Estonian Journal of Engineering, 2009, **15**, 2, 108–120 doi: 10.3176/eng.2009.2.04

E-manufacturing concept solution for tooling sector

Kaia Lõun, Tauno Otto and Jüri Riives

Department of Machinery, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia; {kaia.loun, tauno.otto}@ttu.ee, jyri@eestitalleks.ee

Received 29 April 2009, in revised form 11 May 2009

Abstract. E-manufacturing as a term was introduced some years ago by semiconductor industry, enabling to handle large production quantities in different locations. Due to globalization, nowadays individual and small-batch production oriented tooling companies need web-based simple manufacturing, planning and monitoring systems that could include larger sensor systems and databases. In this paper an overview of the tooling sector and its needs for such a manufacturing model as well as a new concept of the e-manufacturing model for SMEs of machinery and tool-making sectors are presented.

Key words: e-manufacturing, resource allocation, tooling, virtual manufacturing.

1. INTRODUCTION

Since 1990s, system theory has strongly influenced process management. Instead of examining single enterprises, nowadays networks of interacting enterprises (production systems or supply chains) are analysed. Estonian tool-making industry has long-term experience in manufacturing of stamps and moulds; the larger part of production (about 80%) is exported. Typical for tool-making industry is manufacture-to-order and non-repetitive manufacturing environment. In this environment, the need to work together and to provide cost-effective management of the whole production system is challenging. Tool-makers in Estonia are well-organized, belonging to the Federation of Estonian Engineering Industry (EML) via Estonian Tool-Makers Association (ESTA). ESTA is also a member of the International Special Tooling and Machining Association (ISTMA).

E-manufacturing (e-mfg) is the application of open, flexible, reconfigurable computing techniques and communications for the enhancement of efficiency of the whole supply chain. As e-mfg is supported by information technology (such as the Internet) and has the capability in multi-site management, it will foster and improve the competitive capability of manufacturing in the global competition [1]. e-mfg can be determined as IT-based manufacturing model, optimizing resource handling over the entire enterprise and extended supply chain [2]. Using the Internet and tools that support commerce functions, one can find new customers, reduce the costs of managing orders and interacting with a wide range of suppliers and trading partners, and even develop new types of information-based products, such as remote monitoring and control software and other online services [3]. Sometimes e-mfg is mixed up with other e-terms. e-mfg includes also design of manufacturing and business strategy, sales and marketing, e-procurement, shop-floor operations, enterprise application integration, supply chain collaboration, transactional e-business – providing real-time visibility and collaborative engineering [4,5].

Some research groups [6] have concluded that in e-mfg simpler algorithms can be used, but one must be ready to accept solutions of inferior quality. In first e-mfg solutions in semiconductor industry the ratio of the volume of the product was very high, whereas the equipment necessary for production is expensive and difficult to transport and install [7]. One important characteristic of semiconductor capacity planning is that both the product demand and the manufacturing capacity are sources of uncertainty. As is the case in hi-tech industries, the market has a demand structure that is intrinsically volatile [8]. If e-mfg was successful in case of the semiconductor industry, one can expect good results also using similar approach in the tooling industry.

In order to resolve the information exchange problems, a standardization approach has been at the core of most research efforts. Technical standards for product information and CAD/CAM documents have been realized by Standard for the Exchange of Product Model Data–STEP. The main problem is that the used Semantic Web technologies and tools require considerable technical expertise, and are thus not well suited for users outside the field of computer science. This makes it hard for domain experts and ontology engineers to work together on e-manufacturing tasks [9,10]. Another e-mfg related problem is that the bandwidth and the inherent delays of TCP/IP impose a strong constraint to the teleoperation systems through the Internet [11]. Although several commercial CAD systems offer interference inspection functions, these systems are very expensive and inadequate to perform collaborative work over the Internet [12]. Therefore a Best-Matching Protocol for geometrical as well as supplier matching has been proposed [13]. Thus results of this approach have been promising: after implementation of e-mfg principles the required time for mould manufacturing was reduced by 35.6% in 2006 compared to 2004, and the time required for designing a mould was reduced by approximately 40% [14].

