A Model of an ERP-Based Knowledge Management System for Engineer-to-Order Enterprises

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Abstract. Today's enterprises require effective systems of knowledge management (KM) that guarantee proper know-how recording and processing in order to create innovative products and technologies. Part of a company's know-how is recorded in an enterprise resource planning (ERP) system database as data and information which could be transformed into knowledge. In this, paper, a model of a KM system for manufacturing companies that carry out engineer-to-order (ETO) production is proposed. The model is based on ERP systems and includes tools that enable data and information processing and its subsequent conversion into a form of knowledge. An analysis and understanding of the model may result in an improvement of innovation processes in high-tech manufacturing companies. The proposed model may additionally support the research and design activities of manufacturing enterprises. Illustrative examples are provided.

Keywords: Enterprise resource planning · Knowledge management · Innovation · Research and design · Engineer-to-order production

1 Introduction

An engineer-to-order (ETO) production approach is one in which a company designs and manufacturers a product based on very specific customer requirements. When an engineer-to-order manufacturing company signs a contract for a new product, it often has only a general concept based on customer assumptions for the functionality of the product. However, in the contract the most important information about total price, delivery time and guarantee should be included. It means that engineer-to-order companies can draw upon their own experiences when preparing a cost-effective and competitive contract. ETO production includes, for example, the manufacturing of production lines, machines, tools and equipment, etc. Such companies are typically based on the technical knowledge and competences of designers and technologists. A very important role in this kind of production is played by the research and design department which is responsible for the implementation of innovation via new products and technological development. In the area of production and services, an implementation of best practices and the permanent training of employees is of crucial

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importance. To support the process of production and technological development, an effective KM system is required [5]. ERP systems can be a very important knowledge repository for each manufacturing enterprise. The data registered in an ERP database could be first transformed into information, and after interpretation, into knowledge about products and processes. The number of functional areas of a company included in an ERP and the lifetime of the system determine the size of a database (amount of data) and its resulting knowledge potential [7]. Effective KM is especially important for innovative engineer-to-order manufacturing companies which make high-tech prototypes of products or technologies whose research and design demand is relatively great. The research problem of this paper can be formulated as follows. Given is a manufacturing enterprise that realises ETO production based on an ERP system. How can it effectively manage knowledge in the enterprise to support the development of innovative products or technologies using the ERP system.

In this paper, a model of a KM system dedicated to engineer-to-order companies is proposed. The model is based on an ERP system database in which both tacit and formal knowledge could be acquired. The model includes algorithms of processing information and transforming it into a form of knowledge.

2 ERP Systems in Engineer-to-Order Enterprises

Engineer-to-order production is dedicated to the manufacturing of short series or individual prototype products or technologies. The management system of this kind of production is mostly based on project management techniques. The ERP systems implemented in ETO companies not only support typical production and logistics processes, but also R&D or product developing processes. In Fig. 1, a framework of product development in engineer-to-order enterprises supported by an ERP system is presented. On the basis of customer requirements, a concept of a product is prepared. ETO companies have to closely cooperate with customers during new product development. Product concepts are based on economic limitations and technical assumptions specified by customers, these are often contradictory [6]. Producers are expected to offer high-tech solutions, low prices, relatively short times of product delivery and solid guarantee conditions. ETO companies often make prototypes that need to be preceded by scientific research (new materials, functionality, etc.). In ETO enterprises, the ERP system should support project management. On the basis of customer assumptions, the product design (costs, functions, variants, etc.) and technology is defined and registered as data in the ERP database. Since the form of the product is prepared together with the customer, the process of product development should be registered in the ERP database too (ideas, solutions, variants of design, bill of materials, technologies, etc.). Additionally, the negotiation process, variants of sales offers, delivery conditions and operating conditions are registered in the ERP database by the CRM system. During the manufacturing process, data about technological operations and quality control are also collected by the ERP system. Therefore, the database of ERP is not only a set of data, but also a very important knowledge repository about the processes and projects realized by a manufacturing company. For the KM process, it is highly important to transform data from the ERP database into know-how about products and processes carried out by the ETO company.

