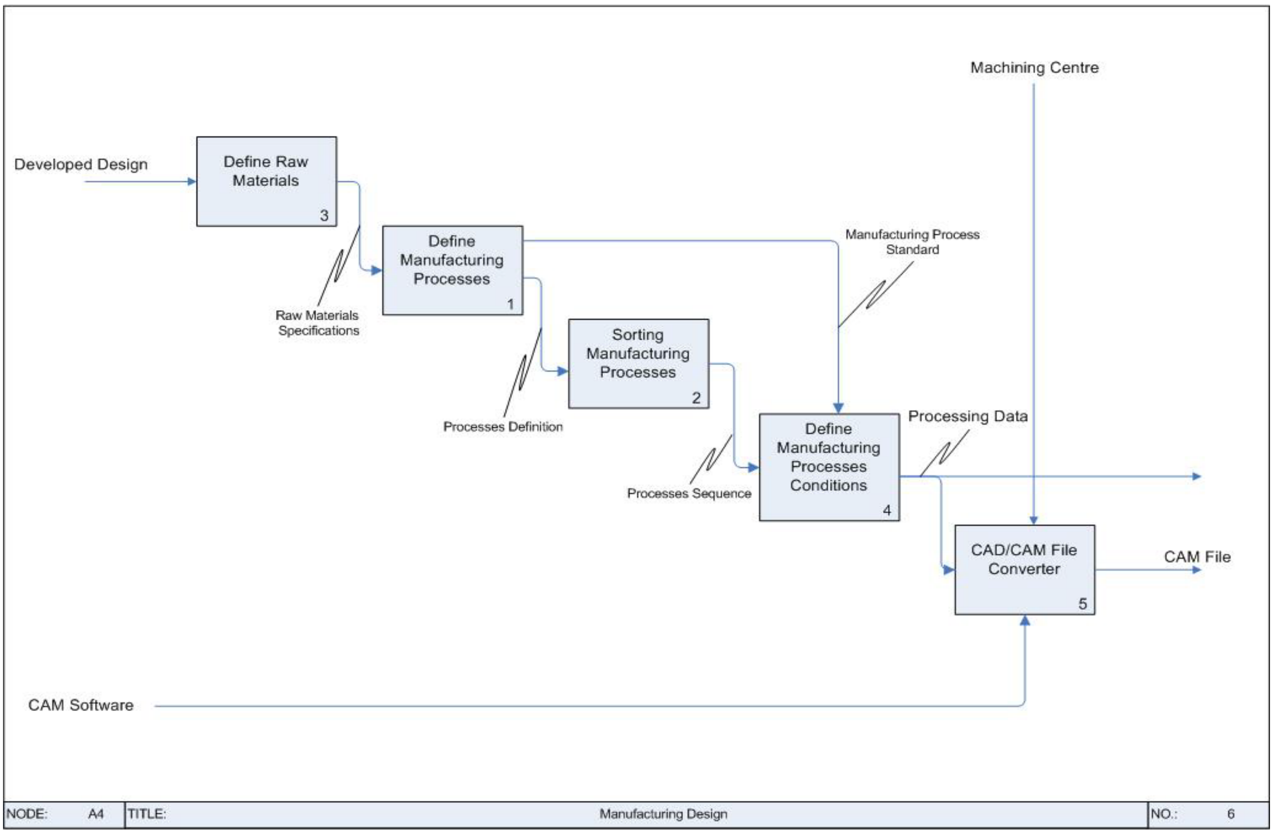

Figure 8 Manufacturing design process decomposition

Figure 8 presents briefly the manufacturing design process in which, after developing the final design for the product a manufacturing process design were be needed to specify all conditions required to meet the new product design. First, the raw materials for all components and its specifications must be defined to help in specifying the manufacturing processes needed to produce such product with respect to the manufacturing processes standards. After then the sequence for the manufacturing processes will be defined to minimize time & cost and to be ensure that the product will meet quality standards for each process, processing conditions will be defined briefly to ensure that this process will going in the right way. Finally the CAD file will be converted to a CAM file according to the processing data using CAM software.

As mentioned before there is two techniques could be used in manufacturing the required product (traditional and non- traditional machining).
Figure 9 describe the flow of processing the prototype for each technique. (A5 node)
If the prototype will be produced by using traditional machines such as (turning, shaping, drilling, and etc machines) then the CAD file will be feed to the workshop to be produced. Otherwise, the CAM file will be feed to the CNC machine to be produced.
The produced prototype will be inspect to ensure that it meets the quality considerations which specified before using CAI technique, after then an inspection report will take place.
According to this report the modification can be made to ensure that the developed product meets customers' requirements.