The aim of this paper is to elaborate new management and planning models and decision processes to increase the efficiency of the entire supply chain, not only of an individual manufacturing company.

2. ESTONIAN TOOL-MAKING INDUSTRY

Estonian tool-making companies have comparatively modern machinery, technology and skilled labour, so it is quite difficult to find soft options for raising the productivity. Therefore modern radical integrated techno-economic measures such as cluster development and e-mfg, should be implemented.

Nowadays manufacturing companies require high degree of product customization to fulfil market demands. Therefore e-mfg system should fulfil the following requirements:

- to be an open and dynamic environment;
- heterogeneous software and hardware applications;
- enterprise integration and cooperation (joint manufacturing systems: ordering, purchasing, design, scheduling and planning, manufacturing, sales networks etc);
- ability to adapt quickly to changes in environment;
- additional resources can be added to the system as required without disrupting other previously established systems;
- the system should be able to detect failures and minimize their impact on the working environment.

2.1. Benefits of cluster development

Clusters are often at the core of innovative development. It is widely recognized that innovative companies are in tight cooperation with other companies, investors, educational institutions and research centres.

Cluster initiatives facilitate acceleration of innovation and then bring them to maturity, thus ensuring the long-term economic success of the companies involved. They present an efficient instrument for the concentration of resources and funding. Through cluster development, critical dimensions of knowledge, flexibility and mobility can be achieved. Mobility can be maximized when there is a local labour market that allows regular flow of people from one situation to another, with a diffusion of knowledge.

2.2. Cluster development in Estonian tool-making sector

Cluster development in the tool-making sector means manufacturing products that belong to the same product family (moulds, stamps) by all of the companies belonging to the sector. Although the products themselves may be very different by their parameters, functionality and accuracy class, their production is carried out by technologies of similar type. Two important aspects, contributing to cluster development in Estonian tooling sector, are the company aspect and production aspect.

2.2.1. Company aspect

The company aspect is characterized by similar structure of Estonian tooling companies, similar order handling processes and quite similar starting points (Figs. 1, 2).

Data presented in Figs. 1, 2 is based on the results of questionnaires of the Estonian engineering enterprises research [15]. This research covered 60 machine-building companies in Estonia, but for analysing competitiveness and productivity of tooling companies, only the data about tooling companies was used for our research. As competitiveness of a company depends mostly on the company itself, questions were directed to competitiveness, human resources and innovation issues in the company.

Competitiveness was determined by experts. It is expressed by company's activeness and development ability (reflected on the x axis) and flexibility and compass of the value chain (reflected on the y axis). Points reflecting these two dimensions were summed for each tooling company. Maximum points in case of activeness and development ability were 55 and in case of flexibility and compass of value chain 40 (Fig.1).

On the basis of possible combinations of the two main dimensions shown in Fig. 1, four different scenarios are formed for the economic development that in previous investigations [16] have been marked with the names "Stagnant water", "Natural selection", "Idling speed" and "North star". These scenarios represent various development paths and lead to various states, whereas it is possible to switch over from some (not from all) development paths to the other ones in the course of the process. "Stagnant water" is a scenario where enterprises continue the previous very slow (too slow) restructuring; "Idling speed" is a scenario where the state is active and tries to do something significant, but that does not match the goals; "Natural selection" is a scenario where enterprises become

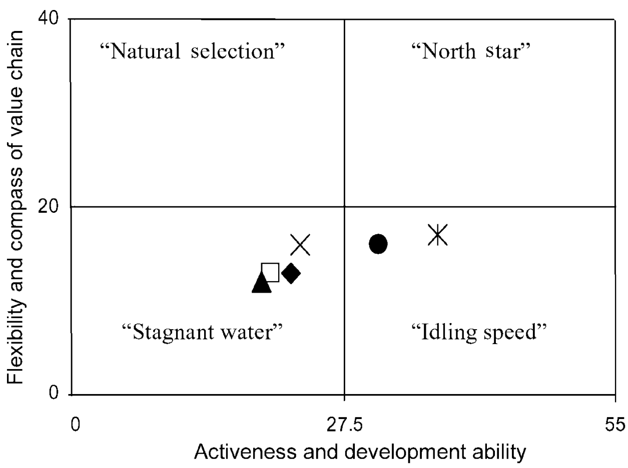

Fig. 1. Competitiveness of Estonian tooling companies.