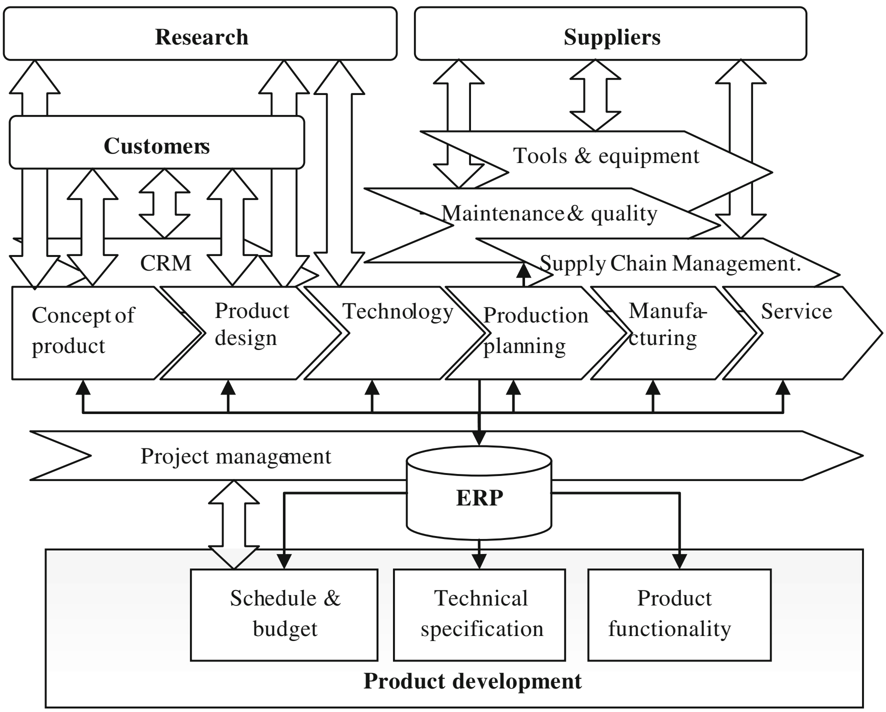

Fig. 1. A framework of product development in an ETO enterprise supported by an ERP system

ERP databases include a lot of data about both completed and ongoing projects. To create an effective system of KM, the data should be classified and interpreted (transformed into information). The method of access and indexation (tagging of information) is very important. To transform the information into a form of knowledge, the form of its presentation is also very important [8]. A part of the information could be presented as a best practices after verification by experts. Therefore, the methods and tools for information verification, and classification should be elaborated and implemented in a KM module of the ERP system. The methodology of the transformation of data into knowledge is proposed in Fig. 2.

In the first step of the proposed methodology, data analysis and interpretation should be performed. On the basis of data analysis, a set of information can be prepared. For example, in the area of product design, the following data can be analyzed: structure of products, average time of product module design, most problematic areas of product design (time-consuming), design errors, cards of design changes, etc. The interpretation of data enables the classification of modules (parts) of products according to labor intensity, the possibility of errors, reasons for changes in design, reasons for design errors, etc. Next, relationships between the data should be analyzed. For example, data from manufacturing related to reducibility are very important for the design department. Therefore, comparisons between assumed operation times and real

