UDK 621.91

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A FRAMEWORK SUPPORTING CONCURRENT 'PRODUCT FAMILY AND MANUFACTURING SYSTEM' SYNTHESIS DECISION MAKING

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ПРИЙНЯТТЯ РІШЕННЯ, ЩО ОПИРАЄТЬСЯ НА ІНФРАСТРУКТУРУ, ПРО ПОГОДЖЕНИЙ СИНТЕЗ "ЛІНЕЙКА ТОВАРІВ І ВИРОБНИЧА СИСТЕМА"
Ця стаття представляє систему поглядів з випереджальним і обґрунтованим змістовним забезпеченням прийняття зацікавленими сторонами рішення про концептуальний синтез, що підтримує як конструювання лінійки товарів, так і планування виробництва. Переслідується мета підтримки відповідних зацікавлених сторін головним чином шляхом забезпечення інформованості результатом вибору на етапах життєвого циклу як виробничої системи, так і товару. Підтримувана базами знань підтримка також забезпечується у формі рекомендацій з використання виробничих ресурсів і рекомендацій, що допомагають уникнути несподіваних наслідків рішення. Ця система поглядів використана як основа для розвитку базованого на комп'ютерних можливостях інтелектного інструментарію, що підтримує конкурентне проектування виробничої системи й лінійки товарів.
Ключові слова: ухвалення рішення, планування підприємства, лінійка товарів.

Эта статья представляет систему взглядов с опережающим и обоснованным содержательным обеспечением принятия заинтересованными сторонами решения о концептуальном синтезе, поддерживающем как конструирование линейки товаров, так и планирование производства. Преследуются цели поддержки соответствующих заинтересованных сторон главным образом путем обеспечения осведомленности результатом выбора на этапах жизненного цикла как производственной системы, так и товара. Поддерживаемая базами знаний поддержка также обеспечивается в форме рекомендаций по использованию производственных ресурсов и рекомендаций, помогающих избежать неожиданных последствий решения. Эта система взглядов использована как основа для развития базирующегося на компьютерных возможностях интеллектного инструментария, который поддерживает конкурентное проектирование производственной системы и линейки товаров.
Принятие решения, планирование предприятия, линейка товаров.

This paper presents a framework for providing both product family design and factory planning stakeholders with proactive and content aware support during conceptual synthesis decision making. The framework aims to support the relevant stakeholders primarily by providing awareness of decision consequence on both manufacturing systems and product life cycle stages. Knowledge based support is also provided in the form of guidance on avoiding unintentional decision consequences and manufacturing resource usage. This framework is used as the basis for the development of an intelligent computer based tool that supports concurrent manufacturing system and product family design.
Keywords: Decision Making, Factory Planning, Product Families.

1 INTRODUCTION

Faster technology uptake and increasing customer demands have meant that manufacturing is under a continuous state of change, and new paradigms for the future of manufacturing are being developed [1]. Thus in the modern manufacturing scenario, product development has become a task of fundamental importance for any company. Good product development practices can set a company apart from its competitors, giving it a leading edge in extremely competitive markets.

This said product development is a complex task which involves many stakeholders, each having a different specialisation, such as product design and manufacturing system design, therefore each having different perspectives and aims.

This has led to the development of models such as the Integrated Product Development (IPD) model [2] which is based on the concept of concurrent consideration. In the IPD model product designers and manufacturing system designers work concurrently on developing solutions aimed at satisfying the customers' needs.

With this in mind Borg et al have developed a tool to support product designers during concurrent synthesis decision making [3]. This tool helps product designers by providing an insight into the intended and unintended consequences of decisions made on future life-cycle phases such as the manufacturing system, but also the use, service and disposal phases of a product. As presented by [4] there are also many tools, methods and approaches aimed at providing support for product family and platform design. From a manufacturing perspective several modelling and simulation tools are also provided to support manufacturing system stakeholders [5].

Having said this current tools and methods do not provide explicit support during conceptual stages for concurrent product and manufacturing system design for a group of products.

Therefore the lack of solution to this problem provided the motivation for carrying out this research and achieving the goal of supporting the different stakeholders in product and manufacturing system design for a group of products. This paper presents the hypothesis that relevant product development stakeholders can be supported by providing them with an insight into the intended and unintended consequences on future product families.