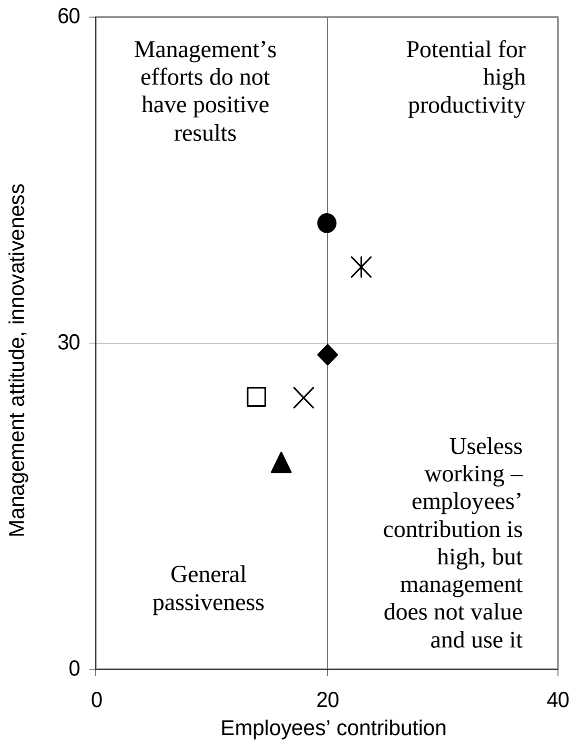

Fig. 2. Comparative analysis of Estonian tooling companies regarding productivity.

active, but their activities are mainly individualistic; "North star" is a scenario where a leap in development could be made by connecting the enterprises' readiness and ability to change with the supporting activities of the state.

In the case of productivity, it was determined by experts that productivity of the company depends on the employees' contribution to raising the productivity (*x* axis) and management's attitude and innovativeness (*y* axis). Points reflecting these two dimensions were summed for each tooling company. Maximum number of points in case of employees' contribution to raise productivity was 40 and maximum number of points in case of management's attitude and innovativeness was 60 (Fig. 2).

On the basis of possible combinations of these two main dimensions, illustrated in Fig. 2, four different scenarios are formed: "General passiveness", "Useless working – employees' contribution is high, but management does not value and use it", "Management's efforts do not have positive results" and "Potential for high productivity". As it is seen in Fig. 2, Estonian tooling companies should make efforts to reach the scenario "Potential for high productivity".

Questioning of the companies according to the questionnaire was carried out during November 2007–January 2008. Dots in Figs. 1 and 2 represent different Estonian tooling companies and their location regarding the competitiveness and productivity. The results, presented in Figs. 1 and 2, reflect quite similar level of competitiveness and productivity of Estonian tooling companies and also the need for urgent development activities in order to increase the competitiveness and productivity and to assure companies' sustainability.

2.2.2. Production aspect

Main technologies used in the tool-making process are milling, turning, drilling, grinding, assembly and measuring. Specific technologies are electro-erosion machining, coordinate grinding, micro-welding and fitting.

As the manufactured products are complex, have different surfaces, require high processing accuracy and have high requirements regarding surface quality, all Estonian tooling companies use numerically controlled machine tools. These machine tools have large technological possibilities, but high cost as well. Therefore these machine tools have to be operated at full capacity and their technological possibilities exploited rationally. Technological capabilities of machine tools that are used form the company's technological capabilities and nomenclature of products manufactured.

Regrettably such machine tools have high investment costs that excessively raises net cost of the products if these machine tools are not rationally exploited. Hence, the need for every company to specify its technological capabilities and to determine in which direction to develop its capabilities.

