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A PRE-TENDER ADVISORY SYSTEM: DESIGN REUSE FOR THE CONCEPTUAL DESIGN OF LARGE, MADE-TO-ORDER, CONCEPTUALLY STATIC PRODUCTS

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Abstract

Conceptual designs for large, made-to-order, conceptually static products are generally created based on similar historical designs. However, new solution requirements rarely exactly match with a historical design. Historical designs thus have to be altered or design modules from different past designs combined together in order to develop an acceptable design solution. Owing to the severe time and budget restrictions of the tendering phase, it is not possible to perform a detailed analysis in order to investigate the adverse effects of design adaptation. The objective of this paper is to explore the possibility of reducing latent technical problems in conceptual designs through positive interaction between the client and supplier during the pre-tender stage. A pro-active strategy, described as a 'pre-tender advisory system' is suggested as a possible method to promote collective decision-making, thus reducing technical and commercial uncertainty in the tendering phase. This method has been developed for the design of rail car dumper systems in conjunction with an industrial collaborator.

Keywords: pre-tender stage, conceptual design, design reuse, conceptually static products

1 Introduction

It is a common practice to reuse historical designs during tendering. The ability to quickly produce concept designs which are cost effective, easy to manufacture and with guaranteed performance is a prime requirement for successful tendering. The technical performance of historically designed modules has been proven and designers are aware of many of the design risks. Therefore, the apparent technical and commercial risk of designs developed in this manner is considerably lower than the originally derived alternative [1], [2]. Research shows that designers prefer to re-use the concepts and lessons of past designs, especially when the design task is considered to be complex [3], [4].

In a competitive environment, the success of a tender depends on the tender price and crucially on how well the bidding organisation satisfies the requirements stipulated by the client. Therefore, engineering companies make every effort to develop designs that closely match the customer's key requirements. Even though the specification of the new product may have similar functionality to existing machines designed by the company, some customer requirements may demand completely new designs and/or significant modifications to existing designs. This will likely increase the technical risk of the design and due to added uncertainty, the supplier will be forced to set high bid values to reduce their commercial risk exposure.

In order to reduce both technical and commercial risk, conceptual designs for heavy mechanical equipment are often developed by combining historical design modules in an appropriate manner [5]. However, because of the limited time and budget allocated to tendering activities, a comprehensive analysis cannot be performed to check the amount of design adaptation required and identify possible technical problems. Therefore, there may be critical 'latent technical problems' in the conceptual designs developed for the purpose of tendering. In this paper, the possibility of reducing latent technical problems through a method that promote the positive interaction between client and supplier during the pre-tender stage is explored.

1.1 Large made-to-order conceptually static products

This paper is concerned with large, made-to-order, mechanical systems. Typical examples include: bulk material handling equipment, mineral processing equipment, cranes, oilrigs, etc. These systems can typically weigh up to some several thousand tonnes. The research has been undertaken in collaboration with a company specialising in the design of bulk material handling equipment. The type of bulk handling equipment includes rail car dumper systems, stockyard equipment (stakers, reclaimers) and ship-mounted unloaders. The research is predominantly based on the study of rail car dumper systems. However, many of the findings are generally applicable to the general product class of rail car dumper systems.

As Pugh [6] pointed out, when products become mature they tend to possess stable product architectures. Therefore, the designs of such products are said to be conceptually static. Rail car dumper systems generally have stable product architectures and can be regarded as mature products. In general, other large made-to-order products also have stable or semi-stable product architectures. Therefore, in this paper, the class of products that the rail car dumper system represents is termed 'large made-to-order conceptually static products'.

1.2 The Pre-tender phase

The activities related to tendering as a whole occur in three distinct phases, namely, the pre-tender phase, tender phase, and post-tender phase. This division of phases is based on the different type of activities (related to tendering) performed by a tendering organisation when they bid for a new project or product. For clarity, in this paper, all the tender related activities occurring before a formal invitation for tender is received are termed as pre-tender activities.