This paper starts with explaining the impact of product and factory design decisions on costs and therefore highlighting the importance of supporting factory planning stakeholders during the conceptual design stages.

The concurrent development of Product Families and Manufacturing Systems is then discussed in detail. Based on this discussion the consequence of decisions made during product and family design is presented.

The framework for supporting concurrent 'product family and manufacturing system' synthesis decision making is then presented. Finally this paper concludes by presenting the prototype ICT tool which was developed based on this Framework.

2 COSTS COMMITED DURING FACTORY DESIGN

2.1 Factory as a System

Based on the theory of systems a product can be decomposed into several system elements. In a similar manner one can also describe a factory as being a system. Westkämper in [1] presents the industrial paradigm "Factory as a Product", modelling the hierarchical scale of manufacturing.

2.2 Factory as a Product

In this manner the production branch of a manufacturing system can be referred to as a Factory. Similarly to a product, the factory also has a life-cycle termed the factory life-cycle [6]. In the factory life-cycle several planning activities precede the ramp-up, factory operation and manufacturing execution phases, and eventually maintenance and recycling or disposal.

2.3 Costs Committed During Factory Design

Cooper & Kaplan [7] have developed a model which compares the actual expenditure with the committed costs during the different phases of product design. By analysing this model one can note that during the early stages the incurred costs are low giving a low cost incidence. On the other hand many decisions are taken during these early stages, meaning that the committed costs are significantly larger. For example during conceptual product design, there is still no tooling costs spent since only prototypes are built. This said, during this phase many decisions are made such as material and form that commit investment costs in relative manufacturing processes during future phases.

Therefore by analogy, this paper presents the hypothesis that during the early stages of the Factory Life-Cycle few costs are actually spent, but since many decisions are being made during these stages this means that substantial costs are being committed (Figure 1).

For example during Internal Logistics and Layout Planning, several decisions are made on the material handling systems and the location of different manufacturing processes. The costs at this stage are tied to the wages of the stakeholders. The committed costs on the other hand are high, since the material handling system carries a high cost.

