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Implications of mass customisation on business information systems

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Abstract: Modern information and communication technologies like the internet or mobile computing are enforcing changes of Business Information Systems (BIS) in the context of an evolving e-business and global economy. This paper analyses the impact of mass customisation on future BIS, with focus on globally distributed value chains. Consequently, we address the question of how to scale mass customisation in existing supply webs. New and innovative concepts are needed to keep transaction costs low and information logistics transparent. Using a case study from the footwear industry, we present an innovative multiagent approach, which uses information represented with explicit machine-understandable semantics for coordinating and negotiating activities throughout the supply web.

Keywords: mass customisation; business information system; supply chain management; multi-agents-systems; product models.

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1 Introduction

Mass customisation has been developed as a hybrid competitive strategy (Pine, II, 1993; Piller, 2003). It combines two oppositional directions for business management: *Cost Leadership* and *Differentiation* (Porter, 1999). Meanwhile, there is a more extensive understanding of this concept. Companies offering mass customised products have to reengineer several processes in order to be successful in the market. This is based on a fundamentally different production cycle: Customer acts as a co-producer and production starts after finishing the process of product configuration.

During the recent years, Information and Communication Technology (ICT) has become one of the most capital-intensive investment fields in enterprises. Applications like Enterprise Resource Planning (ERP) software, for example, are used for supporting and optimising any business processes by ICT. It is intended to create an integrated infrastructure in order to avoid inconsistency, data leakage and time lags in communication data transmission. A bottleneck of ERP approaches is that no technical information on processes or products is handled. Even if ERP approaches are very general and aiming at domain-independent usage, there is a strong need for individualisation in concrete domains to realise efficiency and enable low transaction costs, which often leads to the development of individualised Business Information Systems (BIS) for optimal performance of the overall system.

We are using the British English spelling as per Inderscience style.

Therefore, this paper discusses the implication of Mass Customisation on BIS. For sure, Mass Customisation is applicable in various domains and involves specific adaptations. So we will propose generic requirements for a BIS supporting mass customisation. One focus for that is to understand the mass customisation process as a distributed value chain, which can be represented by Intelligent Agents.

Beginning with basic aspects of mass customisation, BIS and coordination technologies for electronic business (Section 2), we introduce agent-mediated value chains, agents in the manufacturing domain, and requirements for future BIS (Section 3). In the following sections we provide a practical view using a case study in the mass customisation shoe industry (Section 4) and present intermediate results of the Deliberative Agents for Intelligent SImulation SYstems (DAISIY) approach within the research project 'EwoMacs' (Section 5). A vision of BIS will be provided in Section 6. This contains a selection of requirements, if globally distributed enterprises use BIS locally. ICT like ontologies for standardising communication, web services for standardising service descriptions, as well as agents for interaction of partners within the supply webs are introduced. To coordinate the loosely coupled actors within mass customisation value chains, a bundle of strategies for acting is required, which allows each participant to adjust its behaviour *intelligently*. Finally, the conclusions will summarise the lessons learned so far and identify unsolved problems as well as future work (Section 7).

2 Rationale

Three basic concepts underlie the paper presented here. First of all, mass customisation is described as a business strategy for enterprises that has a dramatic effect on their structures and processes. Secondly, a short introduction into BIS is provided. These systems should support any business transactions to make them efficient, transparent and more reliable. Basics on coordination technologies for electronic business are depicted last, because this paper focuses on coordination problems among several enterprises, distributed spatially.

2.1 Mass customisation

As described above, mass customisation is a modern management strategy. This concept is best defined as a transaction process, which focuses on individualisation of mass-market products and services to satisfy specific needs of the customer, at an affordable and reasonable price. Therefore, mass customisation should satisfy customers' current needs: regularly new and individual products as well as low prices. Thus, enterprises have to manage short product life cycles, must have a high degree of flexibility within the production process as well as take advantage of efficiency potentials (for example *economies of scale* or *economies of scope*).

Theoretically, there is no restriction concerning the industrial application area of mass customisation. To organise the diversity of this strategy, several classification schemes have been developed and published (*e.g.*, Gilmore and Pine, II, 1997; Piller, 2003). They illustrate explicitly that mass customisation could be implemented on different types of goods (product or service) and branches (automotive industry, shoe industry *etc*.).

Mass customisation as an abstract business model has impact on product design, manufacturing, and assembly processes as well as logistics and information processing, *e.g.*, small lot sizes and increased diversity of variants. Four main issues should be considered (Piller and Stotko, 2002):

1 split of production process
2 flexible production control due to ex ante loose specification of products
3 information on individualisation throughout the value chain
4 unique identification of each product.

During the production process of mass customised goods, the so-called decoupling point indicates the point within the supply chain, which differentiates customised production from mass production; *i.e.*, after that point each former anonymous order is assigned to a specific customer. Mass customisation is characterised by defining the decoupling point after receiving the customer specific order. Individual configurations are created with regard to width and depth of variation. However, underlying production control processes, *e.g.*, production control, planning and scheduling, have to realise a high degree of flexibility, ensuring robust production processes – even in logistics networks – on the basis of ex ante imperfect product specifications. In consequence, production processes should be defined independently from specific configuration parameters. Furthermore, information of customised orders has to be propagated throughout the network as soon as possible.

The focus of this paper lies, in terms of mass customisation, on the effects of distributed value chains as well as on the importance of information management. Firstly, mass customisation scenarios in general consist of several independent players. For example, a vendor offers mass customisation products in the market, a retailer provides the configuration process, a network of contractually joined enterprises assemble or manufacture the product and a forwarder completes the order by delivering it to the customer. Among the difficulties of distributed production and logistics handling, the management of mass customisation orders throughout the value chain is one of the most relevant efforts. Insufficient coordination between players, exploited autonomy of each player and failure in information transmission are severe problems affecting smooth configuration, production and delivery of mass customisation products. Also, an essential target for mass customisation models is to optimise information management. The importance of information in the field of this concept is obvious: the customer's requirements have to be integrated in a product specification. In order to realise efficient and effective production of individual products, it is necessary to supply each player of the value chain with information about the product and customer. Thus, BIS could be used for efficient information management and will be introduced in the next paragraph.