Consequently, it is essential to determine the structure of the production system that creates prerequisites for efficient and effective functioning. Determination of the structure of the production system is a process of sequential decisions, which leads to the configuration of the system, possible transport routes, storage principles, but also to basic organizational measures. Solving the optimization task, it is possible to determine the nomenclature and number of main machine-tools. The aim is to minimize the objective function F :

$$F = \sum_{j=1}^{J} (X_j K_j E_H + C_j \sum_{i=1}^{I} \sum_{k=1}^{k_i} Y_{ikj} t_{ikj}) \rightarrow \min, \tag{1}$$

subjected to constraints:

$$\sum_{i=1}^{I} \sum_{k=1}^{k_i} Y_{ikj} t_{ikj} \leq X_j F_j \eta_j, \; j = 1, 2, ..., J, \tag{2}$$

$$\sum_{j=1}^{J} Y_{ikj} = A_i, \quad k = 1, 2, ..., K; \quad i = 1, 2, ..., I, \tag{3}$$

where

$X_j \geq 0$, $Y_{ikj} \geq 0$ (X_j and Y_{ikj} are integers),

i – workpiece type, $i = 1, 2, ..., I$;

A_i – amount of production programs of workpiece i;

j – type of the machine-tool, $j = 1, 2, ..., J$;

t_{ij} – production time of workpiece i using machine-tool j;
J_i – number of machine-tools that enable producing workpiece i;
I_j – amount of workpiece types that is possible to manufacture using machine-tool j;
k – type of manufacturing operations, $k = 1, 2, ..., K$;
J_k – amount of machine-tool types that enable processing operation k;
t_{ikj} – time of performing operation ik using machine-tool j;
F_j – effective working time of the machine-tool j;
η_j – planned workload coefficient of machine-tool j;
K_j – cost of the machine-tool j;
E_h – machine-tool utilization coefficient;
C_j – cost of machining using j type machine-tool a minute;
X_j – number of j type machine-tools;
Y_{ikj} – number of i type workpieces, for which the processing operation k is made using machine-tool j.

3. ORDER HANDLING PROCESS IN TOOLING COMPANIES

Typically tool-making companies are oriented to order fulfilment, whereby the number of products in an order is small and similar orders recur seldom. Therefore tooling companies are typical engineer-to-order non-repetitive production companies. Order handling process in tooling companies, based on interviews of ESTA members, is presented in Fig. 3.

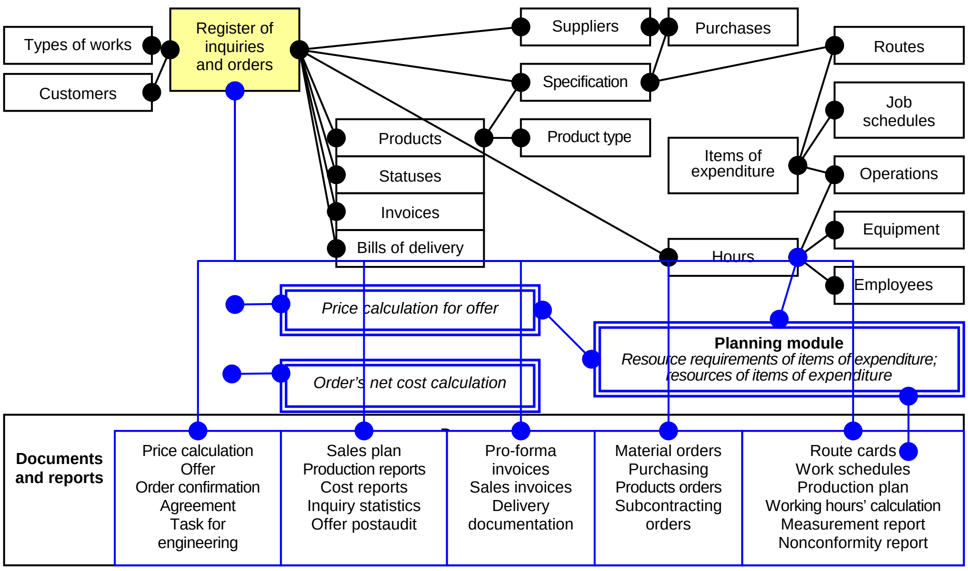

Fig. 3. Generalized order handling process in tooling companies.

