

Characterization and Evaluation of Just-In-Time Production and Distribution

Paul Davidsson and Fredrik Wernstedt

Department of Software Engineering and Computer Science

Blekinge Institute of Technology

Soft Center, 372 25 Ronneby, Sweden

{Paul.Davidsson, Fredrik.Wernstedt}@bth.se

Abstract. We study the applicability of multi-agent systems to just-in-time distribution networks. The goal is to create and evaluate sets of intelligent agents that can cooperatively support supply network production and distribution decisions. A short description of supply networks and the just-in-time philosophy is given, as well as a formal characterization of the problem space under investigation. We outline a general simulator which allows for a systematic evaluation of different multi-agent approaches across the different parts of this problem space. This is illustrated by a case study on district heating systems. A major concern in this domain, and other just-in-time domains, is how to cope with the uncertainty caused by the discrepancies between the estimated and the actual consumer demand. Another concern is the temporal constraints imposed by the relatively long production and/or distribution times that typically are present in this domain. In the case study we show how to lessen the impact of these problems by the usage of agent clusters and redistribution of resources.

1. Introduction

Manufacturing strategies has moved from large mass to small batch production, driven by rapid changes in customer demands [1]. A typical supply chain faces uncertainty in terms of both supply and demand. Thus, one of the most common problems faced by managers concerning production decisions is to anticipate the future requirements of customers. Something, which typically results in one of following two symptoms: *overproduction*, or *shortages*.

Large errors in prediction lead to large discrepancies between production and actual demand. This results in higher inventory costs, i.e., larger buffers are needed and/or the worth, or quality, of the products in the buffers decrease over time (deterioration). To deal with this problem, Just-In-Time (JIT) strategies have been developed. However, the

tendency of such strategies to shrink buffer sizes increases the frequency with which a system is likely to exceed a buffer capacity, resulting in a nonlinear behavior of the system [2]. Furthermore, if a manufacturer supplies parts to a JIT-oriented customer, the production may have to be adjusted on a short time basis, adding to the dynamics since one cannot assume linear production capacity [1], and finally the distribution network must be streamlined to provide for quick transportation of commodities.

The objective of the work presented in this paper is to investigate which multi-agent-based approaches are suitable for JIT production and distribution. Many interesting agent-based approaches to supply-chain management has been suggested, e.g., Collins et al. [3], Fox et al. [4], Labrou et al. [5], Marsh et al. [6], Parunak et al. [7], and Wagner et al. [8]. Thus, it can be argued that time has come to try to develop methods and tools for systematic evaluation of these (and other) approaches in different types of supply-chain problems.

In the next section we give a short description of supply networks and the JIT philosophy. This is followed by a formal characterization of the problem space under investigation. We then outline a general simulator of production and distribution domains and argue that this type of simulator allows for a systematic evaluation of different multi-agent approaches across the different parts of this problem space. A major concern in this domain is how to cope with the uncertainty caused by the discrepancies between estimated and real demand. Another concern is the temporal constraints imposed by the relatively long production and/or distribution times (compared to the storage and/or consumption times) that typically is present in this domain. Finally, a case study concerning district heating systems is described. We show how to lessen the impact of these problems by the usage of agent clusters and redistribution of resources.

2. Supply Networks and Just-In-Time Strategies

A supply chain is a network of autonomous or semiautonomous suppliers, factories, and distributors, through which raw materials are acquired, refined and delivered to customers. According to the simplified view that we will adopt here, and which is illustrated in Fig. 1, supply networks can be outlined as an hourglass shape [7]. Moreover, we will here focus only on the distribution part of the supply network, i.e., the manufacturers, the distributors, and the consumers. Of course, a supply chain is sometimes more complex with multiple end products that share components or facilities. The flow of material is not always along a tree structure, e.g., there could be various modes of transportation. Also, distribution, manufacturing and purchasing organizations along the supply chain often operates independently and have their own objectives, which may be in conflict. However, we believe that the simplifications made do not change the applicability of the general approach we are suggesting.