2.2 *Business information systems*

From a technical perspective, Information Systems (IS) generally support acquisition, processing, storage, transmission and retrieval of information (Schwarze, 2000). In a broader understanding, IS include machine and human (sub-) systems in order to allocate information and communication technology under economic criteria (Krcmar and Schwarzer, 1999). In the context of business and economy, the main target of IS are management and control of information flow along the value chain. BIS can be classified into systems for administration, disposition, scheduling and controlling. BIS for administration are especially used to perform routine tasks on the basis of huge databases. While BIS as disposition applications support decision making in well-structured business cases, BIS for scheduling tasks assist irregular and semi-structured tasks. Lastly, BIS, applied on controlling tasks will enable the user to supervise and monitor business plans and realise specific objectives (Mertens, 2000).

2.2.1 *Types of integrated BIS*

IS, by themselves, are often implemented as monolithic systems for specific enterprises or applications. Due to the need for interaction and transmission of information between organisational units and even BIS of several companies, integrated BIS have been developed with various changing requirements in the last years. There are different forms of integration that can be distinguished. Beneath the degree of integration on the IS level (data, function, organisation, process *etc.*) the direction of integration is a proper classification: vertical versus horizontal integration. Horizontal integration refers to the conjunction between subsystems of the added value. Opposite to this, vertical integration focuses on coordination and conjunction between different detailed BIS (Picot and Reichwald, 1991).

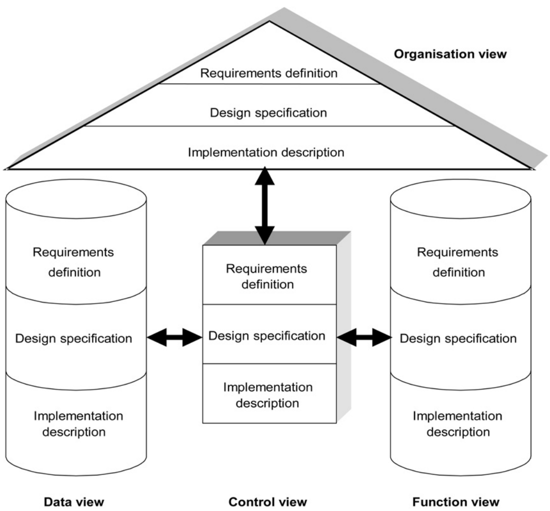
Although full integration of BIS on an intra- and interorganisational level (inside and between enterprises) is a theoretically ideal concept, connecting loosely coupled legacy systems as well as the missing flexibility of a resulting system should not be ignored. Depending on the business models of the value chain (types of business coordination), different kinds of IS adequately support the chain (Picot and Reichwald, 1991):

- BIS for accounting, analysing, reporting, planning and scheduling in a hierarchical organisation (as described above)
- BIS for interorganisational information exchange (electronic markets, EDI, ebXML *etc*.)
- BIS for supporting market transactions (for example: initiation – decision – fulfilment)
- BIS for computer supported cooperative work (group decision support systems, groupware systems).

2.2.2 Information system architectures

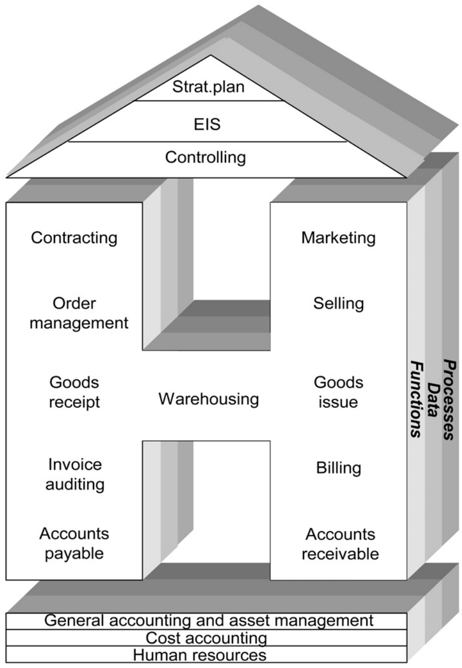
In order to design BIS for specific companies or branches, adoption of so-called Information Systems Architectures (ISA) have been successfully considered as an appropriate approach. An ISA describes all elements of IS and their relationships on a highly abstracted level. Two well-known representatives of business ISA are 'ARIS' (architecture for integrated information systems) (Scheer, 1995) and 'Handels-H' (especially designed for trading business) (Becker and Schütte, 1996) as shown in Figures 1 and 2.

Figure 1 ARIS



Source: Scheer (1995)

Figure 2 Handels-H



Source: Becker and Schütte (1996)

Objects of IS are all elements of an economic system (*e.g.*, resource, document, employee). In order to reduce its complexity, modelling of an economic system is divided into separate layers. Using this methodology, abstraction of the real world is gained from different perspectives. On the one hand, there are static layers: data, organisation or function. Dynamic layers like processes, on the other hand, represent the conjunction between each static layer, *e.g.*, description of where to (organisation) transport the invoice (data) after accounting control (function). By combining all levels, dependencies and interference are shown (cf. ARIS).

2.3 Coordination technologies for electronic business

The spreading of networked households, manufacturer, and suppliers provides the opportunity of small proximities within business partnerships or between consumer and OEM. Conceptually, there is no difference between electronic business (e-business) or partnerships in the *real* world (Adam and Yesha, 1996). However, implementing e-business with partially autonomous functionality requires specific features from information and communication technologies (Sandholm, 1998). Two main aspects have to be supported by computer systems in electronic business: coordination of participants and integration of e-business system and BIS (Parunak, 1999).

