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TOWARDS AN INTEGRATED SYSTEM FOUNDATION FOR QUOTATION PREPARATION

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1. Introduction

For many products, the adaptation to different customer specifications is essential. To enable a high level of adaptation requires both flexible product design and flexible manufacturing. By the use of a design automation system with integrated automation of product design, process planning, and cost estimation different design drafts can be generated in a short time with minor effort. This enables efficient generation and evaluation of product variants cutting the delivery time of offers and products [Elgh and Sunnersjö, 2003] while guaranteeing consistent design calculations. One task suited for automation is quotation preparation, including the definition of principle product design, process planning and cost estimation. Support for quotation preparation is frequently used in manufacturing companies. The level of support is varying, ranging from single-user spreadsheet solutions based on heuristics of individuals to configuration systems based on thoroughly defined corporate knowledge. Many manufacturing companies are subcontractors acting in an environment of continuous demands on cost reduction. Subcontractors are frequently involved in several quotation processes and this is time and resource demanding. For the companies who make a request for quotation (RFQ), the price per item quoted by different competitors is of major importance and in some cases the only criteria for the evaluation and selection of the winning bid. To be able to provide affordable products in a short time and be at the competitive edge, every new design must be adapted to existing production facilities. This requires collaboration between engineering design and production engineering, which in many companies is a critical issue. Collaboration requires that information and knowledge have to be shared for the purpose of striking a good balance between product properties and the resources required for the manufacturing. In discussions with a number of Swedish subcontractors it has been made clear that there is an emerging need of support in the quotation process (ranging from production preparation and cost estimation of a single component to an engineered-to-order multi-component product). The companies have to adopt new ways of working, including processes, methods and tools to be able to respond quickly on requests with a competitive price while at the same time ensuring profitability. The bidding cost must be at a level that satisfies the customer and at the same time guarantees product profit. However, with increasing competition the gap between the two reduces. This implies that a higher level of accuracy of the cost estimations in the quotation process is a necessity. It is also important to enable detailed product, manufacturing and cost analysis to bolster the product and manufacturing improvements. Further, detailed analyses support the evaluation of different solutions, the communication between engineers and managers of the relations between product, manufacturing and cost aspects and, the evolution of company knowledge (e.g. definition of rule-of-thumb statements and design guide-lines).
From a technology view, there is a potential to develop application systems that are tailor-made for companies' specific needs. Commercial software is getting more and more adaptable and application

programming interfaces (APIs) with open object models are provided. These facts extend the possibility to build in-house systems. To address the industrial relevance and need of such an approach, an interview study was conducted including eleven Swedish companies [Cederfeldt and Elgh, 2005]. The overall conclusion, based on the interviews and discussions with the companies' representatives was; there is potential for in-house developed systems in varying areas, and there is a need for principles, models, methods and tools supporting the realization of such systems. The purpose of this work is to explore this industrial potential and provide means to support system realization. The main objective is to provide an integrated system foundation for quotation preparation with a focus on a solution that enables efficient generation of product variants. It is also important that detailed analyses of product, process, and cost data can be executed. The industrial and scientific objective is to provide an integrated system foundation, comprising concepts and principles, to support application system development and utilization.

2. A system for automated variant design

The need of an integrated system foundation derives from a previously developed system, the CoRPP system (Coordinated Realization of Products and Processes). The CoRPP system (figure 1) was developed in cooperation with an industrial partner to enable automated variant design of heavy welded steel structures [Elgh and Cederfeldt, 2007]. Both automated product design and quotation preparation were to be supported. The objective was a system, realized by combining and enhancing a set of application software already in use at the company, for automatic design, process planning and cost estimation of submarine bulkhead variants. At execution, the system generates design layouts of a submarine bulkhead and its structural stiffeners. The calculated and optimised geometry output results in automated: CAD model generation using parametric CAD models, generation of process plans using standard process plans, and cost estimations generated in a spreadsheet application software.