Decisions made during the pre-tender stage, both by the client and the supplier individually or collectively, have a considerable impact on the cost and performance of the final product. A key issue in the tendering of large, made-to-order, mechanical systems is whether the customer involves the supplier(s) in developing the specification for new product requirements. There are two extreme approaches that can be followed by the customer in developing requirements. One extreme approach is for the customer to not rely on the capabilities and historical products designed by potential suppliers and to concentrate on developing requirements which are tailored specifically to the customer's need. In this case, the customer may develop requirements based on their own experience and incorporate their own design principles. The other extreme approach is for the customer to allow potential suppliers a major role in developing requirements for the intended product. The danger of not involving suppliers in requirement formation is that tender documents can subsequently contain requirements which are not compatible with historical designs. The result will be that the supplier will bid higher than usual as they rely on re-using historical design knowledge. The proposed solution may also not be technically adequate because the company have no proper solution experience for the new design requirements. In contrast, the danger of over-reliance on supplier input is that the customer may not get a solution which is suited to their needs.

Being the experts in their specialised fields, solution providers should be able to influence the clients during the pre-tender stage in order to encourage them to produce solution requirements incorporating the company's design principles. This would help the solution provider to reduce the design effort drastically through an effective reuse of historical design knowledge while clients are guaranteed technically sound products at a lower price. A pro-active strategy, described as a 'pre-tender advisory system' is suggested in this regard as a possible method to promote collective decision-making during pre-tender stage in order to reduce the technical and commercial uncertainties in conceptual designs.

2 Research method and observations

The tendering and concept machine development process for a rail car dumper system was studied in detail. The key activities of the pre-tender-stage were thus established. Information was gathered through semi-structured interviews and informal discussions with senior design engineers, engineering managers and tendering engineers of the collaborating company. The contract information register that contains key information of 547 projects undertaken by the industrial collaborator and bulk electrical & mechanical product database were also consulted. Interviews with a tendering engineer indicated that the company, prior to the receipt of formal invitation for tender, would have informal discussions with their clients based around historical design configurations. The tendering process of seven other companies operating in range of engineering sectors (civil, mechanical, electro-mechanical) [7] has also been studied. The details of each company's tendering procedures were elicited from company representatives possessing extensive experience of their company's internal tendering practices through semi-structured interviews. Some of the key observations made during this study were:

- Generally, the client plays the dominant role during the pre-tender stage when there are many potential suppliers for a particular made-to-order product.
- The solution provider generally plays a subdued role in the pre-tender stage. Conventionally, the solution provider's role in the pre-tender stage is limited to promotion of their engineering capabilities using printed and electronic media that provide some superficial data about their product range. Most of the time they fail to answer clients' specific problems or influence their decisions.
- The provision of necessary advice to the client during the pre-tender stage is a difficult and delicate business because the potential supplier only has a limited amount of time to have discussions, understand the solution requirements and propose a design or provide the necessary advice. In order to influence the customer's decisions effectively, it is essential that a potential supplier have fast access to historical design data.
- One of the key problems that hinders the effective reuse of historical design knowledge is over-elaboration of client specifications [8]. This problem can effectively be mitigated through the active participation of the solution provider in the pre-tender decision making process.
- Engineering companies are ill equipped to cater for the requirements of the pre-tender stage. Solution providers generally treat pre-tender activities as an advertising exercise that could possibly secure another contract for the company. Little or no attention has been given to exploit any technical advantages through influencing the decisions made by the client during the pre-tender stage.

- A software system designed to cater for the requirements of the pre-tender stage should support decision-making rather than attempt to solve complicated analytical problems.

These observations suggest that there is a need for change in current strategy of tendering in order to minimise problems associated with concept design development.

3 A proposed pre-tender advisory system

In this section a pre-tender advisory system for conceptually static products is presented. The system is a method to promote collective decision-making during the pre-tender stage in order to reduce the technical and commercial uncertainties. This rule-based decision support system enables solution providers to have effective pre-tender discussions by performing upfront design in conjunction with their clients. The technical and commercial benefits of developing a solution that incorporates the company's design principles can thus be demonstrated to the client. The over-arching purpose of the pre-tender advisory system is to reduce possible technical risk by promoting reuse of technically proven design principles (i.e. the solution provider's technical expertise) during pre-tender discussions.

