Integration of Non-networked Software Agents for Collaborative Product Development

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ABSTRACT

Recent advances in web technologies have led to the concept of collaborative product design and development. This includes geographically separated teams, co-located over wide area networks for the marketing, design and manufacturing. In this paper a practice of implementing a non-networked knowledge-based system for product development over a networked environment. The integration enabled designers to collaborate in the product design process rather than just relaying on the knowledge stored in their own systems. This integration gives the product development more flexibility and provides early collaboration between the different product design phases.

Keywords: collaborative product development, computer-aided design, system integration.

1. INTRODUCTION

Nowadays, global product development is a contemporary inclination supported by advances web technologies which have led to the concept of collaborative product design and development. This includes geographically separated teams, co-located over wide area networks for the marketing, design and manufacturing. This has led to an increased ability of manufacturing organisations to expand the supply chain, to reduce lead times and to reach larger global markets. The focus of the next generation product design and development process is on developing products using the expertise and facilities that are distributed over wide area networks. Concurrent engineering (CE) is the consideration of the factors associated with the product life cycle during the design phase. These factors include product functionality, manufacturing, assembly, testing, maintenance, reliability, cost and quality. CE has been defined as an attempt to optimise the design of the product and manufacturing process to achieve reduced lead times and improved quality and cost by the integration of design and manufacturing activities, and by maximising parallelism in working practices [1]. In this context, researchers have proposed and implemented new methodologies for distributed product development. The most well known and significant ones are the approaches based on software agents and computer aided collaborative product development [2-7].

Software agent-based approach focuses on synthesising specialised intelligent system characterised by autonomy and goal orientation [8, 9]. ProDefine [10] is a knowledge-based stand-alone system which posses the capability to assist product designers in bringing out their thoughts and developing their designs based on the product required function, the system then can advices the designer with the most suitable set of materials based on the design objectives, and finally demonstrates the product detailed design on a CAD solid modelling system.

In contrast, the focus of computer-aided collaborative product development is on real-time collaboration, such as communication and information sharing, between humans to support virtual teamwork [11, 12]. CoDevelop [13], which is a prototype human-centred system for collaborative product development, is developed where the seven layer open systems interconnection (OSI) reference model [14] for collaborative product development has been enhanced and adapted using as bridges for human agents and collaboration technologies. The implementation of prototype is addressed by carrying out a simulation of distributed product development which, apart form its primary objective of integration, captures the creative roles of humans at various stages of collaborative product development.

In a fully integrated distributed process, a necessary condition is that all components must be networked and be able remotely to operate. This paper is an example of implementing this by utilising ProDefine which is a stand-alone knowledge-based system over CoDevelop.

2. AN INTEGRATED COLLABORATIVE PRODUCT DEVELOPMENT ENVIRONMENT

Integration in organisational terms is concerned with facilitating collaboration between varied functional entities. These functional entities include humans, computer-based tools, machines and other facilities. There are several requirements for successful distributed collaborative product development such as efficient communication, information sharing and project management.

Collaborative Product Development Environment (Human Roles)	
Project manager (HA1)	• Project management • Decision making • Team member recruiting • Control of activities • Communication and negotiation
Human presenter (HA2)	• Integration of non-networked software agents • Re-using existing facilities and resources • Conversion of non-sharing information at various stages of product development • Provision of data- and functional- interoperability • Support of the project process and operation • Communication and negotiation
Marketing professional (HA3)	• Define market segments • Identify lead users and competitive products • Develop marketing plan
Industrial designer (HA4)	• Investigate feasibility of product concepts • Develop industrial design concepts • Build and test experimental prototypes • Communication and negotiation
Industrial engineer (HA5)	• Generate alternative product architectures • Define major sub-systems and interfaces • Refine industrial design • Define part geometry • Choose materials • Assign tolerances • Complete industrial design control documentation • Communication and negotiation
Manufacturing engineer (HA6)	• Estimate manufacturing cost • Assess production feasibility • Identify suppliers for key components • Perform make-buy analysis • Define final assembly scheme • Define piece-part production processes • Design tooling • Define quality assurance processes • Begin procurement of long-lead tooling • Communication and negotiation
Supplier (HA7)	• Provide material and resources • Communication and negotiation

Tab. 1. Human roles in collaborative product development environment

An integrated collaborative product development environment was developed to realise the methodology for the integration of non-networked software agents and facilities. The architecture of the proposed environment includes human agents, agent-based tools (ProDefine) and CoDevelop tools. Components of the proposed environment and their functions are explained in the following sub sections which show how the components of the proposed environment were configured in the prototype environment.