Earlier efforts in computer and information science have researched environments for collaborative work, workflow management systems and data interchange; *e.g.*, Electronic Data Interchange (EDI) (Hales and Lavery, 1991; Boss and Ritter, 1993). The spreading of internet technologies is leading to a new generation of application design. The change from developing a BIS to using service-based computing is tremendous. The service-based computing approach does not anymore assume, that a BIS or other computer system is developed for a specific application, but services of an enterprise are designed and implemented. If a BIS is in question, the web-based application should be able to identify, look-up and coordinate services, such that the primary functions of the applications can be fulfilled (Papazoglou and Georgakopulous, 2003). Thus, enterprises are providing services to other enterprises using techniques like Simple Object Access Protocol (SOAP, 2003), Web Services Description Language (WSDL, 2004), Universal Description Discovery, and Integration (UDDI, 2004), Web Services Flow Language (WSFL, 2004). These techniques allow enterprises to realise quasi-autonomous and automatic e-business applications if connected to ERP systems (Stafford, 2003). However, these approaches leak on semantics of information exchanged between cooperating partners. As long as standard products are in question, connection to ERP systems is sufficient, as semantics can be specified offline. Dealing with customised products or products with small lot sizes, costs of information exchange have increased significantly within this setting.

Another technique emerging in the context of the internet, ontologies, could be of interest here an ontology is an explicit specification of a concept; *i.e.* it can be referred to as a formal context description (Gruber, 1993). An important feature of ontologies is that computer programmes can be designed, which are able to understand and use it. In the context of the Semantic Web, the integration of heterogeneous information is particularly in question (Intelligent Information Integration) (Noy and Musen, 2002; Visser *et al*., 2002). These approaches are of high concern within e-business, especially computer-supported mass customisation, as they integrate heterogeneous systems (Paolucci *et al*., 2002).

Next to formal specification of products or orders and service directories, coordination techniques are important for computer-supported mass customisation. The approach of Intelligent Agents seems to be promising (Jennings and Wooldridge, 1998) and will be introduced in the next section.

3 Agent-mediated mass customisation

Intelligent Agents and multiagent systems represent a modern approach in Artificial Intelligence (Ferber, 1999). Since the early 1990s, cooperative multiagent systems and Intelligent Agents are of increasing concern within software engineering of large-scale distributed systems. In the last years, multiagent systems have become a leading edge technology (Luck *et al*., 2003).

Multiagent systems consist of distributed computational entities, the so-called agents. From the implementation point of view, they are comparable to objects, realised by using mainly object-oriented programming approaches. However, the design of Intelligent Agents requires sophisticated analysing and modelling as used for expert system design. The design and implementation of multiagent systems use the service-based computing paradigm introduced in the last section. Agents are capable of sensing their environment and reacting according to the situation they perceive. Agents are goal-oriented, *i.e.*, they get tasks and pursue them subsequently (Wooldridge, 1999). In contrast to objects, Intelligent Agents are autonomous in their behaviour. They pursue goals, but are able to choose the concrete realisation of the goal or choose the next goal to pursue. The autonomy is restricted to the scope granted by the instructing entity. To enable Intelligent Agents with such a behaviour, mental states and an explicit knowledge representation is integrated (Weiss, 1999).

Agents situated in an environment are able to cooperate in dealing with limited resources or conflict resolution (Durfee and Rosenschein, 1994). Working concurrently with other agents and restricted resources requires coordination skills and proper social behaviour, *i.e.*, they must be able to communicate and cooperate to reach their goals. Therefore, the most important feature of a cooperative multiagent system is the communication between its agents (Haddadi, 1996). The communication language determines the power of expression and therefore the problem-solving capabilities and the efficiency. Furthermore, agents need to know their own competence and the existence as well as competence of other agents. This enables them to act in open systems. In particular, they need the capability to recognise agents entering or leaving the system. Internally, agents have their own views of their environment, and they need to adapt to and learn from changes that occur at runtime (Timm *et al*., 2001a).

The application of agent technology to mass customisation has been researched in several publications. Aspects of agent-based support for mass customisation in networks of Small- and Medium-Sized Enterprises (SME) are discussed in Timm *et al*. (2001c). A communication protocol for software agents within mass customisation is described in Turowski (2002).

3.1 Distributed supply chains

Global competition forces companies to deal with new challenges, especially those concerning the customer side. Challenges like flexibly manufactured products available worldwide and flexible services have to be faced by each company trying to stay competitive. The result is a concentration on the producers' core competences and following the trend to cooperate. Outsourcing and merging, ranging from short- to long-term, force enterprises to change significantly (Jäger and Boucke, 1999). Products are not only made by a single company but by a cooperating network of companies. But even these networks do not have to be static during the production processes, *i.e.*, structural changes are quite normal. This yields the introduction of the term 'temporal logistics networks' (Knirsch and Timm, 1999). Of course, these changing environments have a dramatic impetus on the participating players. On the one hand, they have to realise these changes and react to them sensibly. On the other hand, they also could be or become part of it (Dinges and Büttner, 1996). For cooperating within temporal logistics networks, detailed exchange of information between the participating companies is necessary. However, as the period of cooperation does not have to be persistent, an individual solution for information interchange is far too expensive. Thus, a technology is needed, enabling enterprises to provide their competences to a network as well as to coordinate ongoing activities, Doing so, this technology has to be flexible in a way, that it can overcome existing information system barriers.

Intelligent Agents and multiagent systems seem to be a promising approach for application in computer-mediated supply webs. Supporting the management and integration of the planning, scheduling and controlling processes, they can be used as 'enterprise delegates' (Timm, 2001). Computer-mediated supply webs have to handle critical paths, bottlenecks and risk of failures along actual paths (*e.g.*, accidents) to meet the strict just-in-time requirements in real-time. Summarising, agents have to provide the following functionalities (Timm *et al.*, 2001c):

- knowledge about internal structures and organisations
- awareness of other players in the environment
- perceive changes in their environment
- ability to communicate, cooperate and coordinate with other agents.