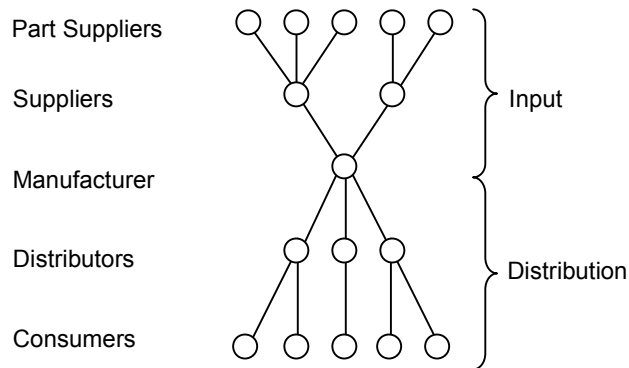


Fig. 1. The hourglass shape of a simple supply network

Supply chain management is generally considered to lie between systems with fully vertically integrated facilities, where the entire material flow has a single owner, and those systems where each member operates independently. Thus, coordination between the various players in the chain is of most importance. Four of the major decision areas in supply chain management are [9]:

- Location of facilities: determines the possible paths by which resources flows through to the final customer.
- Production decisions: determines the capacity of the manufacturing facilities.
- Inventory decisions: determines the size of the buffers (taking into account any uncertainty that might exist in the supply chain).
- Transportation decisions: these are normally a trade-off between cost for the transportation and the cost for the inventory capacity.

The term JIT, used for instance to describe the delivery of electricity to a customer, suggests that electricity will be delivered to the customer's location and consumed upon arrival. JIT has been widely implemented in manufacturing industries as a survival strategy against global market competition [10]. Monden [11] gives a brief definition of JIT as "producing the necessary items, in the necessary quantities at the necessary time".

The primary objective of JIT is generally seen as waste elimination. Elimination is generally achieved by minimizing inventory and delaying production and distribution of commodities as long as possible. A selection of the sources of waste that the father of JIT, Taiichi Ohno at Toyota motor company, identified is [12]:

- overproduction,
- transportation/movement,
- processing products longer than necessary, and
- inventory.

Various benefits of JIT have been widely discussed in literature. However, most success stories take place in large manufacturers with stable demand, such as the automotive and electronic industries.

3. A Formal Characterization of the Problem Domain

In this section, we formally define the problem space under investigation, i.e., the distribution part of the supply network, see Fig. 2. Thus, we will not model the complete supply chain network, e.g., the details of the manufacturing process within the producer and interaction with sub-contractors are not modeled.

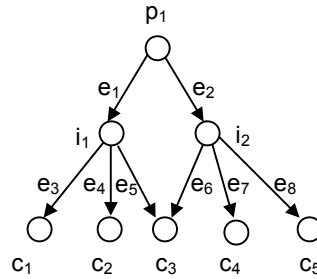


Fig. 2. An example of a simple production and distribution network.

We divide the description of the production and distribution network in three parts, *production*, *distribution* and *consumption*.

Production. Let $P = \{p_1, \dots, p_n\}$ be the set of all producers and $K = \{k_1, \dots, k_m\}$ be the set of all commodities. Then we denote;

- the production time $TP = \{tp_j^i : i \in P, j \in K\}$,
- the production cost, $CP = \{cp_j^i : i \in P, j \in K\}$,
- the production capacity, $PC = \{pc_j^i : i \in P, j \in K\}$, and
- the actual production as a function of time, $Pr(t) = \{pr_j^i(t) : i \in P, j \in K\}$

Distribution. Let the distribution network $N = (DN, E)$ be a directed acyclic graph, where $DN = \{P, C, I\}$ is the set of all nodes, $I = \{i_1, \dots, i_r\}$ is the set of all internal distribution nodes, C is the set of all consumers (defined below), and $E = \{e_1, \dots, e_q\}$ is the set of all edges. Then we denote;