2.1 Human Agents

The human agents in collaborative product development (CPD) environment shown in comprised individuals with relevant expertise in marketing, design, manufacturing and project management. The roles played by humans included those such as data analysis, decision making, etc (see Tab. 1). For instance, at concept development stage, this involved tasks such as analysis of competitive products, developing industrial design concepts and estimating manufacturing cost. In this case, the roles of human agents are:

- To analyse competitive products, an understanding of competitive products is critical to successful positioning of a new product and can provide a rich source of ideas for the product and production process design. Analysis of competitive product is also called competitive benchmarking. Competitive benchmarking is performed in support of the specifications activity as well as in support of concept generation and concept selection. Most of the analysis of competitive products was carried out by human agent HA3 and incorporated with human agents HA4, HA5 and HA6;
- To develop industrial design concepts, there are two simple steps to successful concept design. Firstly, generate a large number of concepts and, secondly, select the best. A product concept is an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the customer needs. A concept is usually expressed as a sketch or as a rough three-dimensional model and is often accompanied by a brief textual description. The human agent, HA4, was responsible for sketching or describing the outline of product concepts for other human agents (such as HA1, HA3, HA5 and HA6) and agent-based tools in the environment;
- To obtain an appropriate estimation of manufacturing costs, an initial process plan should be used. The initial process planning includes generation and selection of machining processes, their sequence, and their machining parameters. The machining parameters comprise cutting tool type and cutting conditions (e.g. feed rate and cutting speed). The human agent HA5 was responsible for providing the necessary input and for analysing the economic manufacturing. The procedure will be incorporated with other human agents, H1, HA4, HA6 and HA7, and agent-based tools, such as cost estimation system [9] in the environment;
- Finally, the role of the project manager, HA1, was to advise in distributed product development, to provide management support, make decisions, negotiate conflicts and evaluate results. The human presenter (HA2) was responsible for information transfer and conversion, support of project processes and operation of CoDevelop. The human agents were distributed over a local area network and required virtual co-location in order to work as a team.

2.2 Agent-based Tools (ProDefine)

ProDefine (see Fig. 1) is intelligent system for innovative product design. The system possesses the capability to incorporate the product life cycle issues into the early stages of design process. It also incorporates a powerful product design modelling technique that utilises communication between designers and customers. Consequently, a quicker response to customers' expectations is guaranteed through:

- A systematic methodology for innovative products design that incorporates key product life cycle issues such as material selection, and product ergonomics;
- Assistance of designers to stimulate their minds' to pursue intuitive and imaginative thinking;
- An automated materials selection technique that possesses the capability to be accomplished at the early stages of product design;
- A powerful design modelling technique. This is accomplished through the integration of the proposed system with a CAD solid modelling system.

A knowledge-based approach has been developed for innovative product development, through the entire product life cycle. The proposed system composes of a KBS (knowledge-based system) for design alternatives, a design analysis module, a design evaluation module, a knowledge acquisition and storing module, and a user interface. It is also integrated with a computer-aided design (CAD) solid modelling system, spreadsheet application for storing data and numerical analysis, and work in cooperation with a material selection software package CES (Cambridge engineering selector) to facilitate the material selection process. All these elements interact one with another, subjected to the type of information required. The proposed overall framework of the developed system is illustrated in Fig. 2.