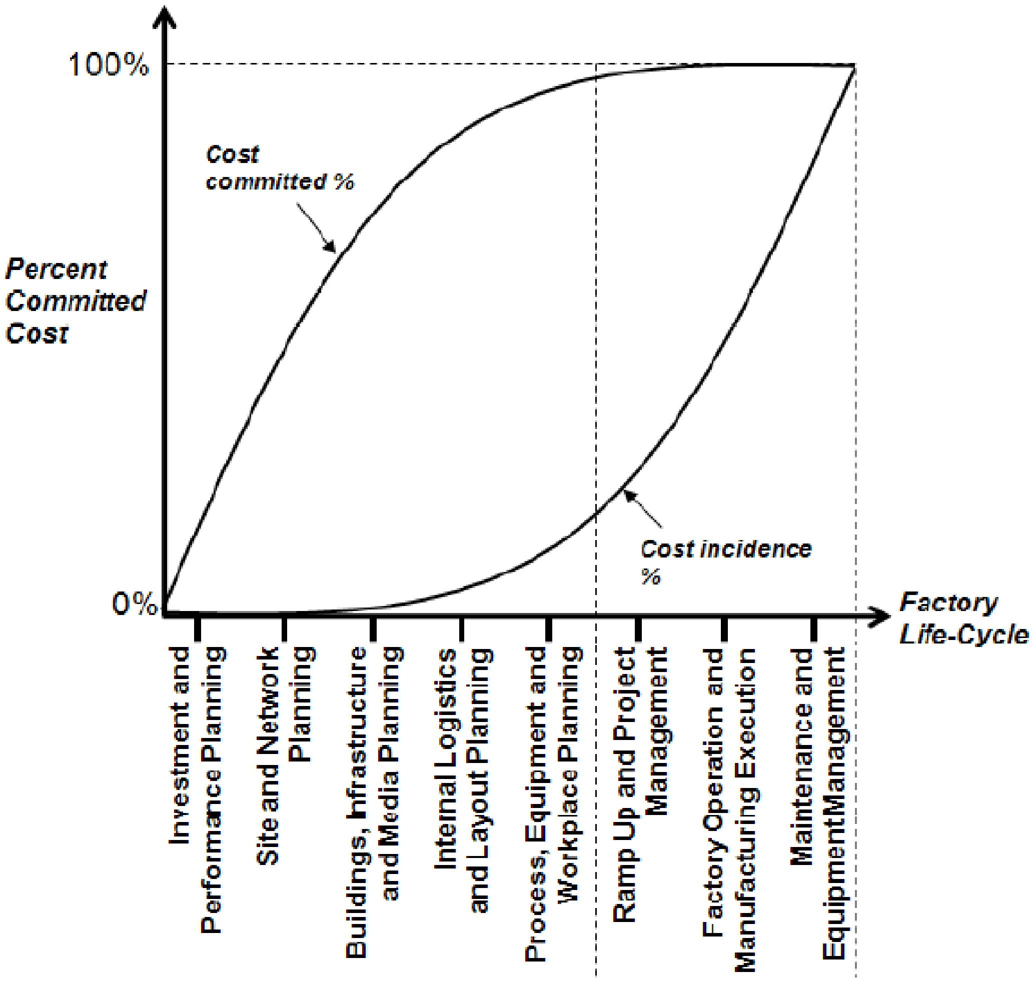

Figure 1 – Costs committed vs. cost incidence during the Factory Life-Cycle

As previously highlighted reduction of planning time also means that there is an increased pressure on stakeholders to take faster decisions. This hypothesis therefore highlights the importance and significance of the conceptual design stages in the factory life-cycle. Hence this leads to the principal of supporting the stakeholders during these stages.

3 THE NEED OF CONCURRENT PRODUCT AND MANUFACTURING SYSTEM DEVELOPMENT

This argument has therefore led to an in-depth study of how product development stakeholders can be supported with an emphasis relationship between the product and manufacturing system.

3.1 Product Family Design

One of the solutions adopted within the product development scenarios to achieve a high level of customisation whilst maintaining competitive costs is the introduction of product families and platforms.

Product family design is aimed at making the best use of the large investments made in the areas of product development, manufacturing, and marketing

[8]. Much research work has been carried out in the area of product families and platforms from a product design, manufacturing, production and supply chain management perspective. This has been well documented in [4]. Product families can be generated by having variants at different product levels, i.e. from product level, to subproduct and feature level.

3.2 Changeable Manufacturing Systems

Wiendahl in [9] portrays the different classes of Factory Changeability and their relationships to the hierarchy of Product Levels, from Product Portfolio to the individual Workpiece, and Production Levels classes. For example, to achieve Sub-Product Flexibility one has to act at the segment level. These factors, together with the volatile nature of the international markets, mean that manufacturing companies and their facilities have to be flexible and avant-garde, whilst remaining constantly aware of their operating environments. The implementation of transformability in the manufacturing strategy and structure can therefore provide companies with enormous advantages in both market oriented innovation [10].

3.3 Concurrent Development

It is now the aim of the authors to highlight the relationship between product family design and the factory life cycle stages.

This paper therefore presents a model that relates product levels the Hierarchic Scales of manufacturing, classes of factory changeability and the factory life cycle stages (Figure 2).

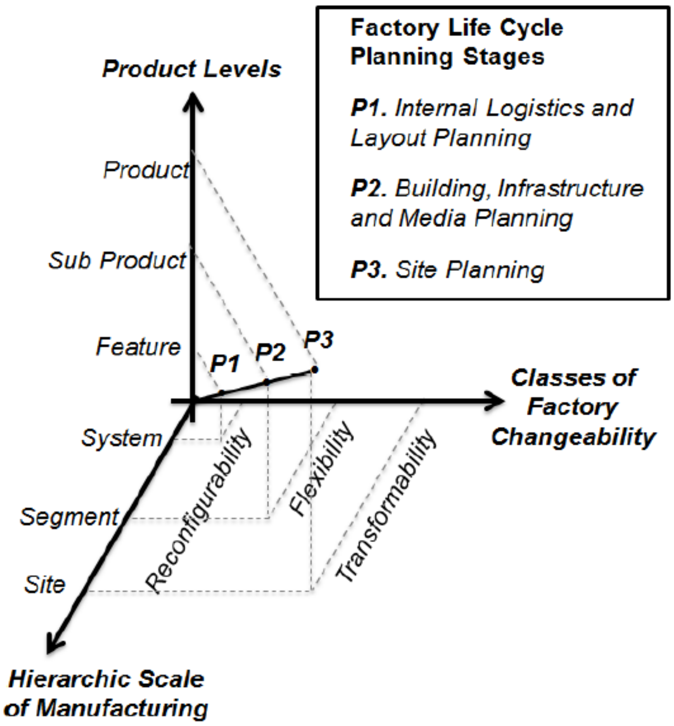

Figure 2 – Relationship between product, manufacturing systems and changeability

Therefore if a product designer aims to achieve product variability at the product level, this means that this has to be taken into consideration during the site planning stages. This is done during the design of the site and by integrating the principles of factory transformability.