The system is especially designed for conceptually static products. The great asset of companies which specialise in the design and construction of conceptually static products is the huge collection of historical designs. Even though there are many different product variants, the basic architecture of conceptually static products is essentially similar. All design variants can therefore be represented by an abstract master model. This model will be called 'Master Concept Product Model' (MCPM).

3.1 Master Concept Product Model (MCPM)

The master concept product model is an abstract representation of a library of variant designs of a product. It is developed by extracting common design principles of historical designs and specific features of variants (Figure 1).

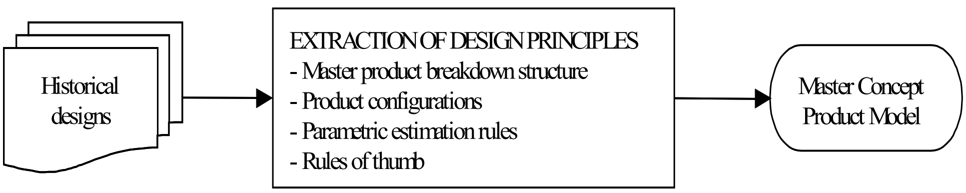

Figure 1 Development of 'Master Concept Product Model' (MCPM)

The objective is to use the MCPM to develop concept design variants that satisfy new solution requirements rather than manually searching through large design archives to select matching past designs. Elements of the MCPM are arranged in a hierarchical fashion similar to a product breakdown structure, aka PBS (Figure 2).