3.2 Agents in the manufacturing domain

Modern manufacturing needs flexible and adaptive concepts for production control to meet market requirements. Knowledge about products and the necessary manufacturing operations have to be handled within production control to enable just-in-time planning as well as reconfiguration of schedules in the case of unforeseen situations, *e.g.*, defective machine tool (Tönshoff and Teunis, 1998).

Several applications of agent technology in manufacturing focus on digital marketplaces where intelligent agents act on behalf of enterprises, customer or other organisations to achieve goals like acquiring a specific good for the smallest possible price (Parunak, 1999). Since enterprises have begun to consider several departments as individual profit centres, market-based coordination mechanisms become of increasing concern not only for inter-enterprise relationship but also for internal processes of enterprises like scheduling tasks at the shop floor.

With respect to manufacturing of customised products in small lot sizes in batch job production, scheduling becomes a distributed problem: orders have to be manufactured by different resources located at different places at the shop floor. Each resource possesses its own schedule, its own capabilities to perform different manufacturing operations and its own economical profile (*e.g.*, specific machining costs). On the other hand, orders need to be manufactured according to customer's requirements and due dates. From point of view of the shop floor, an order schedule must be 'calculated' in cooperation of order and resources, where each individual resource decides on the price it will offer its capabilities to the order. Unfortunately, the structure of the shop floor and the orders is not a static one since new machines are taken into operation, others suffer breakdowns, or typical orders change due to altered customer's demands. The shop floor for customised manufacturing is a very dynamic environment (Tönshoff *et al.*, 2002). Recent research projects deal with shop floor planning problems, *e.g.*, by improving scheduling with respect to robustness and dynamic distributed environments (Frey *et al.*, 2003). However, agent technology may also be used to overcome existing traditional limitations in today's manufacturing systems (Maríк *et al.*, 2002).

3.3 Product models

Different information has to be handled for manufacturing of a specific product. These information as well as other relevant information of the production engineering domain could be represented by three major information models: product model, resource model and process model (Timm *et al.*, 2001b). The amount of information rises due to higher product complexity and an increasing number of variants. Furthermore, improvements in the field of manufacturing processes lead to complex manufacturing knowledge. Thus, efficient information management turns out to be a key technology in the future.

In addition, a second bottleneck can be identified. The information flow can be separated into two major flows: one flow focusing on technological details of the product and another one on preserving economical or administrative information, *e.g.*, due dates, priorities, costs, *etc*. The separated information flows correspond to strong borderlines that exist between process planning, production control and scheduling systems. The traditional approach of separating planning activities (*e.g.*, process planning) from implementing activities (*e.g.*, production control and scheduling) results in a gap between the involved systems. It implies loss of time, information and consequently, loss of quality and prolonged time-to-market.

These problems are even more intensive when mass customisation strategies are in question. The interesting aspects of mass customisation product models are two-fold. On the one hand, the standardised aspects of the product and on the other hand individual, customer-selected requirements or specifications have to be handled. These two descriptions are discriminated by the decoupling point as introduced in supply chain management. However, it can hardly be assumed, that only management and spreading of the customer's specification part and an identifier for mass product part is sufficient for production. Each part of the value chain needs specific information on the whole product. This situation should be overcome by the application of techniques as ontologies and intelligent agents use knowledge explicitly.

4 Case study: EwoMacs

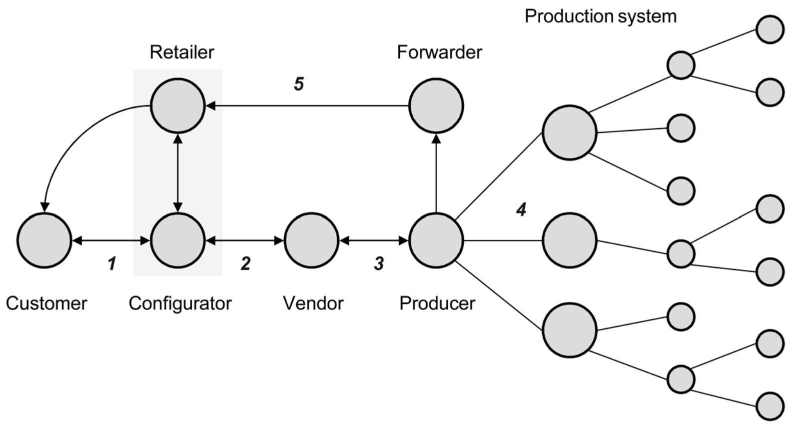
EwoMacs is a joint research project dealing with logistics of mass customisation in the shoe industry. The main target of EwoMacs is to analyse logistic structures and to develop an adaptable business model for mass customisation in the field of custom-made shoes. The project consortium consists of three research partners and five industrial companies and is funded by the German Federal Ministry for Education and Research (BMBF, 2002–2004, 02PD1120). Two of the industrial partners provide special domain knowledge: Adidas-Salomon AG (Mass Customisation project 'miAdidas') and selve AG.

Nowadays, the shoe industry is still characterised by a low level of automation and lack of modern production and logistics processes. This situation becomes more complicated since each customer requests custom-made shoes (colour, form *etc.*) at low costs. For this reason, the shoe industry has to handle two consequences within mass customisation: On the one hand, systems for connecting handwork and machinery must be established. This entails high fixed charges. But on the other hand this results in reduction of stock and return of shoes. Shoes are no longer produced in an estimated number of variety but according to the customer's specification.

Regarding the shoe industry, another research project has been focusing on the production processes of customised shoes: 'EUROShoE'.[1] In contrast to that project, 'EwoMacs' deals with the whole value chain. Because of the importance of logistics and information flow (information logistics) there is an effort to develop an integrative view on mass customisation scenarios.