Usually, some degree of abstraction is necessary by modelling the products. Thus, some parts may be left out of the model completely. Others may be aggregated and represented in the model as a single, “generic” component. The summarized characteristics of the aggregated components must be checked to see if they represent the situation correctly. Production planning method for a supply chain in such a low-volume and make-to-order manufacturing environment has been developed at Tallinn University of Technology, where key performance indicators are used to analyse real enterprise data comparing it with a modelled ideal manufacturing system [[17]].

From the company side, an order is considered as a complex of activities that contribute to technologically rational and economical manufacturing of the product. Main objectives regarding the order handling process are:

– to determine functional and technical parameters of the product and realize complex technical preparation that would assure technologically rational and smooth manufacturing of the product;
– to elaborate and determine rational manufacturing process, specifying the order of performing manufacturing operations as well as resources needed for manufacturing; to determine the essence of stages of order fulfilment and information flows during order handling process that would assure quality of the performance and possibly short lead time;
– to consider alternative possibilities of the manufacturing process with the aim to produce at as low net cost as possible;
– to determine the order of product delivery and relations with the customer after sales (e.g. after-sales servicing).

As it is seen in Fig. 3, it is possible to divide the order handling process into three groups of components:

– events, taking place in the order handling process (events include different kind of activities);
– documents and databases that are needed for starting and fixing the activities as well as saving information flows related to the activities;
– information flows that determine interrelated items and periodicity of information change in the order handling process.

Events, taking place in the order handling process, can be described as information models that include all previously mentioned components and the aim of which is to fix the occurrence of the events in detail. The e-mfg system is a set of related models (Fig. 4).

The number of models depends on the complexity of the system. In Fig. 4, a set of main models that may belong to the e-mfg system, is presented (additional models can be included). In the case of each model, the following should be described:

1) architecture – process management, realization principles;
2) application – planner that gives information about employing the model, how and in what conditions the model should be employed;

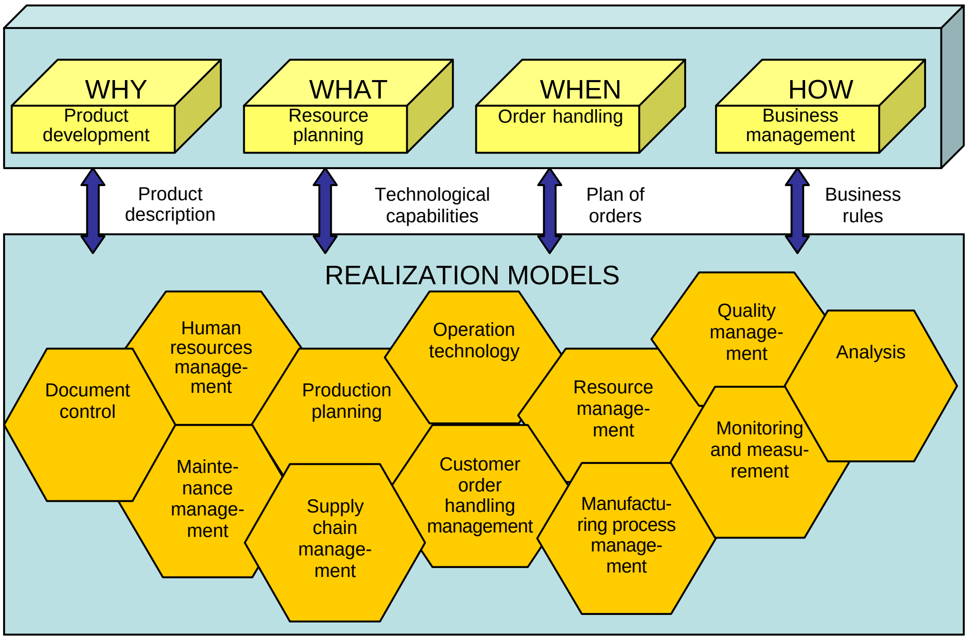

Fig. 4. e-mfg system as a set of related models.