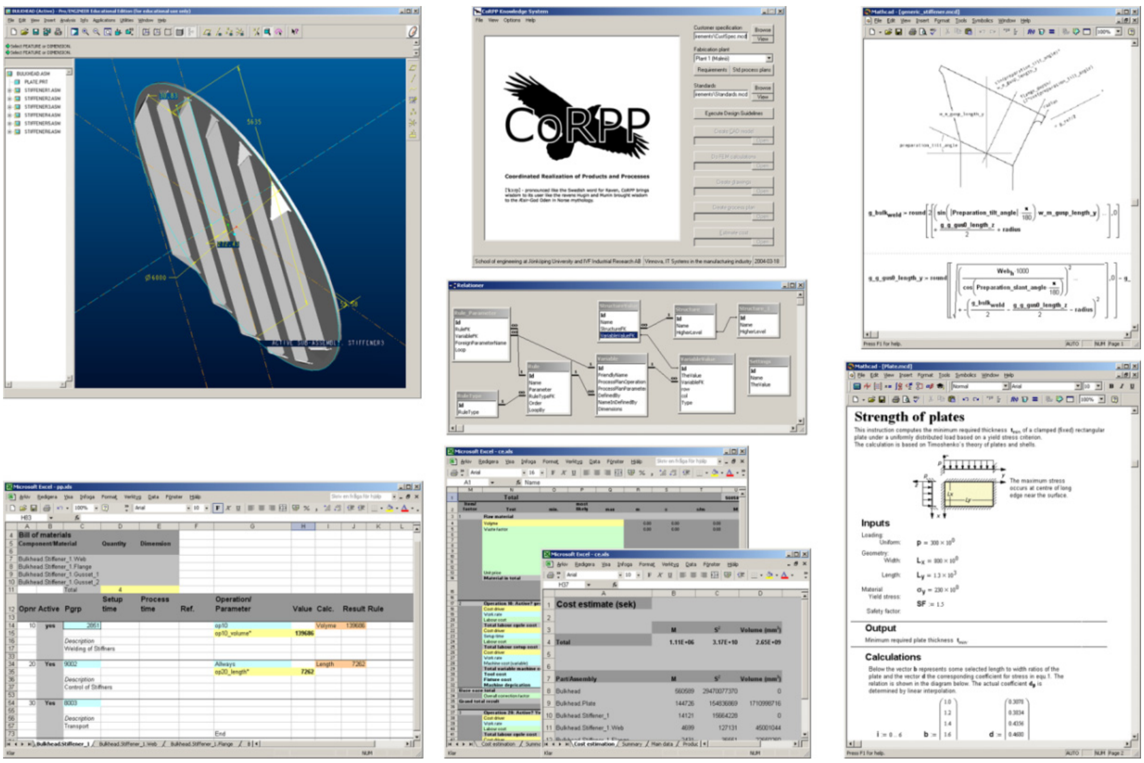

Figure 1. The CoRPP system [Elgh and Cederfeldt, 2007] with its different workspaces. Database schema (middle), graphical user interface (top centre), a product design calculation (bottom right), a geometry model (top right), CAD modeller (top left), a process plan (bottom left), and cost estimation sheets (bottom centre)

2.1 System foundation

The different modules for process planning and cost estimation in the CoRPP system were founded on four conceptual models [Elgh, 2004] representing product cost items, plant resources, process plans, and product geometry entities (see Figure 2).

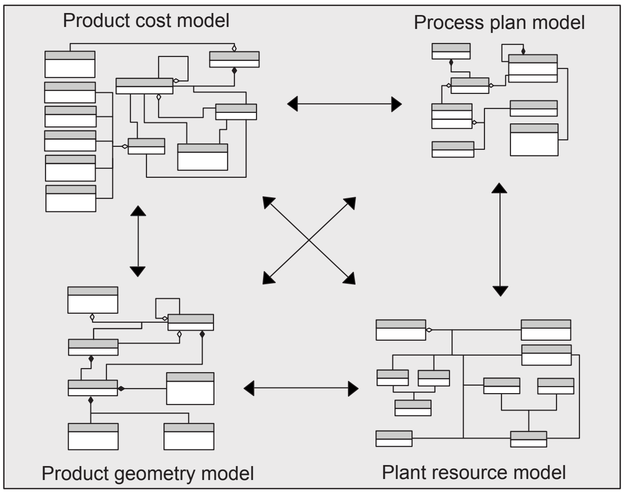

Figure 2. The four information models and their interrelationships [Elgh, 2004]

A computer-aided system was used for the process planning. The system had a set of standard process plans for different groups of parts and assemblies. A group was defined as a collection of parts or assemblies having the same sequence of operations, but the number of operations could differ individually. The set of standard process plans was associated to a master geometry model incorporating parametrical and topological variations on feature, part and assembly levels. When a process plan was to be generated, the system first identified which standard process plan to be used for the part or the assembly. The plan was retrieved from the set of generic standard process plans. Then it was modified in correspondence with the geometry model. Required parametric values were extracted from the geometry model, and the finalised process plan was saved in a new set consisting of generated process plans. A cost estimation was obtain by linking the different operations of the generated process plans to existing manufacturing resources. The cost was calculated by using the cost driver rates of the utilised manufacturing resources together with the associated cost driver levels extracted from the geometry model.