Hence it becomes crucial to support the manufacturing system designer during the site planning stage with the information and knowledge required to achieve the degree of factory transformability to cater for the required product variation.

3.4 Co-Evolution

Furthermore throughout their lifetime product families and manufacturing systems are continuously evolving, new features or parts may be added or replaced to the current range of products. If one had to take the example of an automobile, product ranges may be updated with the introduction of new engine platforms. This represents one of the main difficulties in designing manufacturing systems which cope with product families due to their ever changing nature, especially during the life cycle of the manufacturing system [11] and [12].

This means that decisions made during the planning phases of the manufacturing system have outstanding consequences on both the life cycle of the system and also on the future product families and platforms which can be produced by the system.

4 A FRAMEWORK SUPPORTING DECISION MAKING IN PRODUCT FAMILY AND FACTORY DESIGN

In the development of the proposed framework it was decided to support concurrent product family and manufacturing system during synthesis decision making. Before explaining the framework it is therefore important to understand and be aware of the process which has been identified

4.1 Synthesis Decision Making Process

During design synthesis decision commitments are reflected in the evolving solution models. In the scenario being proposed design synthesis occurs both during the product design process and during the factory design process (Figure 3).

In the case of the product design process, the designer may want to find a solution to having a locating feature on a part. For this problem a number of options may be available, such as having a round or square form. The designer done makes a synthesis commitment action, and the chosen option is added to the evolving product model.

This decision may have several consequences on different life stages. One of these consequences is the limitation on the available options for the factory designer. This consequence is the link between product design process and the factory planning process.

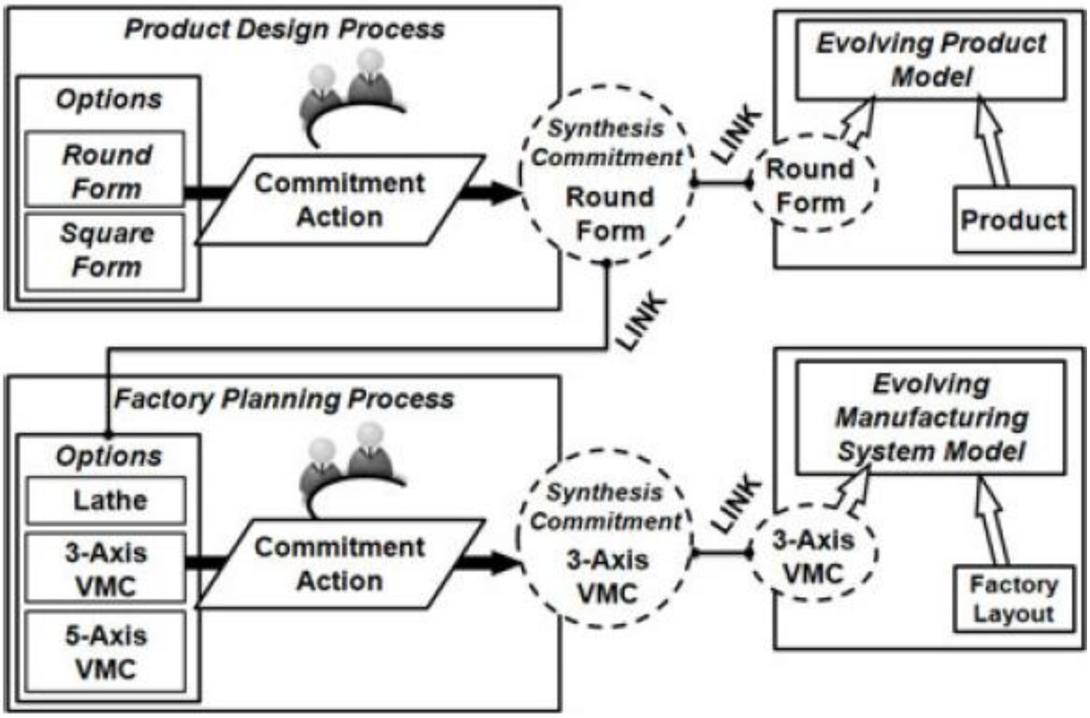

Figure 3 – Product and Factory synthesis decision making processes

The designer now faces the problem of finding a manufacturing solution to creating a round form. From the options available the factory designer has to choose a solution, such as the use of a 3 axis vertical machining centre. This synthesis commitment is added to the evolving manufacturing system model. This decision also has consequences on future factory life phases, such as the location and type of services which need to be installed to operate this process.