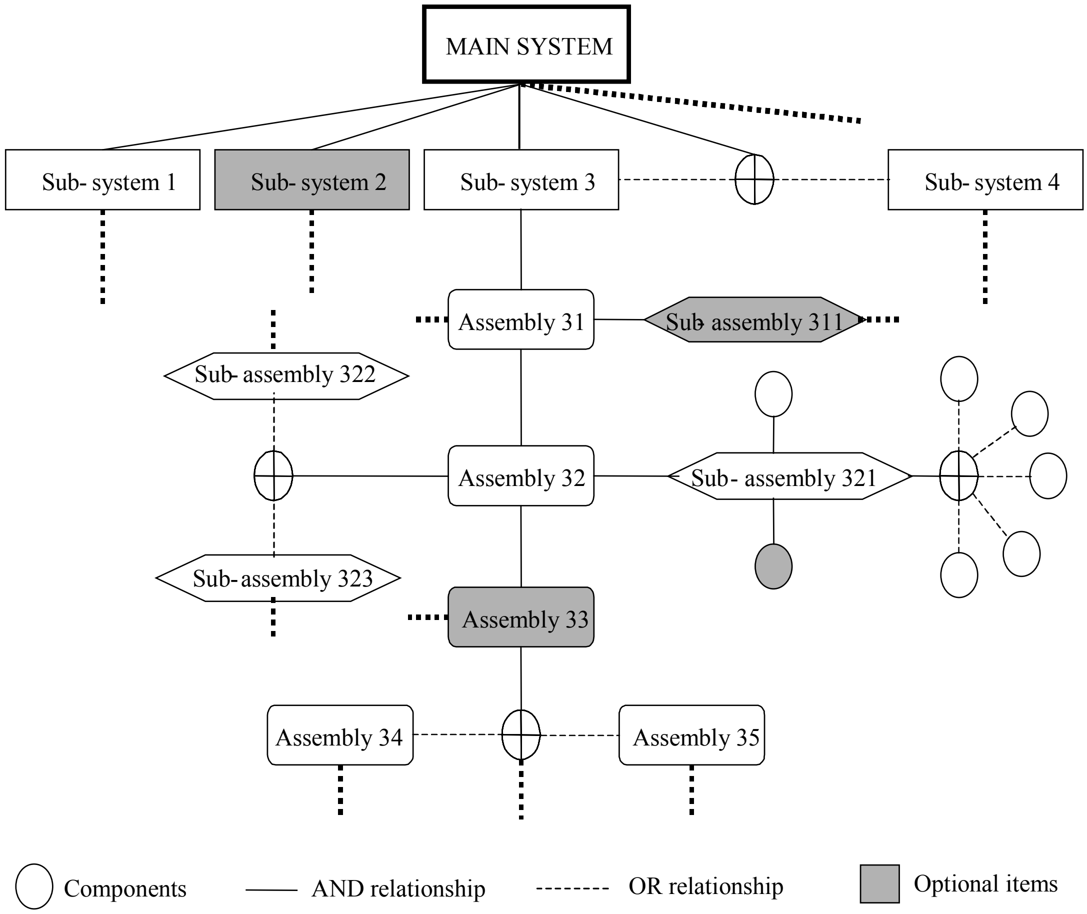

Figure 2 Master Concept Product Model architecture

The key elements of the MCPM (main system, sub-systems, assemblies, sub-assemblies and components) have been linked together using 'relationship links'. There are two types of relationships; AND relationship and OR relationship. The elements linked with AND relationships are the essential elements of the concept variant PBS. The only exception to the rule is optional elements. The inclusion of optional elements in a concept variant is not compulsory. Only one member is selected from the family of members grouped together using an OR relationship. The top-level elements of the model (e.g. main system, sub-systems) are more abstract and act as containers for the lower-level elements. They possess a limited amount of detailed data. The lower-level elements (e.g. assemblies, components) possess data which provide them with clear physical and functional definitions. Each element has sufficient data to define it fully in relation with the other associated elements of the MCPM. Some elements are optional, i.e., the inclusion of those elements in a particular concept design will be decided by the selection of top-level elements. In the case of multiple options, the appropriate element will be selected based on the client's specific requirements. Selection of optimal elements can help to propose additional concept variants.

The lowest level element, described as a component, represents either a single component or a collection of parts (when a collection of parts cannot be identified as a distinct assembly, it has been named as a component, e.g. a collection of auxiliary items). A generic component represents a family of similar components. The components are characterised by several mathematical functions, feature definitions and relationship definitions with the associated assemblies or components (Figure 3).

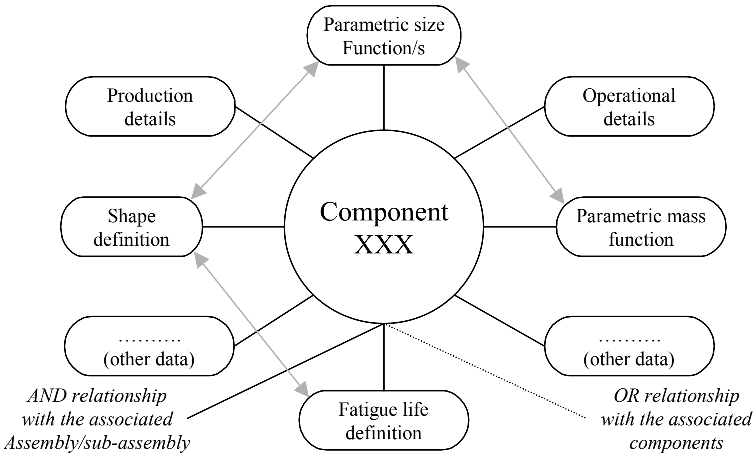

Figure 3 A typical component definition

All the mathematical functions (e.g. parametric estimation rules for a component's major dimensions and mass) that characterise a component are derived from the historical design data. It has been assumed that a considerable amount of historical information is available and can be reused to derive the necessary parametric equations used to characterise all components included in the model. The historical information of design artefacts such as actual mass, their performance measures and life cycle estimates are uncertain in nature. Furthermore, there is uncertainty inherent in the parametric functions. In order to make realistic estimates, it is necessary to consider the uncertainty present in the data used to develop mathematical functions. Mathematical functions can therefore be developed in two ways:

- By fitting a probabilistic distribution to a historical data set (when a sufficient amount of data is available to form reasonably accurate distribution functions)
- By assuming approximate probability distributions in the absence of data. The most popular distributions in this case are triangular and beta distributions.

Some of the functions are inter-related. For example, the mass estimation function is related to the size function/s, fatigue life definition is related to the shape definition, and so on. Some of these functions are not applicable for some components. For instance, fatigue life definition is used only for key components that will have a considerable effect on the life of the whole design and shape definition is not applicable for components that represent a collection of parts.