2.2 Supporting cost and manufacturing analysis

The short execution time of the system (one run-through takes approximately 2 minutes as oppose to several days if done manually) allows for several executions with different conditions to be performed in a short time and with minimal effort. This generates a large number of output data that can be used for multi objective optimisation of different product variants, sensitivity analysis of cost drivers, and to study what-if scenarios in production [Elgh and Cederfeldt, 2007]. Some of the aspects that can be studied are the effects of changes in product design, welding accessibility, welding rate, material cost, and labour wage on the total cost, total weight, and total manufacturing operation time. This functionality was perceived as valuable by the company. Producibility could easily be evaluated and the decisions making, regarding design and manufacturing options, in the early stages of the quotation process was supported.

2.3 System limitations

The solution for process planning and cost estimation was implemented using a spread sheet application program. The cost and manufacturing data were stored in different tables within a single file. This file was instantiated and configured for the specific input data of every system generated product variant. The problem is that the number of files is rapidly increasing, especially when different scenarios are evaluated when searching for the best achievable solution. Every execution generates a certain amount of information. The information is scattered across resources and it can not easily be accessed and used for analyses on a higher level across variants and projects. Further, even though detailed information about manufacturing resources, manufacturing operations, materials, cost items, cost driver rates and product designs was included, the usefulness of the system was limited. The reasons are the systems' foundation with four separate models and the selected application programs for system realization. The limited functionality became apparent when the system was demonstrated and a company representative asked for the total welding cost of a variant. Despite the fact that the required information for a calculation of the total welding cost existed within the set of system generated files, it could not easily be traced and added up automatically. This was only one of a number of queries that the company considered to be of importance that the system could not reply to. The initial system objectives were fulfilled; however, the full potential of the system was limited. The main reasons are the separation of information and the system realization. This problem, with scattered information aggravating the use of the quotation system as a means promoting a deeper understanding, is addressed by the following proposed integrated system foundation.

3. An integrated system foundation – technology, models and principles

The research presented in this paper is explorative and carried out as research through design by the development of an application system. The main reason for developing an application system, from a research view, is the deployment of the system development method [Burnstein, 2002] as research methodology to explore a research issue with the introduction, evaluation, and refinement of new concepts. These new concepts act as prescriptive models in accordance with the design modelling approach [Duffy and Andreasen, 1995]. In this work, the use of the technology provided by a database, AMOS II, for data storage, analysis and management was perceived as a promising approach for achieving the desired functionality. However, a database does not alone provide the required functionality. Of vital importance are the system implemented conceptual models and the principles that the system reside upon.

3.1 Technology

In this work, the Active Mediator Object System (AMOS) II [Risch, Josifovski and Katchaounov, 2003; Flodin et al, 2005] has been used. AMOS II is suited for the development of engineering applications due to important features such as [Nyström, 2003]:

- It is main-memory resident.
- It is object-oriented.
- It uses a query and data definition language.
- It adopts a mediator approach to information integration.
- It is a light-weight database that can be embedded.

AMOS II uses a functional data model. The data model consists of objects, types, and functions. Objects are used to model all the entities in the database, including system- and user-defined objects. Objects are instances of a specific type (a type is in this case equivalent to a class). AMOS II supports multiple inheritance and the types are organised into a hierarchy of subtypes/supertypes. Functions represent the semantics (meaning) of objects. They are used to model properties of objects, computations over objects, and relationships between objects. They are also basic primitives in functional queries and views. Queries are expressed in AmosQL, a declarative query language using a syntax similar to SQL.