Another example may be the decision of the factory designer to use the welding process to join the parts together. This has a consequence that all other products in the range of products, since these now have to be manufactured of the same material; otherwise this manufacturing system will not be capable of manufacturing the future product range.

4.2 A Framework Supporting Decision Making

It is therefore being proposed that the level of product variability is impacted by decisions made during synthesis decision making in factory planning. Furthermore these decisions are made throughout the different phases of the Factory Life Cycle Planning, and therefore support is required throughout this process during synthesis decision making.

This research therefore proposes two methods which can provide support during this delicate design stage. The first one is to make both product and factory designers aware of consequences of decisions made of current and future product families. The second is to provide a visual feedback on the unutilized manufacturing system potential.

4.3 Awareness of Decision Consequences

This leads to the importance of making the product and factory designers aware of the consequences of their decisions on future product variants.

If in the case of the above example the factory designer is made aware of the consequence of choosing the welding process on the limitation for future product variants, then a different decision may be done. This information is therefore required during the synthesis stage, were several options are made available to the factory designer, and only one can be committed.

4.4 Unutilized Resource Potential

It would therefore be ideal for the manufacturing industry to have its product development stakeholders (Product Designers and Factory Designers) aware of the consequences of their decisions, especially when these are unintended. A possible method would be to portray graphically the product variability with respect to a number of Indicators. These indicators would be a set of variables such as geometry, size and weight of the product (Figure 4).