In MCPM, assemblies have been represented as the collection of components. When there are components attached to an assembly, it acts as a container for the components. The definitions of the attached components characterise the assembly. When there are no components attached to an assembly, they are characterised by mathematical functions and feature definitions similar to the ones given for components.

3.2 Generating concept variants from the Master Concept Product Model

The MCPM is an abstract model that represents a large family of products. It cannot be directly used as a representation of 'a product'. Concept product variants are therefore extracted from the MCPM using selection criteria. The concept variants are extracted using logic from the MCPM having analysed solution requirements such as technical design parameters, client's specific requirements and technical constraints (Figure 4). The parameters have to be selected carefully so that they do not hinder or over-complicate the generation of concept variants. There must be a minimum number of parameters to define a concept machine as specifically as possible. It may not be possible to extract a fully defined concept solution from the MCPM if this minimum requirement is not provided. On the other hand, clients may provide very specific requirements that must be satisfied by the product. Therefore, it is suggested that two sets of technical parameters be defined; namely *primary technical parameters* and *secondary technical parameters*. The primary technical parameters are compulsory for extracting concept solutions from the MCPM. The expert solution provider should specify these parameters. The secondary technical parameters specify the client specific requirements. The Analyser (refer to Figure 4) has been designed so that it can take the clients' specific requirements into account when developing suitable solutions. The analyser thus possesses all the required design rules, component selection criteria and algorithms required for logical selection of elements. The output of the concept generation process is a set of concept variants with parametric information about all model elements.

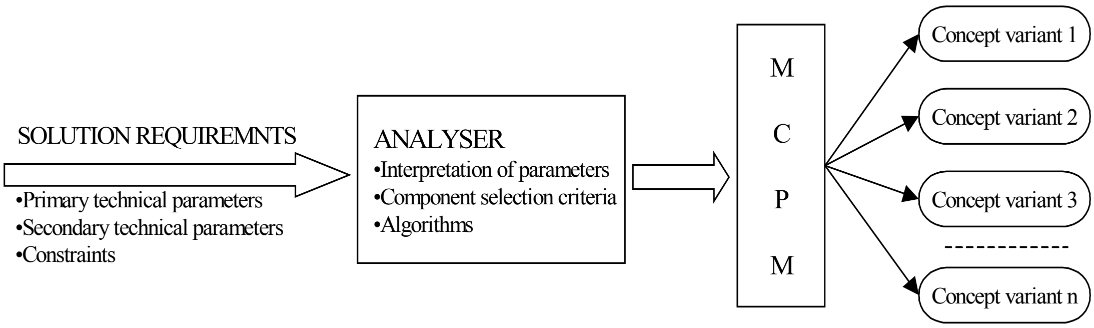

Figure 4 Developing concept variants from the MCPM

3.3 Evaluation of concept variants

The evaluation criteria of concept variants are different for all products. It is necessary to develop a customised evaluation criterion for each product. The concept evaluation technique given by Pahl & Beitz [9] could be a useful guide to develop an effective concept evaluation strategy. In order to promote mutual decision making between the client and the supplier, the pre-tender advisory system employs two levels of evaluation.

The level-1 evaluation is done based on the qualitative evaluation criteria derived mainly from the client's preferences and main solution requirements. For example, production capacity, operating speed, preferred machine control methods, physical size and preferred driving mechanisms could be used as evaluation criteria. All concept solutions that do not meet the limits imposed by the basic criteria are filtered out from the initial solution set. This 'soft evaluation' helps to reduce the solution set to a manageable size.

The objective of the level-2 evaluation is to select the best concept solution for the new design problem. The selection is done based on the results of quantitative assessments of selected key evaluating parameters. The evaluating parameters are generally product specific. In general, comparison is made between the expected cost and the technical performance of the product. Therefore, the concept selection process could be devised as a cost-benefit analysis exercise. The concept of utility theory can also be used to rank the concept solutions based on aggregation of given utility values for each evaluation parameter.