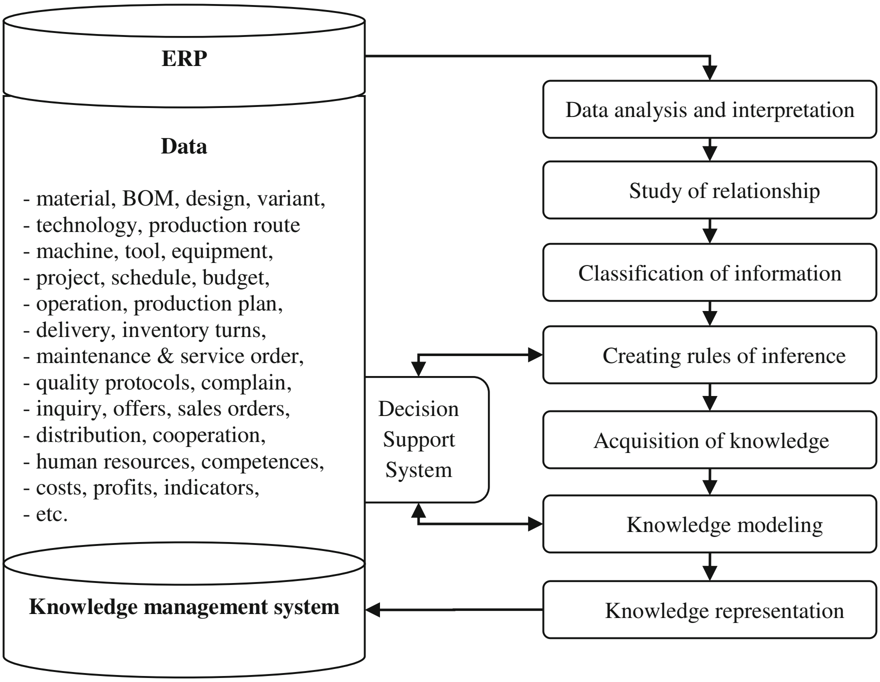

Fig. 2. The methodology of the transformation of data

operation times (registered in the manufacturing department could be crucial for processing guidelines for design.

In the next step, the classification of the information should be done. The information can be classified in different ways, for example – according to processes or functional areas (sales, design, technology, production, logistics, maintenance, etc.). To create an effective KM system, the most important information should be structured. The structure enables the systematization of the information and automated updates of the information downloaded from the ERP database and processes it into a useable form. The information could be used to support different decisions in an ETO company. To create an effective decision support system, rules of inference should be formulated. For example, some rules in the area of product design should identify any assumptions and limitations that may reduce production failures, manufacturing costs or operation times. Another example of a rule could be the application of hard-to-reach materials in the BOM. The rule can be formulated as follows: if material m_i is used in the construction of product P_j, the production plan should be shifted by t_k time because of delivery times. A decision support system is very useful for research and development project verification based on the rules of inference. The acquisition of knowledge includes the method of information collection (extraction from the ERP system) to create a basis of knowledge about products, or structural and situational knowledge about the system (ETO enterprises). The next step of the proposed methodology is the determination of knowledge representation. Knowledge will be obtained on the basis of an ERP database (data in electronic form). Knowledge representation can be performed by tools such as XML (eXtensible Markup Language), XHTML (Extensible Hypertext Markup Language), AIML (Artificial Intelligence Markup Language), FOAF (The Friend of a Friend) and RDF (Resource Description Framework). Models of knowledge can be registered in an ERP system as knowledge maps. For the mapping of knowledge, it is very important to identify knowledge sources (tacit knowledge). Tacit knowledge associated with individual projects could be, for example, registered in an ERP database in the form of discussion forums, best practices, training movies, etc.

3 ERP-Based Knowledge Management Systems Dedicated to ETO Companies

The proposed model of a KM system dedicated to ETO companies is based on data structures that describe resources, business processes and projects realized in the system. Let us consider an ETO company that includes m functional areas and each functional area is described by sets of data Fi where i = 1,2, …, m. In the company, n processes were completed in n functional areas and each process is described by the sets of data Pij where i = 1,2, …, m and j = 1,2, …, n. In Table 1, the sets of data described in an ETO company's functional areas are proposed. Sets of data that enable the description of areas are assigned to the functional areas of the ETO company. Depending on the ERP system, the sets of data could differ - but generally the proposed repository of data should enable a description of the functional areas of the ETO company. The number of functional areas could also be increased or reduced (for example marketing, tool management, logistics, services, etc.) but generally the proposed functional areas carry out the same functions. In the proposed model of data management in an ETO company, only operational departments are taken into consideration. On the basis of the methodology proposed in Fig. 2, ERP data analysis is required to create a KM system which can create useful information. For example: on the basis of a sales offer and sales order comparison, information about offer effectiveness could be obtained. Studying the relationships enables the construction and analysis of different ratios, for example the efficiency of employees, or OEE (overall effectiveness of equipment). In Table 1, the business processes realised in different functional areas are presented. The realized business processes result in the generation of data in functional areas of an ETO company. A model of a knowledge management system in an ETO company should include an algorithm of knowledge acquisition, a representation of knowledge and a modelling of knowledge on the basis of the data registered in the ERP system. The KM system supports the development processes of new products and technologies, operational decisions in functional areas, tactical and strategic decisions for the whole company and the training of workers, etc. On the basis of the structure of the functional areas, data sets and business processes presented in the Table 1, a model of an ERP-based KM system is proposed (Fig. 3).