3) expert for helping decision-making – essential information is gathered from the environment and expert offers optimal solution; decisions made are saved together with the description of the circumstances that were the basis of decision-making, this enables learning of the system and making new decisions based on the previous experience.

Events are divided into three groups:

1) main events – events that are sequential and directly needed for order fulfilment and that essentially influence how well the order handling process is carried out; for example, order acceptance is a main event that activates the order fulfilment process and fixes its nature (Fig. 5);
2) support events – events that directly support the occurrence of main events;
3) ancillary events – events that help carrying out the whole order handling process and raising its efficiency in different ways.

For example, competence of employees influences the quality and productivity of the order handling process. Therefore personnel training may be considered as an important ancillary process that uses important resources of the company and has connections with the whole order handling process.

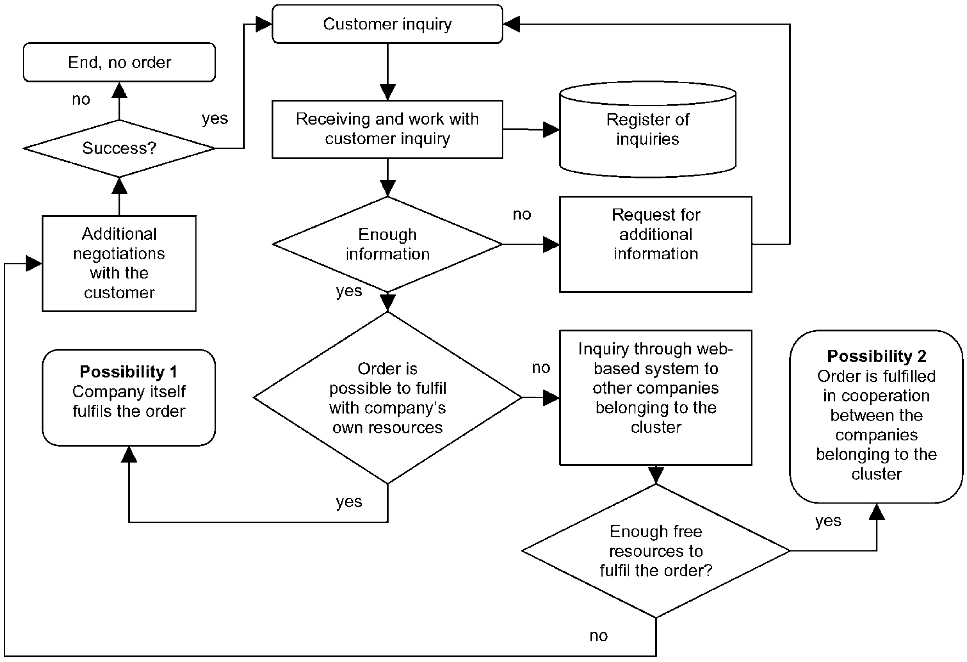

Fig. 5. Example of a main event, the customer inquiry handling model.

4. DEVELOPMENT OF THE E-MANUFACTURING CONCEPT

Basic architecture of the e-mfg system integrates various modules using software and hardware components. A vision of the Internet-based e-mfg system is presented in Fig. 6.

The e-mfg system development consists of the following main stages:

– description of the system architecture and modules;
– system analysis, determination of platforms and software;
– proof of the concept (including final formulation of inputs and outputs);
– analysis of the rationality to use process automation instruments (e.g. smart dust);
– implementation of the system in the tooling cluster.

As concept realization of the e-mfg concerns the tooling cluster, the main general standpoints are the following:

– main events should be described by embracing all companies belonging to the cluster;
– describing ancillary events is every company's own decision (but agreements inside the cluster would be recommendable here, too).