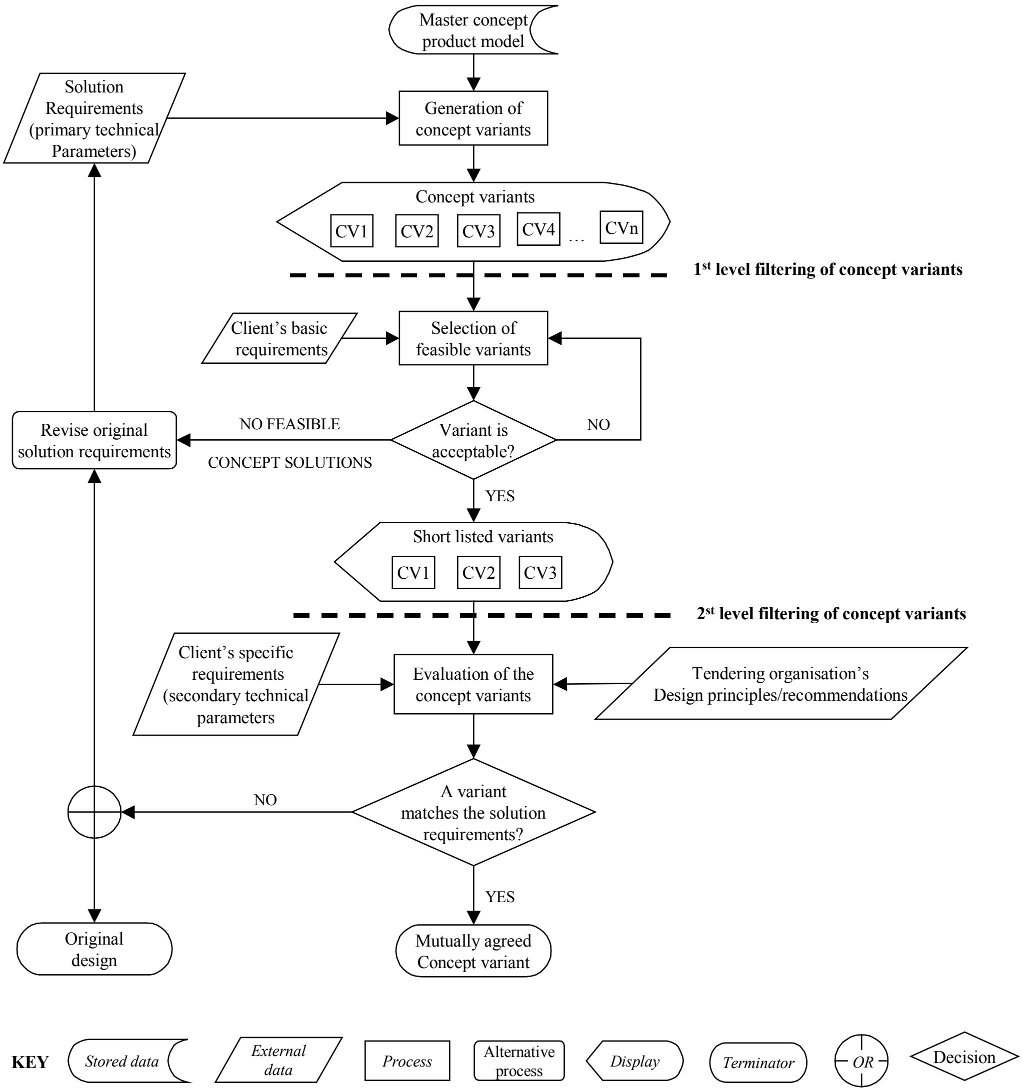

Figure 5 The process of developing feasible concept solution from MCPM

The complete process for concept solution development from the MCPM is shown in Figure 5. If the initial attempt does not result in feasible concept solution/s then the process can be re-run after making suitable changes to the initial solution requirements. When it is not possible to develop a suitable concept solution from MCPM, the obvious conclusion is that the design problem requires an original design, or at the least considerable change to historical products.

4 Issues of pre-tender advisory system

The pre-tender advisory system was developed specially to cater for the requirements of the pre-tender stage of conceptually static, made-to-order products. Because of the highly specialised nature of such products, it is extremely difficult to develop a generic software application that can easily be customised for different industry requirements.