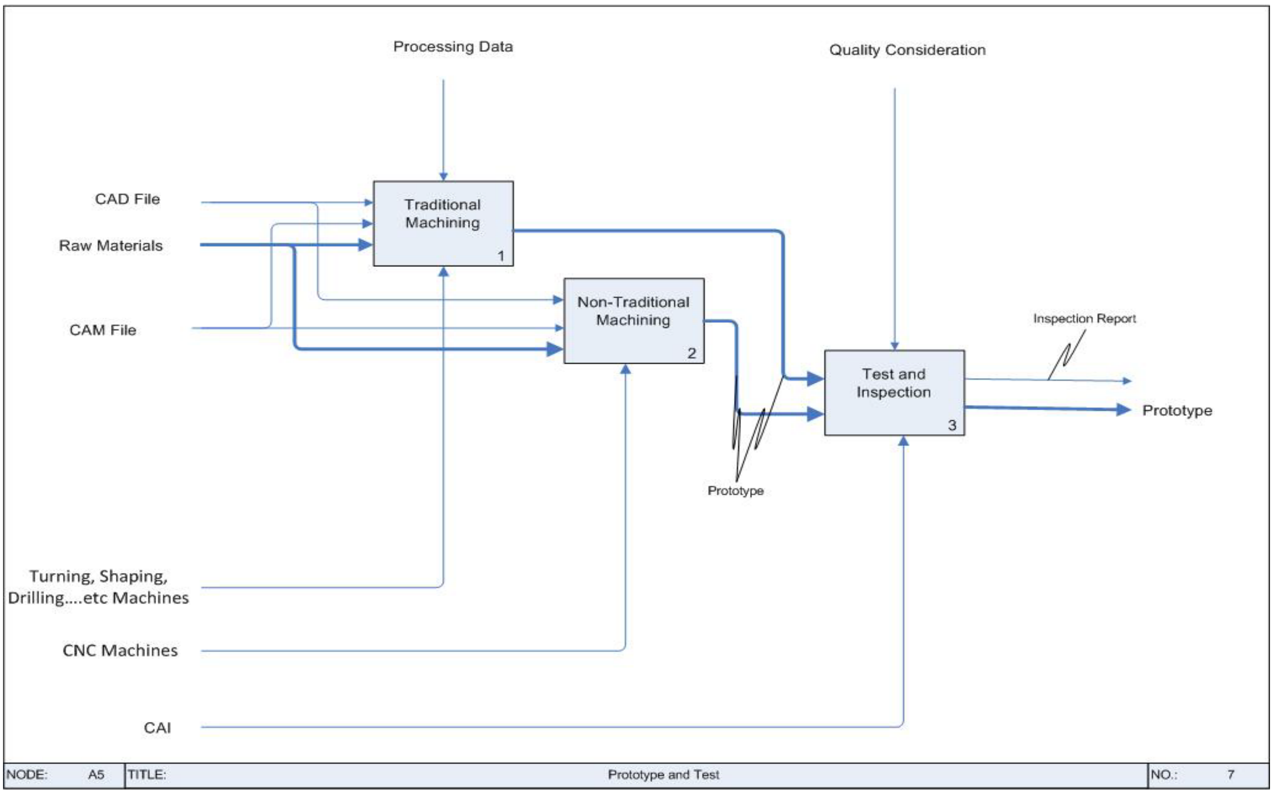

Figure 9 flow of processing the prototype for different techniques

5. CONCLUSION

The structured analysis for reverse engineering can provide not only efficient processing of modified spare parts but having also a high quality and customers' satisfaction. This model specialized by the detailed description for each process has to be taken through the reverse engineering and facilitate the use of it for the inexperienced reverse engineering users. The model makes a correlation between all its process from the disassembly of the entire product going through the production of the developed product, identifying all tools, equipments and conditions could be use, discussing all the data required from the material analysis, components and design to produce a new version product from the original one. The model also presents in a simply way the flow of data and raw materials through the whole processes.

6. REFERENCE

1. Tamas Varady, R. R. M., Jordan Cox (1996). Reverse Engineering of Geometric Models - An Introduction: 28.
2. Kwan H. Lee, H. W. (2000). "Direct integration of reverse engineering and rapid prototyping." PERGAMON 38(Computers & Industrial Engineering): 17.
3. L. Li, N. S., X. Peng, Y. Zeng, P. Gu (2002). "Areverse engineering system for rapid manufacturing of complex objects." PERGAMON 18(Robotics and Computer Integrated Manufacturing): 14.
4. Arie Karniel, Y. B., Yoram Reich (2005). "Decomposing the problem of constrained surface fitting in reverse engineering." ELSEVIER 37(Computer-Aided Design): 18.
5. Zhengyi Yang, Y. C. (2005). "A reverse engineering method based on haptic volume removing." ELSEVIER 37(Computer-Aided Design): 9.
6. You-Min Huang , H.-Y. L. (2005). "CAD/CAE/CAM integration for increasing the accuracy of mask rapid prototyping system." ELSEVIER 56(Computers in Industry): 14.
7. Zhenkai Liu a, L. W. a., Bingheng Lu (2006). "Integrating cross-sectional imaging based reverse engineering with rapid

prototyping." ELSEVIER 57(Computers in Industry): 9.
8. M. Sokovic, J. K. (2006). "RE (reverse engineering) as necessary phase by rapid product development." ELSEVIER 175(Materials Processing Technology): 6.
9. Minho Chang, S. C. P. (2007). "Reverse Engineering of a Symmetric Object." Computers & Industrial Engineering.
10. K.L. Chui, W. K. C., K.M. Yu (2008). "Direct 5-axis tool-path generation from point cloud input using 3D biarc fitting." ELSEVIER 24(Robotics and Computer-Integrated Manufacturing): 16.
11. Lin, Z.-C. L. a. C.-Z. (2000). "IDEF0 Model of the Measurement Planning for a Workpiece Machined by a Machining Centre." The International Journal of Advanced Manufacturing Technology 16(Manufacturing Technology): 11.
12. Chow, Z.-C. L. a. J.-J. (2001). "Integration Planning Model of IDEF0 and STEP Product Data Representation Methods in a CMM Measuring System." The International Journal of Advanced Manufacturing Technology 17: 14.