Typical players in a mass customisation value chain for shoes are depicted in Figure 3. Starting point is the interaction between customer and a configuration system. This could be done by either hardware or software systems (or both), which support the process of formalising the customer's desire into a product specification (1). Finished orders are transmitted to the vendor of the shoes (2). An optional retailer may act as an intermediary (shop-in-shop for example). The vendor might be the producer of the shoes but is not required. The vendor sends order and product specification to the production system (3). Fabrication is finally coordinated by the producer and consists of planning, scheduling, supplying and producing processes (4). A forwarder carries the finished product to the vendor, retailer or directly to the customer (5).

Figure 3 Aggregated view on mass customisation players



The global view emphasises the distributed value net. An obvious problem in this constellation is production, for example, which is considered as a black-box. Because of the contractual cooperation of vendor and the production network there is hardly a chance for influence and transparency. Although 'EwoMacs' does not mainly focus on the production process, there is a need for seamless communication between these participants. This is a precondition for tracking and tracing or managing of the order process. This scenario is used for design and implementation of the DAISIY approach introduced in Section 5.

5 The DAISIY approach

In the domain of mass customisation, complex and highly distributed systems are under research. As mentioned before, we are assuming, that future BIS will use service-based computing, *i.e.*, web services and networking infrastructures like the internet, for collaborative business. The DAISIY approach is based on these assumptions and tries to realise a distributed system for management, control, and simulation of mass customisation with special respect to its logistics. The simulation is a very important aspect of the overall concept. Instead of developing a single system supporting mass customisation in the real world, the simulation is used for analysis and identification of scaling up problems, *etc*. Simulation systems are designed to analyse the domain as well as realise software systems especially for management and control of information flows and business processes. Furthermore, a highly distributed system, which contains modules and autonomous programming units from heterogeneous enterprises, can hardly be tested properly. Thus, simulation is also used for ensuring reliable behaviour of the system. The approaches to this domain are two-fold. On the one hand, simulation systems are used for analysing the domain, planning and reengineering of business processes. On the other hand, development of management and control systems for information flow and business processes is of interest.

The Institute of Business Administration, B.A. Information Systems II at University of Hohenheim is developing the software framework DAISIY1 (Deliberative Agents for Intelligent SImulation SYstems) as an integrated analysis, design, simulation, and implementation methodology. DAISIY represents a generic approach to simulation of domains as well as implementation of information systems. This approach will be evaluated using projects in the domain of health and manufacturing logistics.

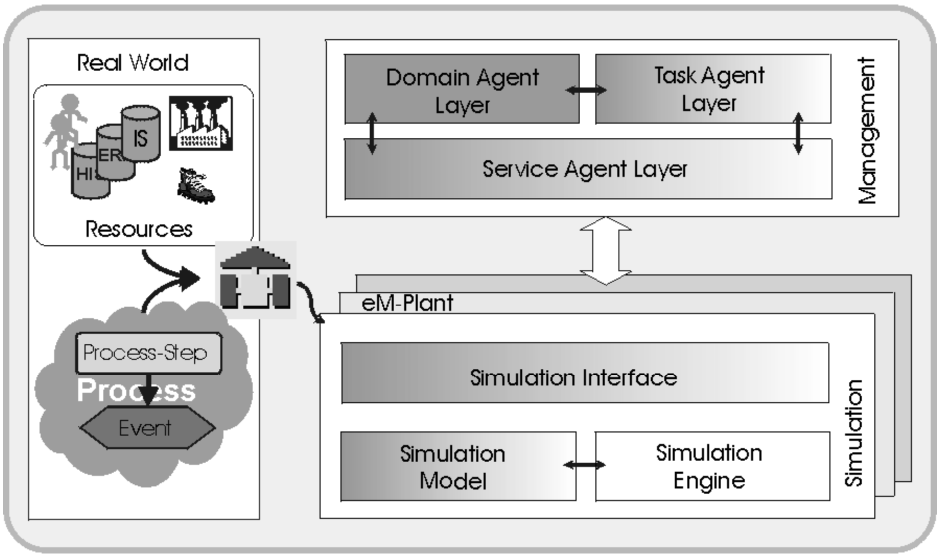
The DAISIY framework will be adapted and applied to EwoMacs. DAISIY integrates a methodology as well as a system architecture for simulation of business processes in logistics networks. The aim of DAISIY is to guide researchers by analysing the domain, designing processes, and implementing an agent-based simulation system for a specific scenario.

Therefore, DAISIY introduces a five-step methodology:

1. Business process modelling using a standard language and tool, *e.g.*, ARIS-Toolset.
2. Transfer of these model into a simulation model, *e.g.*, Simple++ (eM-Plant).
3. Automatic synthesis of generic agent systems from simulation and business process models.
4. Enhancement of the agent model: Intelligent Agents as substitution for agents along critical paths, in order to preserve structure and behaviour of organisations and real world players.
5. Detailed simulation using the multiagent system is performed.

Extending the simulation approach to get a real-time agent-based information system, the methodology has to be rebuilt from a sequential, step-based methodology to a more nested, cyclic one. For example, online information exchange from real world information sources as well as to real world players has to be implemented as a permanent task. Based on a layered architecture in the DAISIY framework three aspects: real world, simulation and management, are considered. These aspects are addressed to introduce respective components: modelling for the real world, multiagent system and simulation. The architecture of this framework including conceptual design of the components can be found in Figure 4.