- the distribution time, $TD = \{td_j^i : i \in E, j \in K\}$,

- the distribution cost, $CD = \{cd_j^i : i \in E, j \in K\}$,
- the distribution capacity, $DC = \{dc_j^i : i \in E, j \in K\}$,
- the buffer capacity, $BC = \{bc_j^i : i \in DN, j \in K\}$,
- the buffer cost, $CB = \{cb_j^i : i \in DN, j \in K\}$,
- the deterioration rate, $DR = \{dr_i : i \in K\}$,
- the buffer usage as a function of time, $B(t) = \{b_j^i(t) : i \in DN, j \in K\}$, and
- the actual distribution as a function of time, $Di(t) = \{di_j^i(t) : i \in E, j \in K\}$

Consumption. Let $C = \{c_1, \dots, c_p\}$ be the set of all customers. Then we denote;

- the consumption capacity $CC = \{cc_j^i : i \in C, j \in K\}$, and
- the actual demand as a function of time $D(t) = \{d_j^i(t) : i \in C, j \in K\}$

Although this model assumes that production and distribution costs etc are linear and does not change over time, we argue that it is possible to describe many interesting production and distribution problems using this formal model. (Of course, the production, distribution, and buffer dynamics are part of the solution rather than the problem.) However, we will here focus on JIT production and distribution problems, which we define as situations where there are limited storage capacity or high deterioration rate, and a considerable delay from order to receipt of commodities (due to large production and/or distribution times).

4. A General Simulator for Just-In-Time Production and Distribution

We are currently developing a general simulator able to simulate all the relevant production and distribution problems that can be described by the formal model presented above. Each part of the model corresponds to a set of explicit simulation parameters. Thus, by setting these parameters, it will be possible to simulate an arbitrary production and distribution problem.

The long-term goal is to systematically evaluate different multi-agent-based approaches in the different parts of the problem space defined by the formal model (and the simulator). Figure 3 illustrates the interaction between the MAS approaches and the general simulator. However, we have thus far only investigated one part of this problem space, namely that corresponding to district heating production and distribution, which will be described below. We have compared two different multi-agent approaches, one semi-distributed and one centralized, in this domain.

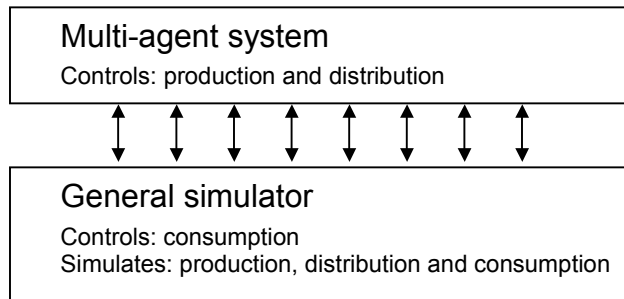


Fig. 3. Schematic view of the relation between the general simulator and the multi-agent system evaluated by the simulator.

4.1. Case Study: Description of District Heating Systems Domain

This case is borrowed from ABSINTHE, a current collaboration project with Cetetherm AB, one of the world-leading producers of district heating substations [19]. The technological objective is to improve the monitoring and control of district heating networks through the use of agent technology. For more information on this project, see www.ipd.bth.se/absinthe.

The basic idea behind district heating is to use cheap local heat production plants to produce hot water. This water is then distributed by using one or more pumps at approximately 1-3 m/s through pipes to the customers where substations are used to exchange heat from the primary flow of the distribution pipes to the secondary flows of the building. (see Fig. 4) The secondary flows are used for heating both tap water and the building itself. In large cities district heating networks tend to be very complex, including tens of thousands of substations and hundreds of kilometers of distribution pipes with distribution times up to 24 hours.