We have defined e-manufacturing for supply chain (SC) management as a system that tries to fulfil the following goals:

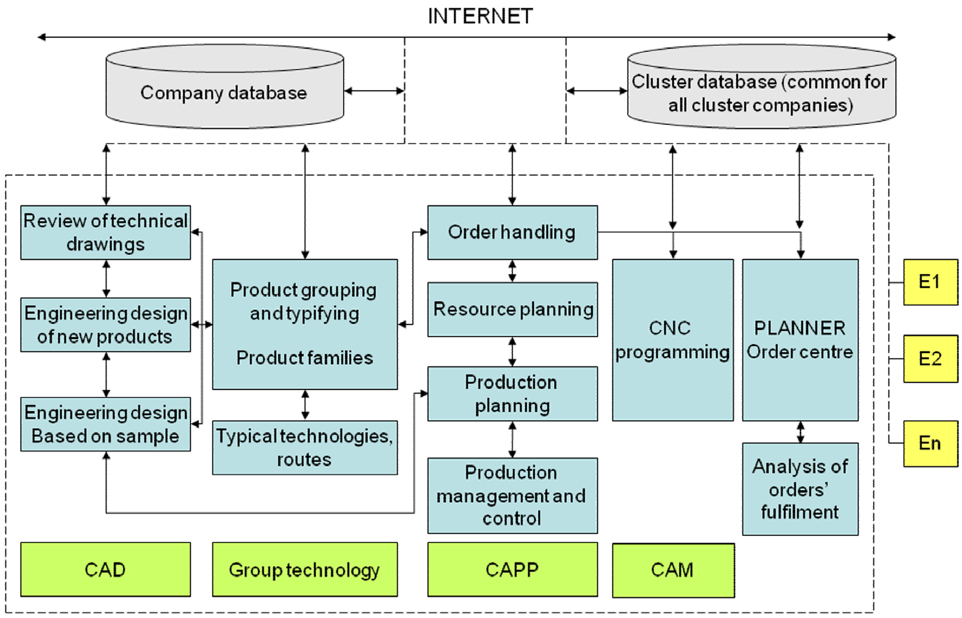

Fig. 6. General concept of an Internet-based e-mfg system.

1) to assure that the investments in SC applications are aligned with SC strategy;
2) to assure that the investments in SC, related to the implementation of e-manufacturing, generate business value;
3) to mitigate the risks that are associated with the SC-related e-manufacturing.

5. CONCLUSIONS

Tooling companies manufacture complex products with individual orders usually different from each other. The companies are already supplied with modern technology and equipment. Therefore it is quite difficult to find possibilities to raise competitiveness of the companies by using traditional methods. Therefore new solutions as integrated production system development and e-manufacturing are to be exploited. Through cooperation between companies, belonging to the system, optimal resource allocation is possible to share technological resources inside the cluster to achieve better use of the resources. The described model is being developed for SMEs in Estonian machinery sector.

ACKNOWLEDGEMENTS

Hereby we would like to thank the Estonian Ministry of Education and Research for targeted financing scheme SF0140113Bs08 that enabled us to carry out this work.

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E-tootmise kontseptsioon tööriistatootmise sektorile

Kaia Lõun, Tauno Otto ja Jüri Riives

E-tootmine on mõiste, mis kasvas mõned aastad tagasi välja pooljuhtide tööstusest, võimaldades hallata eri asukohtades suuri tootmiskoguseid. Globaliseerumise tõttu vajavad ka tänapäeva üksik- ja väikeseeriatootmisele orienteeritud tööriistatootmise ettevõtted veebipõhist lihtsat tootmise juhtimise, planeerimise ning monitooringu süsteemi, mis võib sisaldada ka suuremaid andursüsteeme ja andmebaase. Artiklis on antud ülevaade tööriistatootmise sektorist ja analüüsitud selle vajadust uue tootmismudeli järele, samuti on esitatud e-tootmise mudeli kontseptsioon masina- ning tööriistatootmise sektori väikeettevõtetele.