Figure 4 DAISIY framework



Modelling business processes, organisation and data structures of the real world takes place by using standard modelling tools. These models are used for integrating real world aspects and simulation models. The resulting simulation models combined with a simulation engine establish a virtual reality for agents. Temporal and spatial dimensions are generated by the simulation component to realise simulation close to reality. According to this, the simulation aspects are considered by the use of a simulation system and agents. The management aspects are considered within the multiagent system. We propose a layered multiagent system, the DAISIY system. Embedded in the system are virtual reality agents classified according to three purposes. Each class is realised within a layer assigning each agent with specific tasks, which are domain-dependent (Domain Agent Layer), domain-independent (Task Agent Layer), or services relevant to the DAISIY framework (Service Agent Layer).

Management aspects pertaining to the system's operations are supported by agents of the Service Agent Layer. This includes agents for system introspection, agents that interpret and visualise simulation results, and agents enabling the interoperability of the framework components. According to this, service agents perform the synchronisation and information exchange of the simulation environment and domain-specific agents.

The Domain Agent Layer consists of representation agents which can be human, abstracted organisational units, or technical equipment (*e.g.*, machine tool). These agents incorporate profiles, preferences, or simple decision rules of the real world entities. Embedded in the virtual reality, inter-agent operations, *e.g.*, conversation, can be simulated under the restrictions of spatial relations. Task agents, as they are included in the Task Agent Layer, support these activities by offering generic functionalities like complex scheduling algorithms. Otherwise, these functionalities have to be internalised in the domain-specific agents.

6 Perspectives on future business information systems

Developing BIS for mass customisation leads to requirements, which have to be addressed with a very specific approach (ISA). The required changes of BIS caused by mass customisation are related to the strong demand for high quality of information throughout the whole value chain. The following three aspects, having heavy impact on BIS have been identified:

1. customer integration
2. information flow throughout the value chain
3. loss of autonomy.

In the next subsections these three aspects are discussed and implications on future BIS are summarised.

6.1 Computer-supported mass customisation

Mass customisation initiates new relevance of customer integration, which reaches from co-design of products up to maintenance. Next to customer relationship management, there are new requirements occurring during the configuration of customisable goods. This leads to customer-related production or integration of the customer or the customer's requirements into the whole production process.

Depending on the kind of mass customised products, the customer is involved in the configuration process only or influences the whole value chain directly. This causes the requirement for accessing configuration data in any step of the value chain. A mandatory requirement for BIS in the context of Mass Customisation is that the individualised configuration can be translated into a formal requirements model (*e.g.*, product model). On the basis of this model, a one-to-one equation, which consistently describes the configuration, could be created. Modern information logistics has to ensure that this equation is available at any process step within the value chain.

Beneath customer integration and management of the information flow, a third aspect is very specific for mass customisation: enterprises offering mass customisation products will lose parts of their autonomy. Major parts of the value chain are influenced by the customer's requirements (*e.g.*, configuration or production). Products are no longer offered in a fixed range of variations. The customer himself chooses one-to-many desired product features. This degree of freedom for the customer implies an access to internal information, processes and structures of the company as well as the product. As known from the process of creating services in case of mass customisation the customer is an external factor. Therefore, there is a temporal and spatial dependency between configuration, production and customer's appearance. Thus, the customer influences the value chain more directly as opposed to the traditional way of selling mass products, where the customer is 'just' the purchaser of the goods. By resuming these aspects, two main characteristics have to be mentioned:

1. dynamics in the value chain
2. complex information because of the customer's requirements.

Both of them are originally less important for traditional mass production, but they have great impact on the mass customisation process. The dynamics in the value chain is a result of loosely coupled enterprises. To realise seamless cooperation and communication, it is necessary to have methods for an intelligent coordination between each player. Customer information and configuration data must be integrated into the supply chain. They also have to be available in each step of production. But in addition, fabrication has partly to start before obtaining the product specification of the customer. Therefore, parts of the value chain are very customer-centred and some are independent from the specific order. An appropriate insight into the structure of the product is essential.

6.2 Future business information systems

As mentioned in Section 2, we are assuming an increasing impact of network and mobile technology on BIS. Furthermore, the impact of the paradigm shift in programme design from object-oriented to service-based computing will influence modern system design dramatically. This will lead to e-business applications and networks with autonomous decision-makers, who are able to connect to services on the basis of syntactical service descriptions. Thus, there is no automatic handling of meaning, *i.e.*, service and BIS have to be integrated manually. The human effort for developing integrated e-business application will be high. However, that is not a problem, if there is a simple product structure used or the linkage is used over a long term ('static' cooperation relationships). In the case of mass customisation, where a new configuration could be an unidentified product there is need for more sophisticated solutions. Information, which contain formal description of meaning (semantics) are needed, *e.g.*, in form of an ontology, and have to be processed adequately. Therefore we propose an Intelligent Agent approach.

6.3 Challenges for agent technology

In this section we are going to derive specific instruments to close the gap between common BIS and mass customisation. Recent applications usually focus on intra-enterprise information logistics only; there is further need of an integrating approach for implementation of information interchange between cooperating companies. Here, problems of data privacy and security arise when two or more independent companies are interconnected. Only uncritical data needed for the common processes should be exchanged. In addition, owing to heterogeneous BIS, there is a problem in automatic negotiation within industry-wide cooperation relations. This problem is enforced by missing or inadequate standardisations for data exchange and various, partially contradictory definitions of used concepts; first, approaches are researching the use of web services within agent systems to overcome this problem (Lyell *et al.*, 2002). To address this problem and enable flexible and temporal logistics networks, we propose an adaptive cooperative multiagent approach as introduced in Section 5. This approach is based on Intelligent Agents, which represent essential parts of the supply web especially supporting logistics tasks. The multiagent system is providing a framework for modelling and simulation of cooperation within short-term relationships as needed for temporal logistics networks.

In addition, traditional BIS should be evaluated with respect to the described mass customisation specific aspects. Modelling of intra-organisational structure is necessary to represent the distributed supply chain or supply web. As mass customisation goods cannot be qualified by a single article number (EAN – European Article Number *etc.*) only, the modelling of product structure must be allowed to specify standard and customised components, amount of individualisation option and its values and interdependency between all components. In this context, the influence as well as new opportunities for new identification technologies, like RFID, should be considered.