Table 1. Data sets and processes of an ETO enterprise

Item	Functional area	Sets of data	Business proceses
F_1	Sales and distribution	F_{11} – sales inquiries, F_{12} – sales offers, F_{13} – sales orders, F_{14} – invoices, F_{15} – customers, F_{16} – shipments	P_{11} - market research. P_{12} - offers preparing, P_{13} - negotiations, P_{14} – product/project valuation, P_{15} – product/project delivery
F_2	Research & development	F_{21} – projects (products), F_{22} – innovations, F_{23} – patents, F_{24} – research results	P_{21} – prototyping products, P_{22} – research works, P_{23} – laboratory tests
F_3	Design & technology	F_{31} – materials, F_{32} – BOMs, F_{33} – products, F_{34} – variants, F_{35} – technologies, F_{36} – designs, F_{37} – calculations, F_{38} – production resources, F_{39} – maintenance manuals, F_{310} – guarantees	P_{31} – product design, P_{32} – material selection, P_{33} – technology design, P_{34} – cost analysis
F_4	Production planning and control	F_{41} – production plans, F_{42} – production abilities, F_{43} – production routes, F_{44} – priorities, F_{45} – subcontractors	P_{41} – production planning, P_{42} – balancing prod. capacity
F_5	Production and assembly	F_{51} – production orders, F_{52} – registered operations, F_{53} – subcontractor orders	P_{51} – production scheduling, P_{52} – production control, P_{53} – logistics management
F_6	Purchasing	F_{61} – purchasing orders, F_{62} – purchasing offers, F_{63} – material requirements. F_{64} – suppliers	P_{61} – MRP, P_{62} – validation of supplies, P_{63} – verification of offers, P_{63} – material ordering

(*Continued*)

Table 1. (*Continued*)

Item	Functional area	Sets of data	Business proceses
F_7	Material management and warehousing	F_{71} – material turnovers, F_{72} – inventory, F_{73} –structure of storage	P_{71} – registration of material flow, P_{72} – stocktaking, P_{73} – storage mapping
F_8	Maintenance & tools management	F_{81} – tools, F_{82} - equipments, F_{83} – maintenance orders, F_{84} – maintenance operations, F_{86} – service orders, F_{86} – spare parts	P_{81} – repairs, P_{82} – renovation, P_{83} – setups, P_{84} – services, P_{85} – design of tools, P_{86} – design of equipment
F_9	Quality control	F_{91} – quality of materials, F_{92} – quality of processes, F_{93} – quality of tools, F_{94} – quality of products	P_{91} – quality control, P_{92} – preparing procedures, P_{93} – implementing procedures

The KM system includes a data analyzer. The module is available in most ERP systems as a business intelligence (BI) functionality. On the basis of the data extracted from an ERP database, useful information can be created using the tool. For example, on the basis of data extracted from the F_{14} data set (invoices) – information about the lifecycle stage of each product can be delivered.

An analysis of the data should be performed by dedicated experts or knowledge engineers. An information classifier is a very important tool which can enable the systematization of information registered in an ERP database. For example, on the basis of material analyses (F_{31}), the set of data could be divided into many classification groups (steel materials: C-bars, T-bars, double T-bars, etc.). On the basis of the classified information, for example, a product configurator could be implemented to support the process of rapidly offering products. To analyze relationships among the ERP data, specialized tools such as BI, could also be used. For example a study of relationships among the production plans (F_{41}), maintenance orders (F_{83}), production orders (F_{51}) and material turnovers (F_{71}), enables the evaluation of the influence of the frequency of machine inspections and material delivery delays on the deadlines of production orders. The analysis of relationships can result in an elaboration of an advanced system of production planning and scheduling [3]. A time-series analysis of the quality control data of processes and products (F_{92}, F_{94}) and an implementation in

Shewharts charts can result in the creation of a new measurement methodology [1]. The data analysis, study of data relationships and the classification of information result in the creation of inference and decision rules.