3.2 Conceptual models

In order to build a system it is essential to reveal the main concepts that the system can be based upon. Building a system for automated design, process planning and cost estimation requires involvement of different domains. The objects related to these domains need to be formalized, structured, and linked for the purpose of ensuring the system functionality and supporting system realization. The definition of concepts is to some extent intertwined with the system development as it is an iterative process of:

problem definition – problem analysis – solution synthesis – solution analysis. The concepts for a system solution can be outlined based on experiences of previous work, gathered knowledge related to the problem area and an increasing understanding of the specific problem at hand.
Two groups of concepts evolved during this work and were finally defined. One of the groups consists of system classes that are not instantiated when a new product variant is generated. All the instances of this group are predefined, constituting system intrinsic information. The different classes associated to this group are (figure 3): *Plant*, *StandardProcessPlan*, *Operation*, *Resources*, *Equipment*, *WorkCenter*, *Material*, and *Customer*. A number of attributes were defined for each of these classes to be used for the specification of object specific data. The *Resource* class is an abstract class and its attributes and relations are inherited by the classes Equipment and *WorkCenter*. Further, relations between the different classes had to be defined for the purpose of enabling associations to be created between objects of different classes.

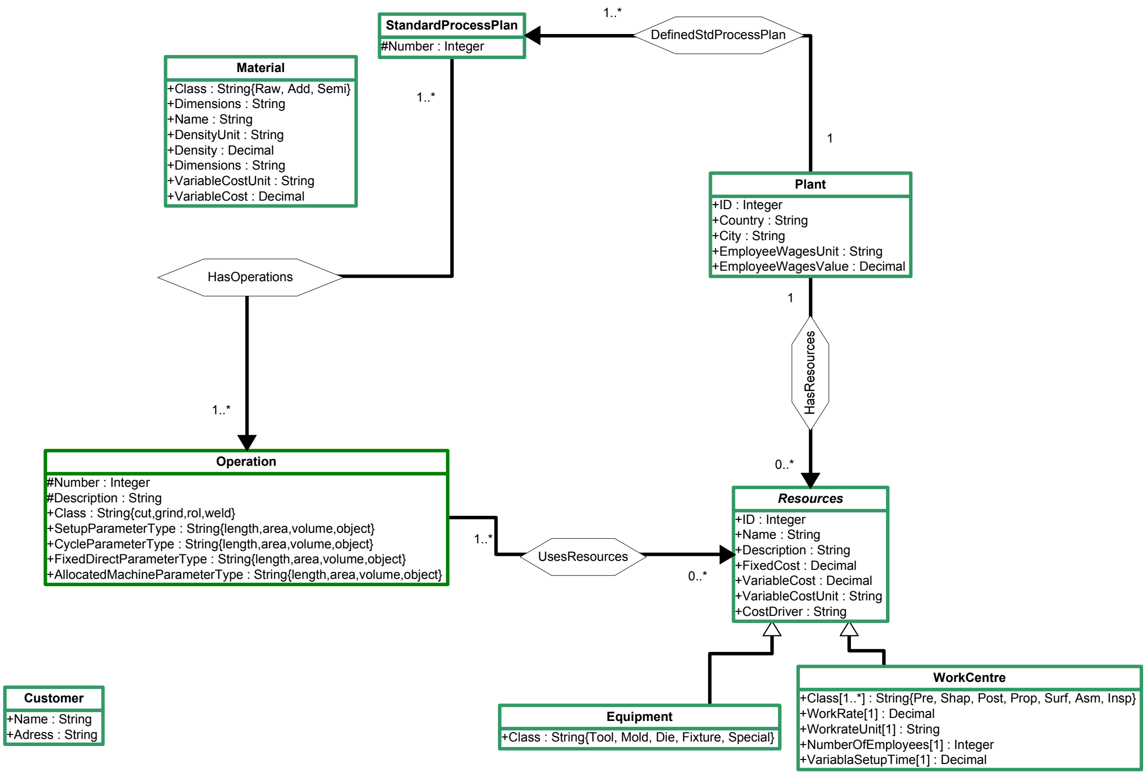

Figure 3. Classes and their relations for storing system intrinsic information

The other group consists of classes to be instantiated into objects at system execution. The different classes associated to this group are (figure 4): *Product*, *Component*, *Part*, *Assembly*, and *ProcessingFeature*. A number of attributes were defined for each of these classes to be used for the specification of object data. Additionally, a number of methods were defined to support the generation of important information at system execution. The *Component* class is an abstract class and its attributes, relations and methods are inherited by the classes *Part* and *Assembly*. The relations between the different classes had to be defined also for the purpose of enabling associations to be created between objects of different classes.