7 Conclusion

In this paper, we discussed new trends in BIS as well as information and communication technologies. In expectation of the integration of these developments to future BIS, we address the question, "What is missing in the application of mass customisation?" The main impact of mass customisation on the design of future BIS is that there is no simple economical information flow left for managing the value chain, and yet all participants of this chain need sophisticated information. Thus, simple product information in future BIS have to be enriched by meaning, such that computer systems can automatically reason about information. Furthermore, the question occurs if scaling up of mass customisation 'test-beds' is possible. If it is not possible to establish robust business information systems for mass customisation, this strategy will only be a temporary fashion for enterprises.

Consequently, an innovative approach for computer-supported mass customisation should provide solutions for the above-mentioned problems of sophisticated information logistics and scaling-up of mass customisation 'test-beds'. In the DAISIY approach presented in this paper, we are introducing a framework for modelling, design, implementation, simulation and realisation of an agent-based system for support of mass customisation. We address the two problems with simulation and use of agent technology. The simulation abilities of the DAISIY approach should guide the user in modelling and analysing current logistics structure used for mass customisation production as well as enable the user to simulate logistics structures using different numbers for amount of orders, production capacities, *etc*. The problem of sophisticated information is handled in the DAISIY system by using Intelligent Agent technologies. Semantics of information are included explicitly within the system using ontologies. Thus, agents serve as front ends of traditional or future BIS and provide sophisticated information to other parts of the mass customisation value chain.

The DAISIY approach is applied to the logistics structures of the shoe industry using the case studies of our industrial project partners. A first prototype has been implemented on the basis of these models. The approach seems to be adequate but this has to be proven using simulation results. As a next step, we are going to analyse and simulate the behaviour of the simple agents and simulate throughput time.

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References

Adam, N.R. and Yesha, Y. (1996) *Electronic Commerce – Current Research Issues and Applications*, Berlin: Springer.

Becker, J. and Schütte, R. (1996) *Handelsinformationssysteme, moderne industrie*, Landsberg/Lech.

Boss, A.H. and Ritter, J.B. (1993) 'Electronic data interchange agreements: a guide and sourcebook', *International Chamber of Commerce*, Paris.

Dinges, M. and Büttner, M. (1996) 'Effiziente logistik durch integration von dienstleistern', in A.D. Little (Ed.) *Management im vernetzten Unternehmen*, Gabler, Wiesbaden.

Durfee, E.H. and Rosenschein, J.S. (1994) 'Distributed problem solving and multi-agent systems: comparisons and examples', *Proceedings of the 13th International Distributed Artificial Intelligence Workshop*, Seattle, Washington, pp.94–104.

Ferber, J. (1999) *Multi-Agent Systems – An Introduction to Distributed Artificial Intelligence*, Harlow, UK: Addison-Wesley.

Frey, D., Stockheim, T., Woelk, P-O. and Zimmermann, R. (2003) 'Integrated multi-agent-based supply chain management', *Proceedings of IEEE International Workshops on Enabling Technologies, Infrastructure for Collaborative Enterprises (WETICE03)*, Linz.

Gilmore, J.H. and Pine, II, B.J. (1997) 'The four faces of mass customization', *Harvard Business Review*, Vol. 75, No. 1, pp.91–101.

Gruber, Th.R. (1993) 'A translation approach to portable ontology specifications', *Journal of Knowledge Acquisition*, Vol. 5, No. 2, pp.199–220.

Haddadi, A. (1996) *Communication and Cooperation in Agent Systems – A Pragmatic Theory*, Berlin: Springer.

Hales, K. and Lavery, M. (1991) 'Workflow management software: the business opportunity', *Ovum Report*.

Jäger, Ch. and Boucke, B. (1999) 'Strukturen und Typen – Ausrichtung der Organsiationsstruktur', in H-J. Warnecke and J. Braun (Eds.) *Vom Fraktal zum Produktionsnetzwerk. Unternehmenskooperationen erfolgreich gestalten*, Berlin: Springer, pp.93–124.

Jennings, N.R. and Wooldridge, M.J. (1998) *Agent Technology. Foundations, Applications, and Markets*, Berlin: Springer.

Knirsch, P. and Timm, I.J. (1999) 'Adaptive multiagent systems applied on temporal logistics network', in M. Muffatto and K.S. Pawar (Eds.) *Logistics in the Information Age, Proceedings of the 4th International Symposium on Logistics (ISL-99)*, ISBN 88–86281–37–4, Florence, Italy: SGE Ditoriali, Padova, pp.213–218.

Krcmar, H. and Schwarzer, B. (1999) *Wirtschaftsinformatik, Grundzüge der betrieblichen Datenverarbeitung*, Schäffer-Poeschel, Stuttgart.

Luck, M., Mc Burney, P. and Preist, Ch. (2003) 'Agent technology: enabling next generation computing – a roadmap for agent based computing, version 1.0', *Technical Report of AgentLink II, European Network of Excellence for Agent-Based Comuting (IST-1999–2003)*, Southampton, UK: Department of Electronics and Computer Science, University of Southampton, Southampton, SO17 1BJ, UK.

Lyell, M., Casagni, M. and Rosen, L. (2002) 'Standards-based interoperation of software agent systems with legacy and web-centric enterprise applications', *Proceedings of MAI '02: International Workshop on Multiagent Interoperability. 25th German Conference on Artificial Intelligence (KI-2002)*, Aachen, pp.55–64.

Maríl, V., Camarinha-Matos, L.M. and Afsarmanesh, H. (2002) 'Knowledge and technology integration in products and services', *Proceedings Balancing Knowledge and Technology in Product and Service Life Cycle (BASYS '02)*, Cancun, Mexico.

Mertens, P. (2000) *Integrierte Informationsverarbeitung 1*, Gabler, Wiesbaden.