The decision rules directly influence the realization of processes. Some examples of decision rules can be constructed as follows:

- *if a customer has overdue payments (F_{14}) > 30 days then a new offer cannot be prepared (P_{12}),*
- *if inventory level (F_{72}) of material M_x < Min_x (F_{31})where Min_x (minimum level of material x then order material M_x), (P_{63}),*
- *if a material M_x quality (F_{91}) is inconsistent with the specification (F_{31}) then the purchasing orders cannot be realized by supplier S_i (P_{63}).*

The inference rules influence other data or enable the determination of some ratios, for example:

- *if in the BOM material M_x is used (F_{31}) then technology T_y should be applied (F_{35}) to minimize manufacturing costs (F_{38}),*
- *if production variants V_y are applied (F_{34}) then production order (F_{51}) will be completed according to plan (F_{41}),*
- *if a production order (F_{51}) cannot be completed in time, then the production plan (F_{41}) will be verified.*

The rules represent a form of knowledge. Knowledge acquisition involves the recording of inference and decision rules by knowledge engineers, but the rules are created by knowledge workers in various functional areas of the ETO company [4]. It is very important to associate experts and knowledge workers with functional areas and the processes carried out in the enterprise in order to create new knowledge about products, technical solutions and manufacturing technologies. To support knowledge acquisition, a knowledge map should be created. The map enables the identification of the intellectual potential of the company and on the basis of decision and inference rules which enable the modelling of knowledge. The knowledge obtained from experts and knowledge workers is saved in a form of rules and creates a knowledge base. The knowledge presentation may be in the form of best practices.

The procedure of knowledge management for new product development in an ETO enterprise is presented in Fig. 4. In the first step of the procedure, the product concept is elaborated on the basis of customer requirements and know-how about products. The product concept defines the assumptions and limitations of the scope of project. The realization of the next three steps is typical for project management (scope, schedule and budget).

The activities of new project development are supported by inference and decision rules created on the basis of sets of data extracted from an ERP database. A result of the procedure will be some variants of the product concepts (different variants of projects). Using the decision support system and decision analysis (for example based on the Analytical Hierarchy Processes methodology) the selection of the best solution is possible [2]. The evaluation criteria could be determined by customers or expert