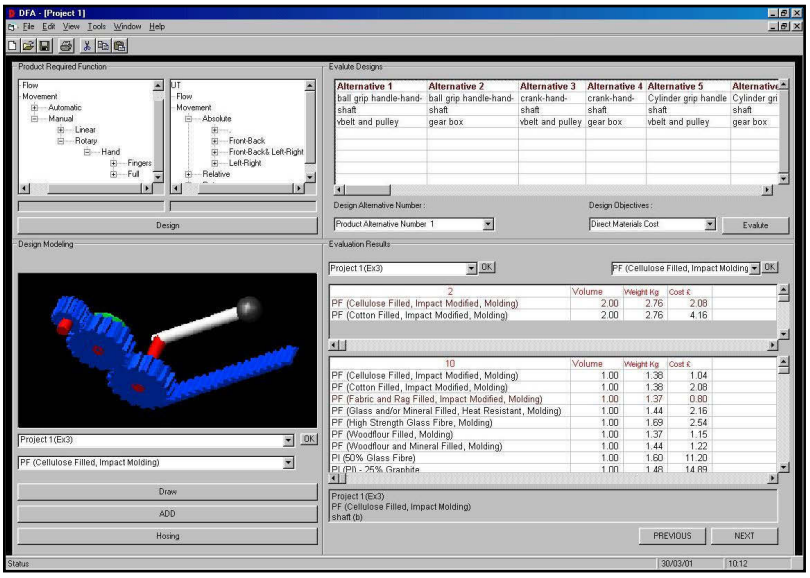

Fig. 1. A Snapshot of user interface (ProDefine)

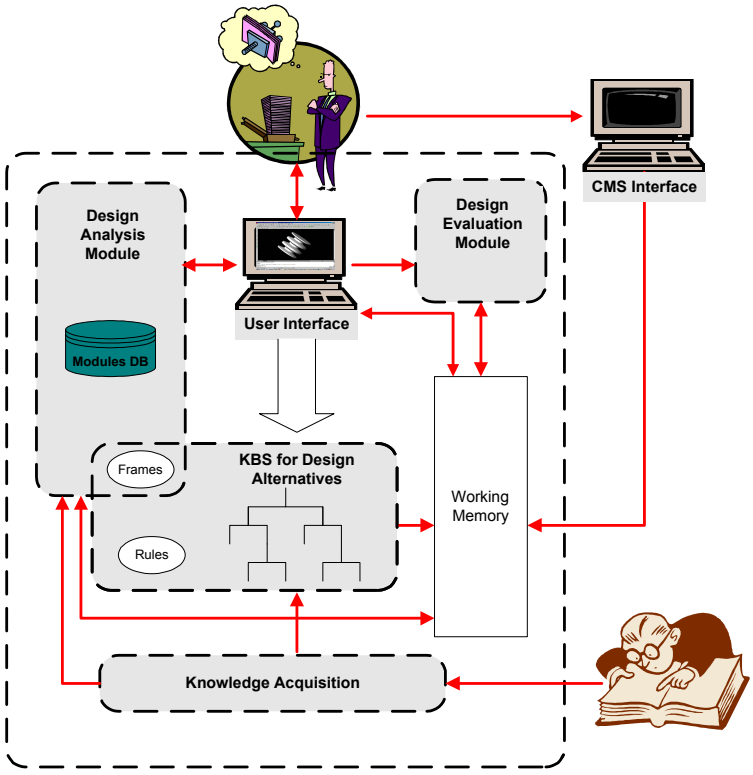

Fig. 2. Overall framework of ProDefine

2.3 CoDevelop Tools

CoDevelop (see Tab. 2) provides a set of tools: project organising, presentation, document editor, conference, spreadsheet, 3D viewer, vision, and concept mapping. Project organising is a project management tool for scheduling project and planning resources in web environment (see Fig. 4). This tool can be operated at two levels which are project level and activity level. The first level includes the information such as project type, project duration, person assignment, resource assignment, etc. At the second level, an activity can be decomposed into sub-activities. In order to speed the organising of new project, the process template database is provided. It is made up of standard sub-processes. Through template mapping, some related activities can be generated automatically. Moreover, for taking advantage of the functionality of commercial scheduling software, API (application programming interface) is used to integrate other modelling tool such as MS Project.

Conference is an online meeting tool provided facilities for group real-time communication in distributed locations. Accomplished with 3D viewer, document editor, spreadsheet and presentation, the group is available for sharing, viewing, editing and manipulation of graphics, text document, presentation and spreadsheet format, and 3D virtual reality models in VRML. In addition, a PDM module supported sharing of project related documents. The items placed on PDM module could be accessed by other team members subject to permission for access control. Vision combined the functions of vision today, e-mail, directory service, task-to-do, notes and calendar for the users. A concept mapping tool was provided for concept classification and evaluation. The tools provided in CoDevelop therefore represented a set of collaborative functions that were necessary for communication and information sharing in a virtual team (see Fig. 3).