3.3 Principles for product design automation

When creating a design automation system one must determine the variables, parameters and knowledge that govern the design. The definition of design algorithms, rules, and relations that transform customer and company parameters to product model variables results in a product structure with associated knowledge. If the product architecture is not modularized, bidirectional dependencies and/or recursive dependencies involving a number of product items can exist. The adoption of a process approach could solve these dependencies by the clustering of the items' related statements in tasks constituting executable knowledge objects (Elgh, 2008). A knowledge object is a meaningful collection of data, calculations and rules that transforms a set of input to a set of output. A knowledge object is commonly pointing at a file (MathCAD, MS Excel, Pro Engineer, Catia etc.) constituting its realization. This file is to be executed when the knowledge object is invoked transforming of a set of input data to a set of output data.

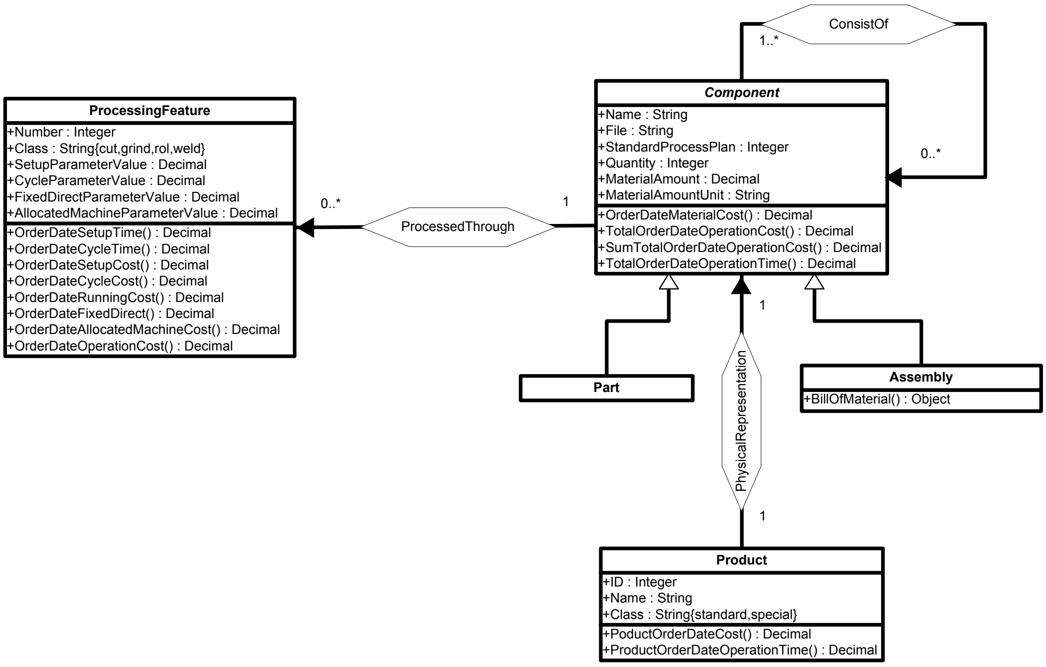

Figure 4. Classes and their relations for storing system generated information

The product structure can either be explicitly or implicitly defined in the system. The former solution requires a generic product structure comprising classes that are predefined in the database. When the system is executed, the number of objects is defined and the objects are subsequently created by instantiation of classes. For the latter solution, the variant product structure is created at system execution. This solution implies that the knowledge objects have to include statements defining the number of instances of different classes to be generated. In this case, the result is a knowledge structure separated from the product structure. The product items are created by knowledge objects on higher levels. These knowledge objects include algorithms for the definition of the required subsequent product items. The final definition of a system created product item is completed by the execution of knowledge objects that are directly related to the product item. This solution was selected for this work in which a generic product structure is implemented by using knowledge objects with embedded rules, containing if-then statements, for the creation of the product topology (figure 5).

3.4 Principles for system execution and database population

The principal information flow at system execution is depicted in figure 6. First, a customer is defined, either by the selection of an existing customer in the database or by entering the data for a new customer, and the required information for an order is specified. The execution of the knowledge objects is initiated when the required input has been feed into the system and the objects are executed one by one. Generally, a knowledge object first calculates design variables using a number of input parameters. This is followed by the execution of rules controlling the selection of a process plan and the configuration of the processing features to be mapped to manufacturing operations. These rules also include calculations of parameters that will affect the selection of manufacturing resources, the calculation of processing time and cost estimation. Finally, the rules for the configuration of the product structure are executed and the necessary classes and numbers of subsequent product items and their related knowledge objects are defined. All new knowledge objects are added to a queuing list of objects to be executed. The active knowledge object is finalized and a new knowledge object from the list of queuing objects is selected and executed. The execution will continue as long as there is any knowledge object in the list.