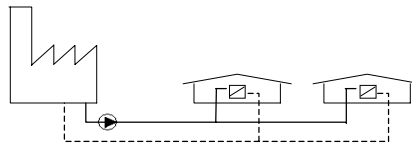


Fig. 4. A simple district heating network containing one heat producer and two substations.

Let us describe this district heating system domain in terms of the general model. (We here present a description corresponding to how parameters are set in the current version of the simulator, in which some simplifications have been made compared to actual

district heating system. For instance, we assume that there is only one production plant and that the production capacity is always sufficient to meet the demands of the customers. However, we intend to remove such restrictions in future versions.)

Production. There is only one heat production plant, p_1 , and the only type of commodity, k_1 , is energy (hot water). We assume that raw materials are always sufficient to support the production (up to the production capacity, PC). Moreover, we assume that:

- The production time, tp_1 , is negligible, i.e., 0 seconds.
- The production cost, cp_1^i , is 1 cost unit for each kW.
- The production capacity, pc_1^i , is larger than the total consumption capacity, $\sum cc_i$ (see below for definition of cc).

Distribution. The distribution network, N , is assumed to be a tree structure with the production plant as the root and the distribution pipes corresponding to the edges. A relaxing constraint in district heating systems is that the distribution time and cost between a group of customers physically close to each other (situated in the same branch of the distribution tree) is negligible. We model this by internal cluster nodes, I , one for each cluster of neighboring consumers, see Fig. 5.

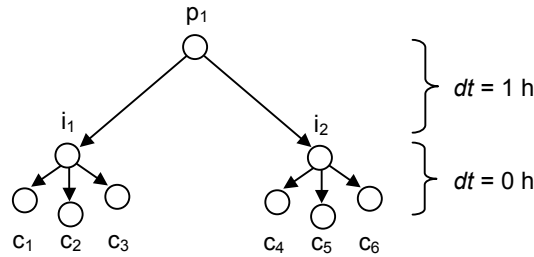


Fig. 5. The amount of heat delivered to a group of customers is available to all members in the cluster. The result is that redistribution in principle takes no time within the cluster.

Moreover we assume that:

- The distribution time, td_1^i , is 1 h for edges, i , between p_1 and internal nodes, $n \in I$, and negligible, i.e., 0 for edges between internal nodes, $n \in I$, and consumers, $n \in C$.
- The distribution cost, cd_1^i , is always 0.
- The distribution capacity, dc_1^i , is greater than $\sum_{j \in T} cc_j$, where T is the tree “after” i .

- The buffer capacity, bc_j^i , is 0 for $i \in C$ (the consumer has no potential to keep an inventory of hot water) and for $i \in P$. However, if $i \in I$ the capacity is greater than $\sum_{j \in T} cc_j$, where T is the tree “after” i .
- The buffer cost, cb_j^i , is negligible, i.e., 0.
- The deterioration rate, dr_j , is computed from the common resistance/capacitance model;

$$T_{xi} = \frac{1}{1 + \frac{1}{TR_x TC_x}} \left(T_{x(i-1)} + \frac{T_{outi}}{TC_x} \right), \text{ where } T_{xi} \text{ is the temperature of a object, } x, \text{ at the}$$

time i which had temperature $T_{x(i-1)}$ one minute ago with thermal resistance TR_x and thermal capacity TC_x in an surrounding environment with temperature T_{outi} .

Consumption. There are 10 customers in the set of customers, C . Each customer, $c_1 - c_5$ is serving 40 households and each customer, $c_6 - c_{10}$ is serving 60 households.