Collaborative Product Development Environment (CoDevelop)	
Project Organising	• Project schedule • Resources planning • Online project management
Presentation	• Online presentation sharing • Shared presentation generation
Document Editor	• Online document sharing • Shared document generation
Conference	• Video conferencing • Text-mode communication • Face-to-face communication
Spreadsheet	• Online spreadsheet sharing • Data analysis • Shared spreadsheet generation
3D Viewer	• Real-time 3D modelling sharing • 3D virtual reality modelling tool
Vision	• Directory service • E-mail and telephone • Calendar
Concept Mapping	• Real-time concept discussion • Concept selection
PDM	• Product data management

Tab. 2. CoDevelop in collaborative product development environment

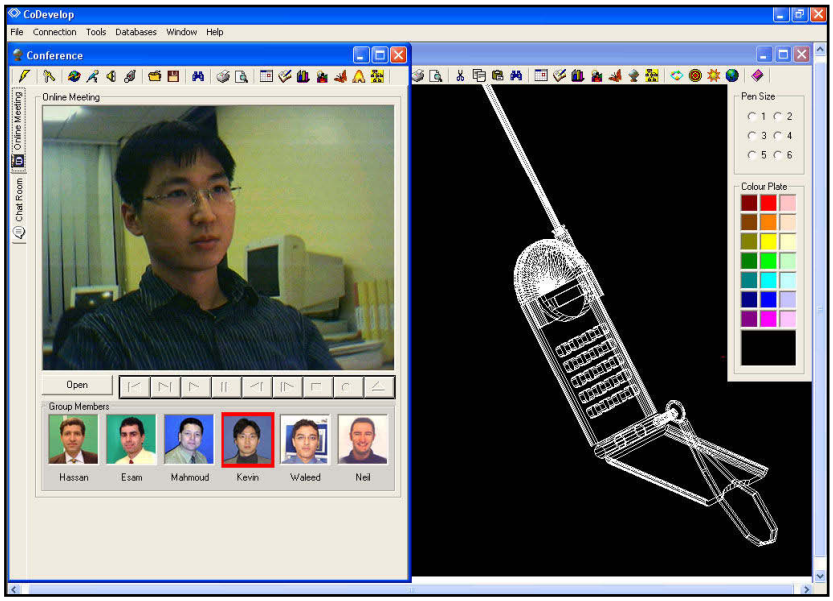

Fig. 3. A Snapshot of communication media (CoDevelop)

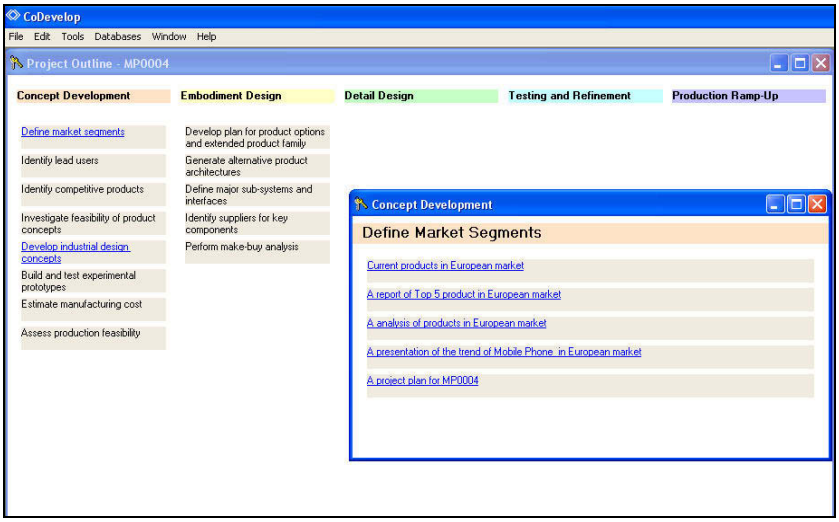

Fig. 4. Product Data Management

3. CASE STUDY: INTEGRATION IMPLEMENTATION

In modern manufacturing organisations, there has been an ever-increasing pressure for production units to be able to produce products in shorter lead-times and respond to the market demands faster, with improved quality, with greater applicability to market and for a low cost. Instead of the traditional product development lifecycle as has been detailed earlier, there is a drive to greater levels of concurrent and systematic advancements, breaking down the barriers of handing over the development at various phases. ProDfine has been built to support the systematic product development process.