Noy, N.F. and Musen, M.A. (2002) 'Evaluating ontology mapping tools: requirements and experience', *Proceedings of the Workshop on Evaluation of Ontology Tools at EKAW'02 (EON2002)*, Siguenza, Spain.

Paolucci, M., Kawamura, T., Payne, T.R. and Sycara, K. (2002) 'Semantic matching of web services capabilities', *Proceedings of the 1st International Semantic Web Conference (ISWC2002)*, Sardinia, Italy.

Papazoglou, M.P. and Georgakopoulos, D. (2003) 'Service-oriented computing', *Communications of the ACM*, Vol. 46, No. 10, pp.25–28.

Parunak, H.V.D. (1999) 'Industrial and practical applications of DAI', in G. Weiss (Ed.) *Multiagent Systems – A Modern Approach to Distributed Artificial Intelligence*, Cambridge: The MIT Press, pp.377–424.

Picot, A. and Reichwald, R. (1991) 'Informationswirtschaft', in E. Heinen (Ed.) *Industriebetriebslehre – Entscheidungen im Industriebetrieb*, Gabler, Wiesbaden, pp.241–393.

Piller, F.T. (2003) *Mass Customization: Ein wettbewerbsstrategisches Konzept im Informationszeitalter*, 3rd edition, Gabler, Wiesbaden.

Piller, F.T. and Stotko, Ch.M. (2002) 'Mass customization: four approaches to deliver customized products and services with mass production efficiency', *Proceedings to the 2002 IEEE International Engineering Management Conference. Managing Technology for the New Economy*, Cambridge, UK, pp.773–778.

Pine, II, B.J. (1993) *Mass Customization: The New Frontier in Business Competition*, Boston: Harvard Business School Press.

Porter, M. (1999) *Competitive Advantage: Creating and Sustaining Superior Performance*, New York: Free Press.

Sandholm, T. (1998) 'Agents in electronic commerce: component technologies for automated negotiation and coalition formation', in M. Klusch and G. Weiss (Eds.) *Cooperative Information Agents II: Learning, Mobility and Electronic Commerce for Information Discovery on the Internet*, Berlin: Springer, pp.113–134.

Scheer, A-W. (1995) *Wirtschaftsinformatik, Referenzmodelle für industrielle Geschäftsprozesse*, Berlin: Springer.

Schwarze, J. (2000) *Einführung in die Wirtschaftsinformatik*, Verlag Neue Wirtschafts-Briefe, Herne.

Simple Object Access Protocol (SOAP) (2003) *Simple Object Access Protocol V 1.1*, viewed 30 August 2004, http://www.w3.org/TR/SOAP/

Stafford, Th.F. (2003) 'E-services', *Communications of the ACM*, Vol. 46, No. 6, pp.26–34.

Timm, I.J. (2001) 'Enterprise agents solving problems: the cobac-approach', in K. Bauknecht, W. Brauer and Th. Mueck (Eds.) *Informatik 2001 – Tagungsband der GI/OCG Jahrestagung*, Wien, pp.952–958.

Timm, I.J., Tönshoff, H.K., Herzog, O. and Woelk, P-O. (2001a) 'Synthesis and adaption of multiagent communication protocols in the production engineering domain', *Proceedings of the 3rd International Workshop on Emergent Synthesis (IWES '01)*, Bled, Slovenia, pp.73–82.

Timm, I.J., Tönshoff, H-K., Herzog, O. and Woelk, P-O. (2001b) 'Adaptive production control emerging from the cooperation of intelligent agents', in B. Katalinic (Ed.) *Intelligent Manufacturing and Automation: Focus on Precision Engineering*, pp.485–486.

Timm, I.J., Woelk, P-O., Knirsch, P., Tönshoff, H.K. and Herzog, O. (2001c) 'Flexible mass customization: managing its information logistics using adaptive co-operative multiagent systems', in K.S. Pawar and M. Muffatto (Eds.) *Logistics and the Digital Economy*, Salzburg, Austria, pp.227–232.

Tönshoff, H.K. and Teunis, G. (1998) 'Modular shop control toolkit for flexible manufacturing', *Production Engineering*, Vol. 5, No. 2, pp.111–114.

Tönshoff, H.K., Woelk, P-O., Herzog, O., Timm, I.J. and Böß, V. (2002) 'Agent-based in-house process planning and production control for enterprises in supply chains', *Proceedings of the 12th International Conference on Flexible Automation and Intelligent Manufacturing*, Dresden, pp.329–338.

Turowski, K. (2002) 'Agent-based e-commerce in case of mass customization', *International Journal of Production Economics*, Vol. 75, Nos. 1–2, pp.69–81.

Universal Description, Discovery and Integration (UDDI) (2004) *Universal Description, Discovery, and Integration*, viewed 30 August, http://www.uddi.org/specification.html

Visser, U., Stuckenschmidt, H., Schlieder, Ch., Wache, H. and Timm, I. (2002) 'Terminology integration for the management of distributed information resources', *Künstliche Intelligenz*, Vol. 16, No. 1, pp.31–34.

Weiss, G. (1999) *Multiagent Systems – A Modern Approach to Distributed Artificial Intelligence*, Cambridge, MA: The MIT Press.

Wooldridge, M. (1999) 'Intelligent agents', in G. Weiss (Ed.) *Multiagent Systems – A Modern Approach to Distributed Artificial Intelligence*, Cambridge: The MIT Press, pp.27–78.

Web Services Description Language (WSDL) (2004) *Web Services Description Language*, viewed 30 August, http://www.w3.org/TR/wsdl.html

Web Services Flow Language (WSFL) (2004) *Web Services Flow Language V 1.0*, viewed 30 August, http://www-3.ibm.com/software/solutions/webservices/pdf/WSFL.pdf

Notes

1 www.euro-shoe.net

2 http://www.ewomacs.de