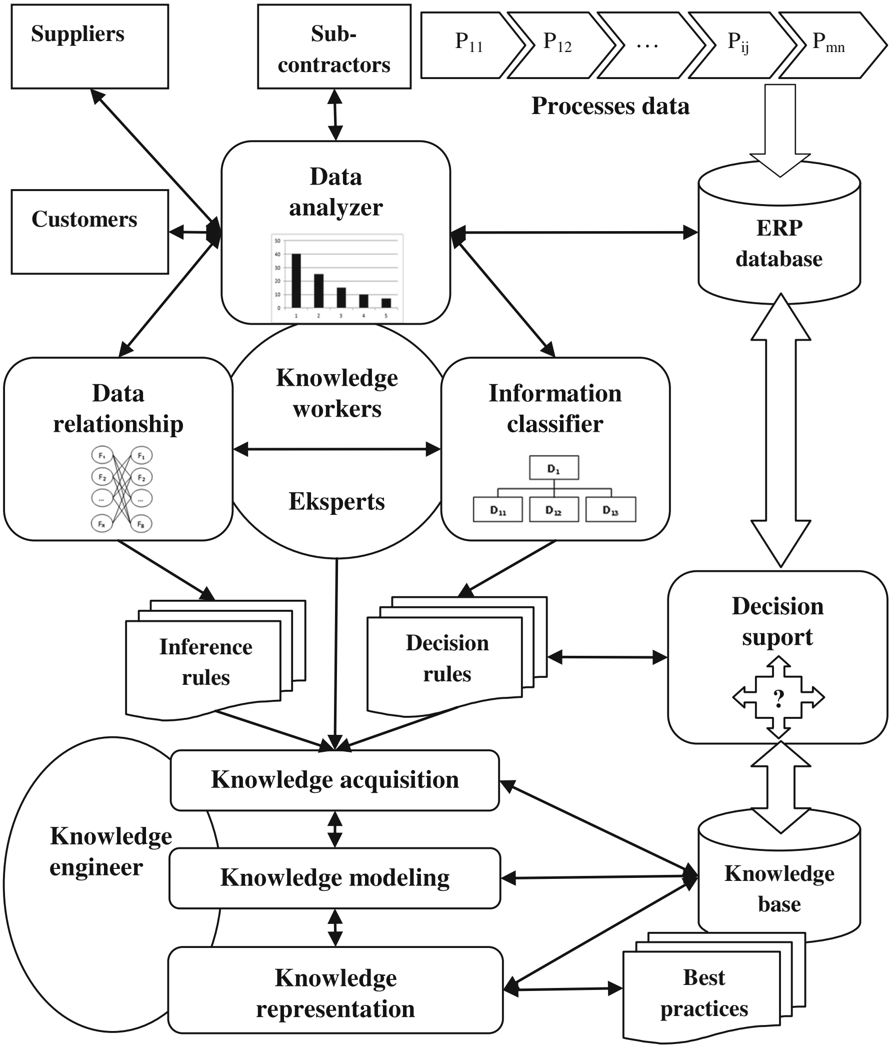

Fig. 3. A model of an ERP-based knowledge management system for an ETO enterprise

experience. Analogical procedures can be proposed for products, technology design, research methodology, maintenance and service procedures, etc. The proposed procedure of product development should be repeated for each new product. The knowledge about preparing a new project could be used for improving inference and decision rules.

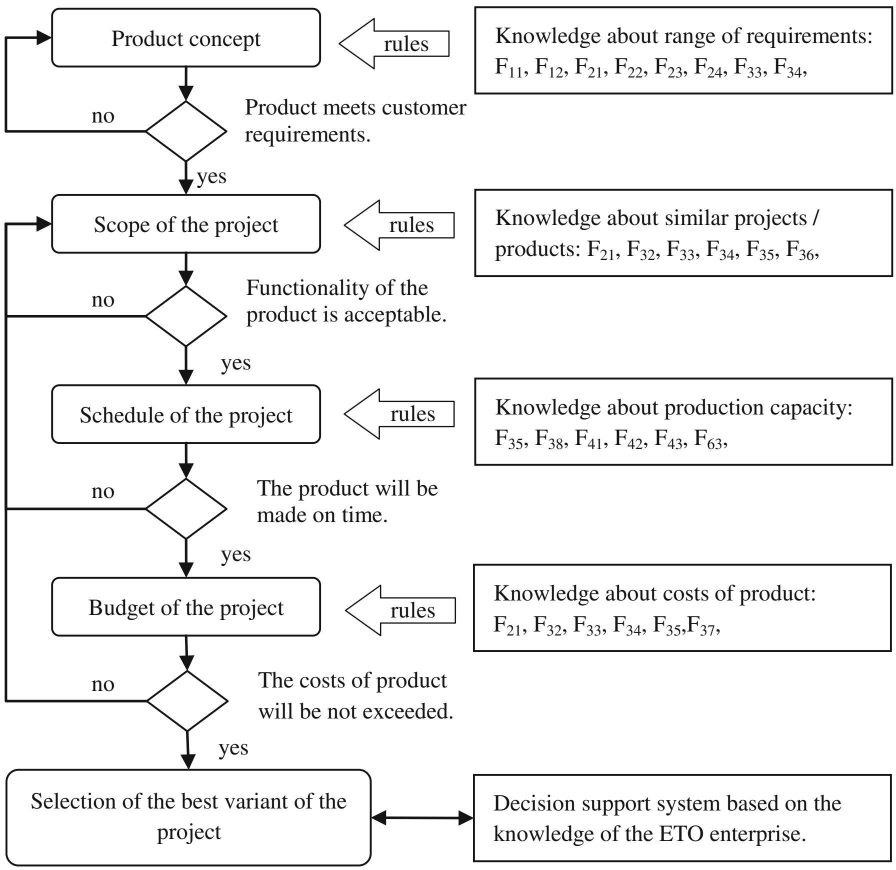

Fig. 4. The procedure of knowledge management for product development in an ETO enterprise

4 Conclusions

A lot of high-tech manufacturing enterprises work on the basis of ETO principles. For such companies, an effective knowledge management system is crucial for reducing the time of a new product development. Most companies use an ERP system to support business processes. An ERP database can be a very important knowledge repository. In this paper, a model of a knowledge management system dedicated to ETO enterprises is proposed. The model is based on the transformation of data from an ERP system using inference and decision rules into a form of knowledge. The procedure of knowledge management for product development is also proposed. An integral part of a knowledge management system is a module of decision support. Decision and inference rules should be created by experts or knowledge workers of an ETO company.

In further research, inference algorithms will be proposed that enable the automatic creation of inference and decision rules on the basis of the data sets of ERP data.

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