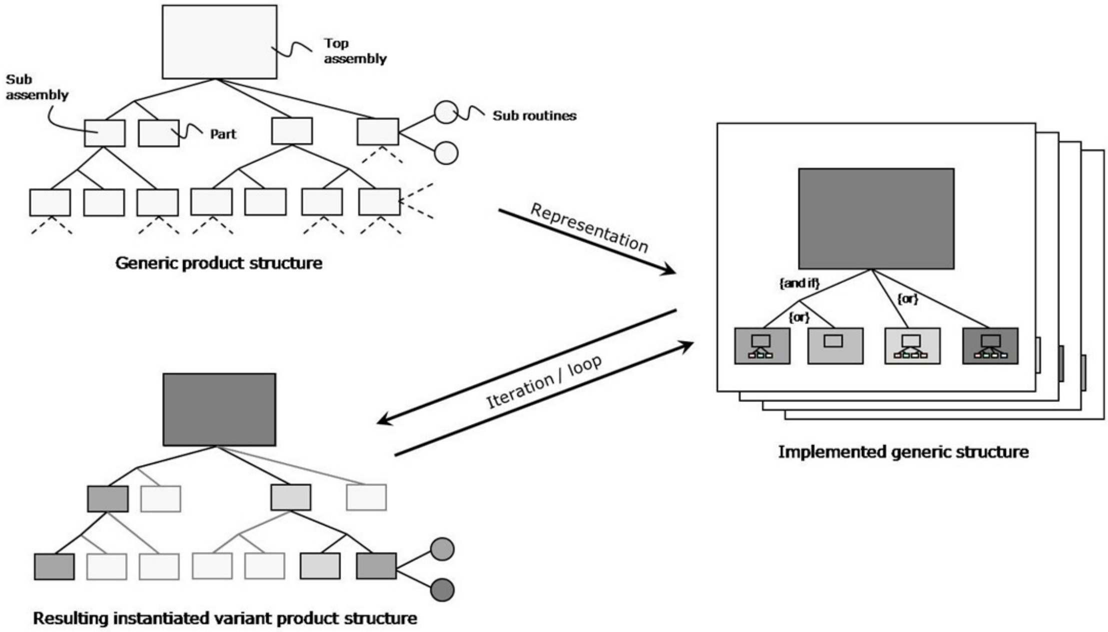

Figure 5. Principles for the implicit generic product structure and instantiated variant structure.