ProDefine is a stand-alone system that does not support collaboration, since it was developed for individual designer's product development. However, software tool such CoDevelop that can provide efficient coordination and decision-making mechanisms for design team members is needed, due to the following necessities:

- During the product development process, design team members often have limited knowledge and information to accomplish product design tasks. For instance, the marketing analyst in the design team has not a sufficient concept of which materials and tools are used and how much they cost for product manufacturing. However, letting the right specialists offer the necessary design suggestions at the right time is essential;
- In the product design process, most design problems can be solved with different strategies, and these strategies may have different impacts on the design cycle, quality and cost of products, so the resolution of single design task is the foundation of the whole resolution plan. Therefore, it is an intelligent requirement for product design tools, suggestions, and processes to facilitate design team members to find a most satisfactory resolution strategy for every design task;
- During the complexities of product development, many agents have been applied to help design team members either analysing market trends or solving technical problems in the product design process. The reasoning module of the agent – a set of member functions of the agent classes, cannot be adaptable enough to satisfy theses design requirements. It should be a feasible method to incorporate the working mechanism of expert systems into the agent to improve its intelligence and adaptability.

CoDevelop is developed to solve the problems mentioned above. In the implementation of the developed system, the design team members can use ProDefine, either running the entire integrated system for online collaboration with other team members, or operating the sub-system for executing individual tasks separately. The system runs in real time. It facilitates and supports the product development throughout the lifecycle.

The advantages to be gained by collaborating in product development include the ability to secure access to new technologies and skills, or to share or acquire information for product development at an early possible design stage. In CPD process, CoDevelop can generally be seen as a cross-agent platform by incorporating the working mechanism of knowledge-based systems. The procedure for the implementation of CoDevelop is illustrated in Fig. 5 and is summarised as follows:

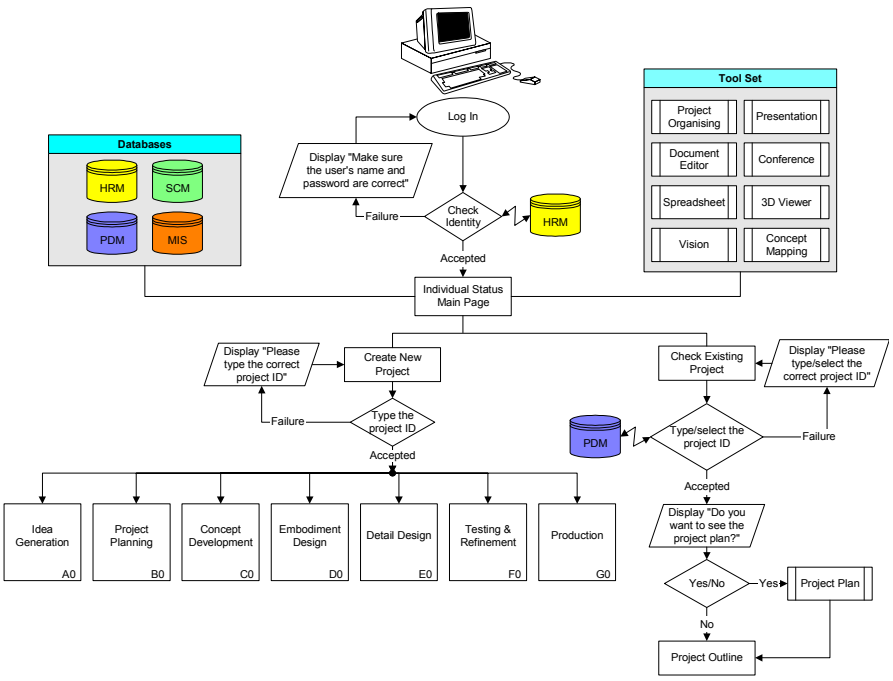

Fig. 5. System scenario of CoDevlop

1. User provides his/her identity to log in the system. An individual web page is displayed with a brief state of current task execution; selected tools, which are based on his/her needs, are provided.
2. User is available either for creating a new project or checking existing projects throughout the proposed system. There are seven stages defined in the developed system which are idea generation, project planning, concept development, embodiment design, detail design, testing and refinement, and production stages.
3. In the business opportunity phase, all human agents are involved in discussion for design idea generation. However, HA3 (marketing professional) plays a vital role for market research and analysis, and the others help the design idea generation in different perspectives to avoid faults in product development at any stages. Normally, a software agent, such as MIS, will be used in the business opportunity phase for market analysis.
4. In the design specification phase, the process activities and information flow were controlled. The product had to meet its functional specifications for applied load while satisfying manufacturing, safety and other design constraints such as cost, weight and size. In the collaboration process, the HA2 (human presenter) plays the role of information exchanging and internal coordination.
5. In the concept/embodiment/detail design phases, the overall function of a product is expressed in terms of its functional input and output, and could be denoted as the overall design problem. Based on a systematic design method [8], each overall problem has an adequate overall solution and both of them are composed of a number of sub-problems and sub-solutions respectively.
6. Agent–based tool (ProDefine) - KBS for design alternatives: Produces the design alternatives that satisfy the overall required function. This process is explained in detail in section 2.2.
7. Referring to the process of concept/embodiment/detail design phases, the collaboration was initiated by the HA4 (industrial designer), HA5 (industrial engineer) and HA6 (manufacturing engineer), who defined product design specifications for the new product design to the software agent such as CAD/CAM systems. HA6 also made a selection from a range of available manufacturing materials (see Fig. 6).
8. In the early stage of conceptual and embodiment design, the manufacturing engineer needs data for all materials, but at a low level of detail, where breadth is important, not precision. In the later stages of detailed design, where the appropriate range of materials is known, the data requirement is for precision, not breadth.
9. Agent-based tool (ProDefine) - Design analysis module: accesses the module's spreadsheet and interrogates HA5 (industrial engineer) about the missing product's required function parameters, E.g. what is the magnitude of the force applied, what is the speed of rotation;
10. HA5 (industrial engineer) provides the design analysis module with the product's required function parameters. E.g. 15 KN, 20 rpm;
11. Agent-based tool (ProDefine) - Evaluation module: assigns a numerical value to the performance of the selected design, and for each material alternative in the appropriate range of materials measured against the design objective;
12. The appropriate ranges of materials are in the lists that contain all the materials that are theoretically applicable to be used for manufacturing a particular module. In the material selection processes, the software agent will consider each module which is composed of only one component and will set one material for all the components in this module. The initial setting of applicable range of material is obtained by using another software agent called Cambridge Engineering Selector (CES) materials' filters. The filters are classified into a number of classes; each one of these classes provides a narrow range of materials that satisfies this particular class's requirements. In order to select a material, the CES filters are used in conjunction with each other, at the different design phases, which eliminate all the materials that are theoretically not applicable to be used in manufacturing this particular module. The software agent then proceeds with the generation of the primary range appropriate of materials for the whole product at the concept design phase. At the embodiment design phase, a sub range of this primary range is generated for each module based on this module's components shape. The product usage materials filter generates a range of materials that can be used for any product anticipated to function in this specific industrial sector. The result of material analysis report will be uploaded by the HA5 (industrial engineer) into the PDM database;
13. In the design for the manufacturing phase, narrowing down this range of material to keep only the materials that exist at the same time under the filter's class of the available 'Manufacturing Process', eliminates all the materials that are theoretically not applicable to be used for this product. For each module within the product, the primary range of materials is used in conjunction with the narrow range of materials that exist under the module's shape class, to generate a final range of appropriate materials for this particular module. Fig. 6 illustrates the procedures for setting the primary appropriate range of materials for the whole product and then the appropriate range of materials for each module in the product. The procedures explained earlier, for

setting the applicable range of materials, using CES filters, are applied whatever the design objective(s) is/are. For precise selection, more materials are eliminated, based on materials' sizing properties and functional attributes, to satisfy the product detailed design. Finally, materials are ranked from top to bottom, based on their degree of meeting the design objectives. The software agent then proceeds with the generation of a safe design for the new product with respect to the alternative criteria, each being subject to the specified design constraints. The manufacturing engineer (HA6) specifies the constraints to the software agent, and communicates it through a GUI (graphical user interface). The proceedings of the session were shared with other team members in real-time, using Communication Media provided by the developed system. The Communication Media also served as an informal conflict negotiation mechanism between different human agents during the design process. The software agent generated a detailed design which included the final geometry of the new product and properties of the selected appropriate material;