The model assumes that a sufficient amount of historical design data sets are available for the product concerned. The accuracy of the design estimates is dependent on the accuracy of the parametric functions used in the master concept product model. Therefore, this model should be used for sufficiently mature products only.

It was assumed that the main requirement of the pre-tender stage was to develop concept designs accurate enough to make rational decisions regarding form, control philosophy, technical performance, etc. of a product. There is a grey area between the expected simplicity of the pre-tender advisory system and the required accuracy of the estimations made for product mass, cost and performance indicators. The key question is 'what is the criteria used to decide suitable tolerance levels for the model output?'. According to the authors', this tolerance is product specific and difficult to specify a general rule. Therefore, it is necessary to find the correct balance between input simplicity and model accuracy when implementing the system.

The static nature of the model may not encourage design innovation. One could argue that this model inhibits design innovation by encouraging designers to reuse the design principles from non-optimum historical designs. However, research has shown that 90% of the designs for large, made-to-order products are either variant or adaptive designs. Generally, innovations and system improvements happen incrementally in the component level, thus maintaining technically proven solution principles in order to keep technical risk exposure low. The purpose of the advisory system is to enhance the traditional approach and reduce technical risk in design reuse by facilitating decision-making during the pre-tender stage.

5 Conclusions

The pre-tender advisory system facilitates the generation of concept designs by incorporating design principles of the tendering organisation and satisfying client specific requirements. The system uses a concept selection strategy that takes into account both the client's preferences and the solution supplier's expertise. The system is capable of predicting the influence of key decisions made by the client and can be used to steer them towards more efficient designs. It has been devised to promote an effective interaction between client and the solution provider in order to make collective solution decisions. Therefore, during the pre-tender stage, clients can be shown the obvious financial and technical advantages of producing specifications using established design principles.

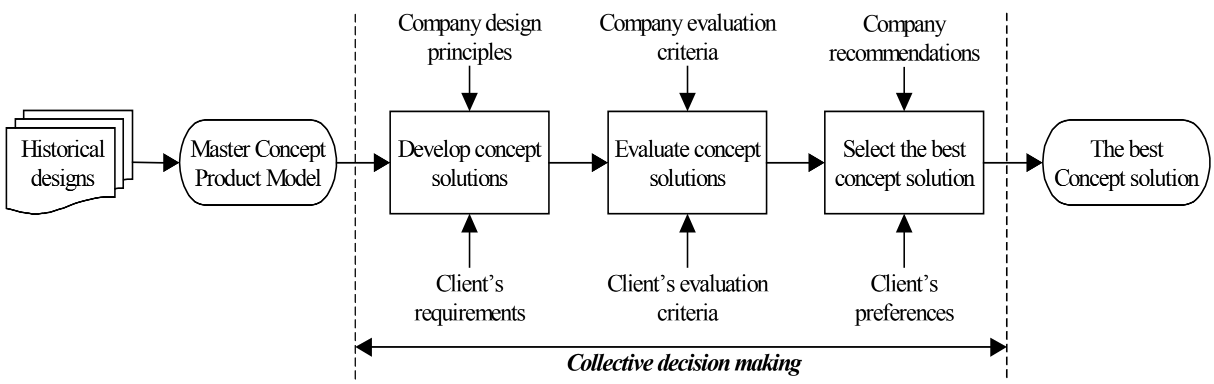

Figure 6 Pre-tender advisory system: Concept solution generation

The pre-tender advisory system can promote a pro-active approach that alters the current customer-dominant tendering practice. A cooperative win-win situation could be created where the client and tendering organisation together benefit from collective decision-making. From the solution provider's point of view, some of envisaged benefits of the system are:

- Reduction of technical and commercial risk in design reuse.

- Escape the limitations imposed by onerous client requirements on the company's solution options.
- A significant reduction in design time expended during tender stage by performing considerable amount of up-front design during pre-tender stage.
- The ability to play a more positive role in the pre-tender stage as an expert advisor.

The pre-tender advisory system has been implemented for the rail car dumper systems in the form of a test prototype application (refer to reference [5] for further information). The functionality of the application has been tested with representative data and parametric equations provided by the industrial collaborator.

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