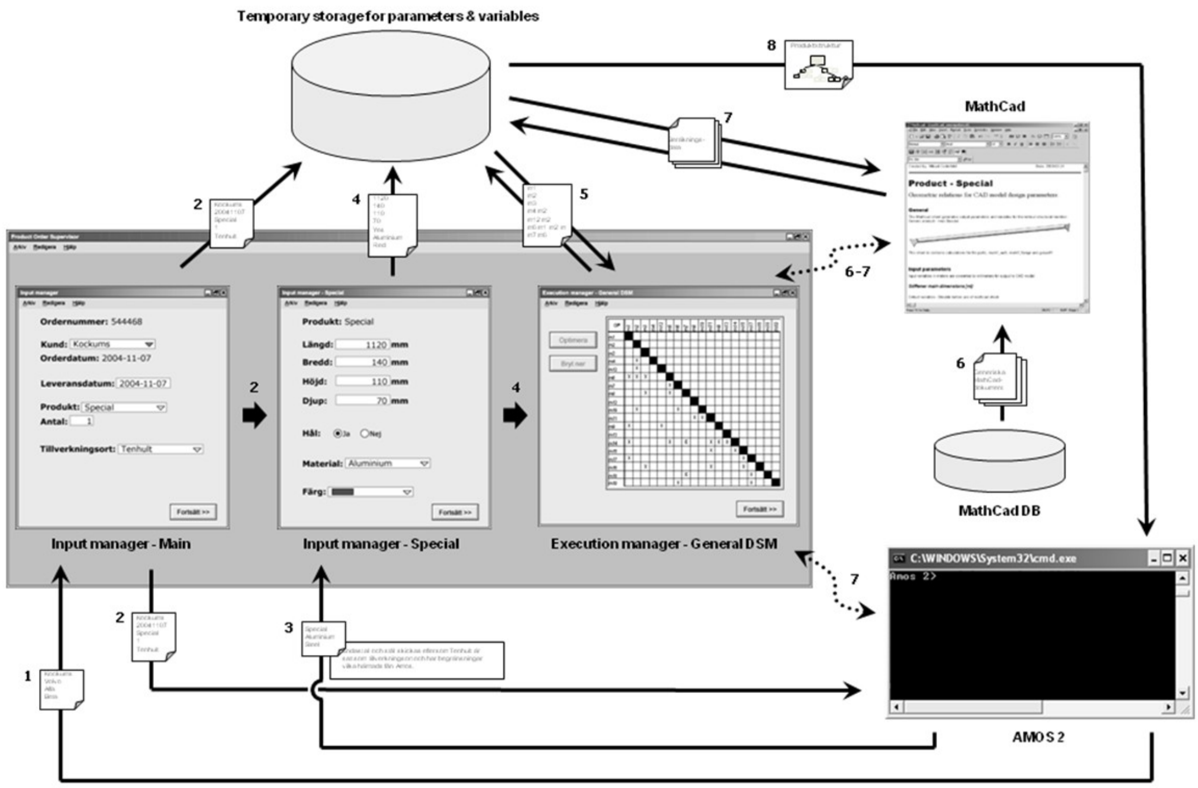

Figure 6. Information flow at system execution

The database is populated with new objects at system execution. New relations are created between system generated objects and system intrinsic objects mapping product, manufacturing and cost information together (see Figure 7).