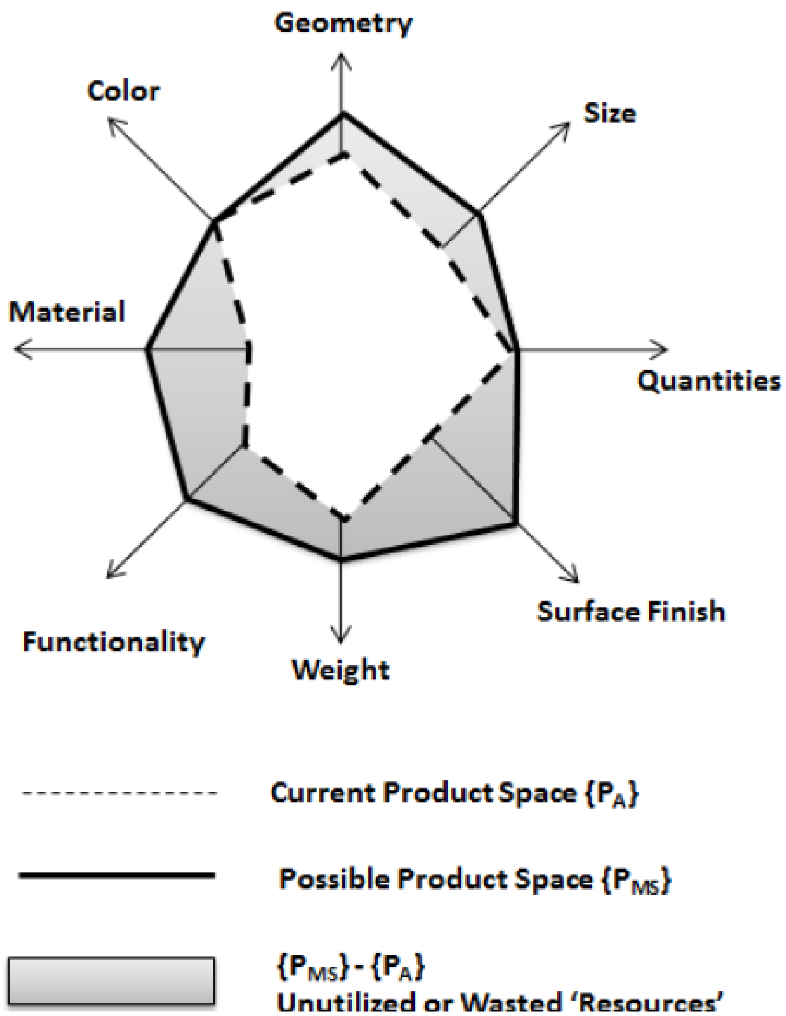

Figure 4 – Product Variability and Unutilized Resource Potential

This method would compare the current product or product family space (i.e. the features of the current product – weight, material, color, etc.) with the possible product space that can be handled by the manufacturing system being designed (i.e. what types of geometry, quantities and surface finish that the manufacturing system can handle).

This means that both the product designer and the factory designer would have a visual reference that makes them aware of the readily available but unutilized potential. In this way during synthesis design, decisions can be made to allow for either greater flexibility in the design, or to opt to make a better use of the wasted resources.

For example in the first scenario a manufacturing system designer has to choose between a number of options for a material handling system. These options may include a fixed position pick and place system a gantry type pick and place and a robotic arm. These three different options give the designer different levels of flexibility in material handling of parts of different size, weight and geometry.

This method will provide the designer with a visual representation of the flexibility which the different options have on the current product (Do they satisfy the requirements of the current product?) and on future possible products (How different can possible future variants be to be accommodated on the same manufacturing system?). In this way the designer will be supported during synthesis decision making, and can therefore make a better informed decision.

5 UNDERLYING FRAMEWORK DEVELOPMENT

The underlying framework philosophy, allows the product designer and factory planner to explore a number of different product and manufacturing system solutions with respect to their changeability and product space. The product space is understood to be the range of products which can be produced by the manufacturing system. Therefore this approach framework aims to reveal and analyse the consequences of commitments made during the factory planning stages on the possible product space, and hence on product families (Figure 5).

The framework illustrated in Figure 5 is therefore being developed to support the factory planning processes by proactively providing the necessary information and required guidance.

More importantly, it focuses on "product family and manufacturing system" synthesis decision making. In this way support is provided when the system solution model is still evolving and therefore helping to proactively foresee and optimize as early as possible the range of product families that can be handled during the product and factory life-cycles.

5.1 Operational Frame

As the product design solution evolves, the product designer and factory planner start to concurrently solve sub-problems encountered in both product and manufacturing system design.

The commitments made are based on a set of intentions, preferences and circumstances. This means that the factory planner might commit to different decisions based on the company's current economic circumstances.

The product designer and factory planner will then interact with a synthesis element library. This library can be restricted depending on the product level flexibility required. The stakeholders can then search the options for a solution to the sub-problems encountered.