14. The industrial engineer (HA5) carried out the design of the mould based on the final geometry of the new product and a shrinkage allowance. This included the consideration of the machine parameters, such as injection pressure and temperature, volume of the plastic and cycle time. The manufacturing engineer (HA6) and the supplier (HA7) fabricated the mould in consultation with the industrial designer (HA4) and the industrial engineer (HA5). This was followed by the manufacturing process using different manufacturing machines. Proceedings of the session were archived by the HA6 using advance manufacturing software agents for subsequent analysis of the new product. The shared information contained movie clips, audio, still images and discussion documents in graphic and text formats;
15. Finally, all the human agents HA1, HA2, HA3, HA4, HA5, HA6 and HA7 performed the collaboration for new product development in distributed locations.

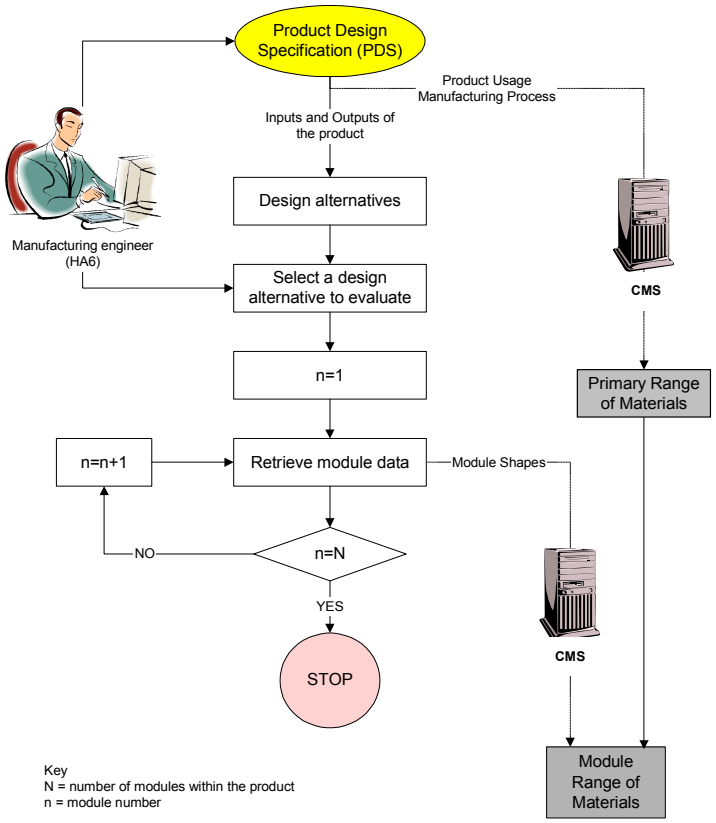

Fig. 6. Procedures for setting the representative range of appropriate materials (ProDefine)

4. CONCLUSION

The tangible benefit of integrating of non-networked software agents is that it provides an integrated environment for the holistic product design from concept to realisation and removes the barrier of collaboration between networked and non-networked environment. Therefore, an efficient product development process is generated and identified. The barriers between people and incompatible computer systems, resulting from non-standardisation, have been solved. The team participant can still implement non-networked software agents collaboratively to perform a project at distributed locations. The main function of CoDevelop, besides allowing the team participants being able to work at distributed locations, is to integrate non-networked software agent into networked environment. The integration enabled designers to collaborate in the product design process using their familiar software agent (ProDefine) rather than just replacing a new software agent. This integration gives the product development more consistency and generates fewer conflicts between the different product design phases. In addition, at an integrated environment it enables project planners, marketing analysts, designers, suppliers, and manufacturing planners to communicate in the early stages to reduce any unnecessary wasted time, resources, and costs, thus increasing the total product quality, maximising the organisation resources used, and reducing the total product cost and product lead time in order to face global competition.

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