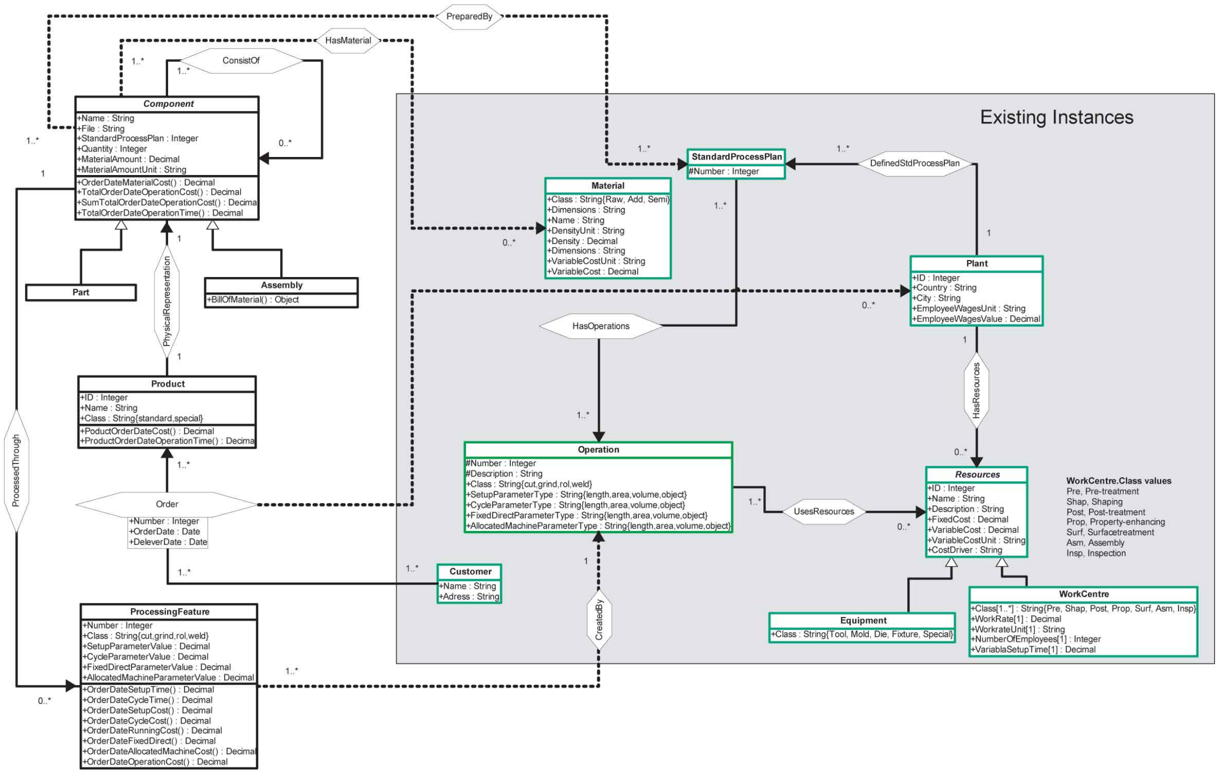

Figure 7. Mapping between system intrinsic and system generated information

4. Pilot system – functionality and utilisation

A pilot system has been developed for a downscaled problem with a focus on the critical parts for a successful deployment of the proposed integrated system foundation. The conceptual models were implemented in AMOS II for persistent data storage and to enable analysis to be performed on system generated information. Instead of four separate models, one model that integrates product, process planning, manufacturing resources and cost information is used. However, the stored information can still be accessed from the four views of product cost items, plant resources, process plans, and product geometry by using different database queries. The previous solution had a course hierarchal structure and the information was scattered within different files with no associations which limited the system functionality, usefulness and future adoption. A system built on the proposed integrated system foundation enables analysis to be made on a higher level, across orders and product variants, as well as on a more detailed level for a specific subassembly or part. The types of analysis include (but are not limited to):

- Total material cost for a product variant.
- Total cost for a specific manufacturing operation of a whole product (i.e. every part and assembly).
- Sensitivity analyses of changes in currency rates, productivity, machine speeds and wages.
- Sensitivity analyses of geometrical cost drivers.
- What-if studies of changes in customer requirements, design parameters and manufacturing properties.
- Total calculated material quantity for all the quoted products over a period of time.
- Number of quotes and their total cost for a specific customer.

This is a few examples of analysis that an integrated system foundation supports. Using a single detailed conceptual model for the database definition gives a flexibility regarding the access to the stored information. Compared to the previous solution, the information is not trapped in a predefined hierarchical structure. There is also an enlarged support for the analysis of system information from different views. The system can be used as a decision tool in the evaluation of different courses of action in early stages in the development of product variants and in the quotation preparation. It supports better decisions and, in the long run, a deeper understanding and awareness of the relationships between the product properties, the manufacturing, the manufacturing processing, the cost drivers, and the cost levels. One example of a deeper understanding was gained at the company that manufactured submarine bulkheads. Among the designers it was a common perception that the total amount of all welds, measured as total length, should be minimised for the reason that welding was considered to the most expensive manufacturing operation. However, when the different cost items were analysed it turned out that the dominate cost driver was the thickness of the circular plate and not the total amount of all welds. To make analysis of the cost items in the old system was cumbersome and required a lot of manual work. By using the proposed approach, the work is reduced to the specification of one database query using the AmosQL language.

5. Remarks

To fully validate the approach presented in this paper requires an implementation of a system for a full-scaled problem in an industrial setting. This is a considered as subject for further work. The use of the integrated system foundation is not limited to AMOS II exclusively and any database system can be used for the implementation of the conceptual model. However, using another type of database requires a definition of a subordinate model adapted for the specific database type. An adaptation is not necessary when AMOS II is used for the reason that AMOS II is object oriented and the implemented schema resembles the conceptual model. One drawback by using a database, compared to using MS Excel for instance, is the lack of graphical user interface and the limited functionality for data manipulation. Working in a well-known application program bolster quick progress in system development initially, but can in the long run limit the overall system functionality, adaptability and extensibility which can be hard to foreseen. Finally, the development of new systems should always include the active consideration of using existing databases that are included in, by example, company implemented PDM-systems and ERP-systems. Using company existing databases eliminates the work of data duplication and it supports access to the latest updated information. Further, an additional database system is not required and the effort for maintenance is reduced. However, these advantages have to be compared with the risk of increasing the information complexity, the systems dependencies, and the effort required for the adaptation of existing database systems.

6. Conclusions

The presented work provides an approach for integration of information in systems for automated design used for quotation preparation. The usefulness of such a system is further expanded and an increased flexibility is achieved regarding the possibility to adapt the system to changes in product properties and manufacturing characteristics. The approach is based on an integrated system foundation comprising of concepts and principles supporting application system development and utilization. In this work the technology provided by a database, AMOS II, for data storage, analysis and management was used as a means for reaching the desired functionality. However, a database does not by its own provide the required functionality, of vital importance are the system implemented conceptual models and the principles that the system reside upon. The flexibility regarding the access to the stored information is increased by using a single detailed conceptual model for the database definition. Further, information is not trapped in a predefined hierarchical structure if a carefully defined model and database for persistent data storage is used. The access to information is augmented and different analyses can be made, by example, on a higher level across orders and product variants, as well as on a more detailed level for a specific subassembly or part. Finally, a system founded on the presented concepts and principles can be used as a means to increase the awareness of the relations between product properties, manufacturing aspects and cost levels among engineers and managers, and to support the evolution of corporate knowledge.

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