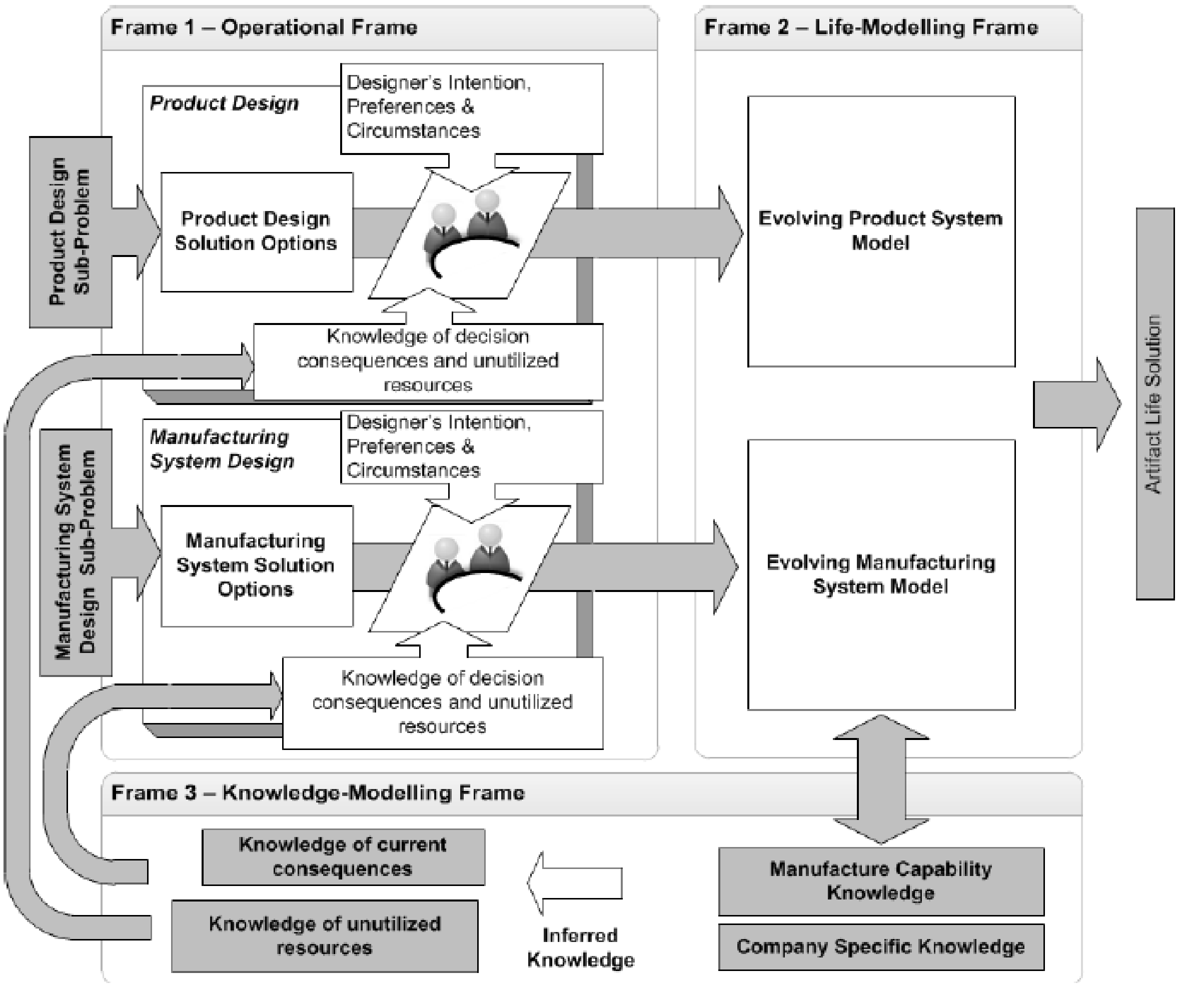

Figure 5 – Framework Supporting Concurrent 'Product Family and Manufacturing System' Synthesis Decision Making

5.2 Life-Modelling Frame

Once the product designer and factory planner commit to a solution these commitments are added to the evolving system models.

Therefore if the product designer commits to having a plastic part, then this will be reflected in the evolving product model. This will therefore drive the factory planner into solving the manufacturing system sub problem of manufacturing this plastic part. From a set of options, such as machining, plastic injection molding or extrusion, the factory designer can then commit to a process to manufacture this part.

This commitment will then be added to the evolving manufacturing system model. Together the evolving product and manufacturing models make up the artifact life solution.

5.3 Knowledge Modelling Frame

Modelling knowledge is an essential part of a decision support system [13]. Since it has been established that support for concurrent decision synthesis is required, it becomes clear that knowledge about both the evolving manufacturing system and the co-evolving product design solution is required, since decisions made at each end affects the other. Therefore from the previously explained relationships between products, manufacturing systems and changeability one can elicit the type of knowledge and knowledge structuring which is required to foresee the consequences on product variability from decisions made, and therefore provide feedback to the user.

Therefore within this frame the evolving product and manufacturing system models are constantly being monitored to infer knowledge of current consequences of decisions made and the evolving product space model.

This knowledge is inferred based on previously gathered knowledge of manufacturing capability and company specific knowledge.

Support is therefore provided by providing this knowledge to the product designer and factory planner. In this method the stakeholder can proactively monitor the effect of the solution elements chosen on the product families which can be produced by the manufacturing system in development.

6 ICT PROTOTYPE FRAMEWORK IMPLEMENTATION

An ICT Tool is being developed to evaluate and demonstrate the concepts which have been discussed in this paper. This tool for Manufacturing System Design Synthesis (MANUSYDS) support was implemented with the use of the JAVA programing language to provide both the Graphical User Interface (GUI) and business end operations.

The aim of this ICT prototype is to enable the concurrent development of the product family and the manufacturing system which will be producing it. It therefore implements the concepts developed by the previously discussed framework into a tangible solution. The domain chosen for this implementation level is the manufacture and assembly of plastic components.

As is illustrated in Figure 6 the implementation consists of an ICT tool that makes use of tabs, control boxes, drop downs and tick boxes that allows the factory planner and product designer to explore several solutions for the manufacturing design problem that is being tackled. All the decisions which have been committed to by the factory planner are then represented in the evolving manufacturing system model on the right of the GUI in real time.

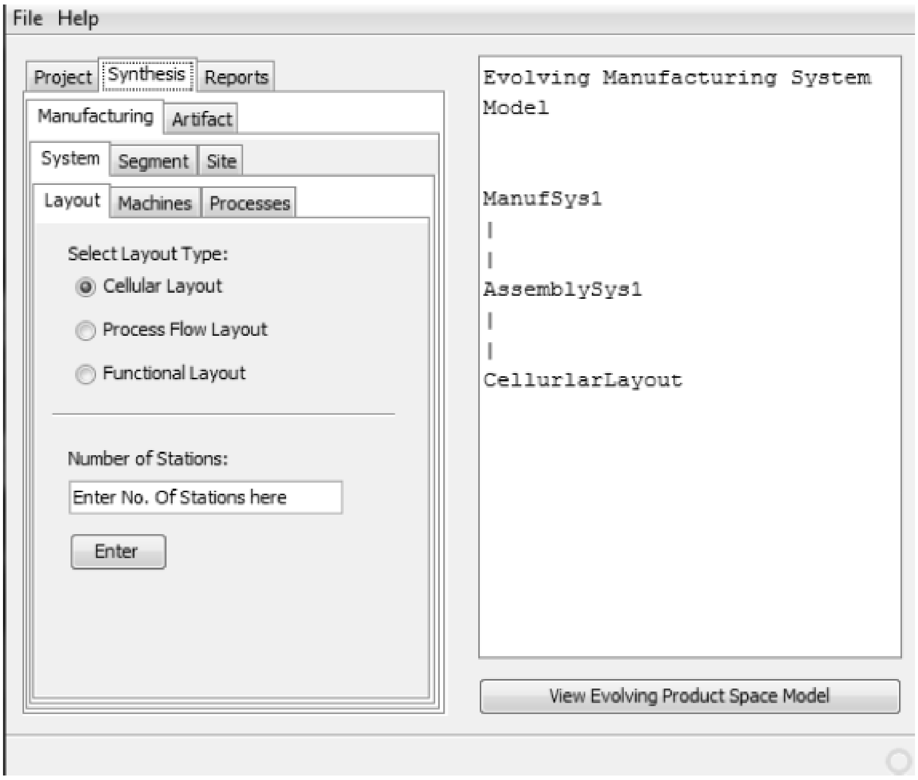

Figure 6 – MANUSYDS

Once the product designer makes a number of product design synthesis decisions, and the evolving product model is available to the tool, the factory planner concurrently starts to develop the manufacturing system. The GUI is then interfaced with an expert system tool. MANUSYDS uses the C Language Integrated Production System (CLIPS) environment to implement a rule and object based expert system. CLIPS is a public domain software.

Based on the previously described underlying framework and the rules and knowledge programed using the CLIPS interface the MANUSYDS Tool evaluates the product space as the manufacturing model evolves. The product and manufacturing system designers can then view the evolving product space model as decisions are being made.

This work can be defined as a preliminary experimental analysis, since all testing has been carried out under laboratory conditions by researchers, and has not yet been evaluated by Factory Planners in a real scenario.

7 CONCLUSIONS AND FUTURE WORK

The arguments presented in this paper highlight that need for product designers and factory planners to be supported during decision making activities. These stakeholders should take into consideration the consequences of decisions made during product and manufacturing synthesis design on the product families that can be handled by the evolving and future manufacturing system.

This hypothesis was the fundamental concept behind developing a framework and ICT Tool to support the factory planner by proactively foreseeing and optimizing as early as possible the range of product families that can be handled by the evolving manufacturing system. The next step of this research is to carry out an evaluation in industry, with the use of a number of case studies and concrete industrial data, to prove the validity of the arguments being proposed by this research work.

8 ACKNOWLEDGMENTS

The first author would like to thank the University of Malta for the financial assistance provided for carrying out PhD research visits to the IFF/IPA, University of Stuttgart through the Research Grant “Digital Planning and Simulation for the Factory of the Future” (Vote No. 31- 394).

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