- The demand of the customers, $d_j^i(t)$, is simulated through a tap water model [14] (which is based on empirical data) where flow size and tapping durability is determined by the simulation of a random number, Y , from a certain distribution with cumulative distribution function F_Y , which can be performed using uniformly distributed numbers, and where the time between tapping is a non-homogenous Poisson process;

$$X = 1 - \exp \left(- \int_0^T \mu(u) du \right), \text{ where } \mu(u) \text{ is the time-varying opening intensity and } T$$

the time to derive. The opening intensities are derived from $\mu = \frac{p}{(1-p)\eta}$, where p is

given from measurement data [15] and η is calculated from the distribution function for open valve time. The resistance/capacitance model described above is used also for simulation of the energy needed for household heating (radiators). The variance over time of the outdoor temperature is simulated by the following model [16];

$To = Tm + Tv * e^{-((i*s-4) \bmod 24-12)^2 / 20}$, where Tm is the lowest temperature to expect, Tv is the maximum temperature to expect, and S is the time interval expressed in hours.

- Finally, consumption capacity, cc_i , is 200 kW for $c_1 - c_5$ and 300 kW for $c_6 - c_{10}$.

4.2. MAS Approaches to JIT Production and Distribution in District Heating Systems

There are a number of different approaches to solve the just-in-time production and distribution problem outlined above. The most basic approach (and probably the most used) is strictly centralized, where the producer based on experience makes predictions of how much resources to produce in order to satisfy the total demand of the consumers. These resources are then distributed directly on demand from the consumers. A bit more sophisticated is the approach where each consumer makes predictions of future consumption and informs the producer about these predictions. Since local predictions typically are more informed than global predictions, this approach should give better results. The MAS architecture we suggest below partly builds upon this insight but also introduces a means for automatic redistribution of resources. In order to solve the problem of producing the right amount of resources at the right time, each consumer is equipped with an agent that makes predictions of future needs that it sends to a production agent. The other problem, to distribute the produced resources to the right consumer, is approached by forming clusters of consumers within which it is possible to redistribute resources fast and at a low cost. This usually means that the consumers within a cluster are closely located to each other. In this way it is possible to cope with discrepancies between predicted and actual consumption. For instance, this happens if the demand of a consumer changes while the resources are delivered. The consumer would then be faced with either a lack or an excessive amount of resources, thus leaving the system in an undesired state.

Based on the above insights, we used the GAIA methodology [17] to design the MAS. This led us to the architecture outlined in Fig. 6, that has the following three types of agents:

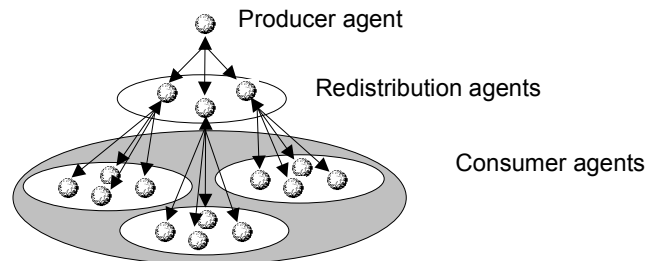


Fig. 6. Each redistribution agent manages a cluster of consumer agents.

- *Consumer agents:* (one for each consumer) which continuously (i) make predictions of future consumption by the corresponding consumer and (ii) monitor the actual consumption, and send information about this to their redistribution agent.

- *Redistribution agents*: (one for each cluster of consumers) which continuously (i) make predictions for the cluster and send these to the producer agent, and (ii) monitor the consumption of resources of the consumers in the cluster. If some consumer(s) use more resources than predicted, it redistributes resources within the cluster. If this is not possible, i.e., the total consumption in the cluster is larger than predicted, it will redistribute the resources available within the cluster according to some criteria, such as, fairness or priority, or it may take some other action, depending on the application.
- *Producer agents*: (one for each producer, however, we will here only regard systems with one producer) receives predictions of consumption and monitors the actual consumption of consumers through the information it receives from the redistribution agents. If necessary, e.g., if the producer cannot produce the amount of resources demanded by the consumers, the producer agent may notify the consumers about this (via the redistribution agents).

The suggested approach makes use of two types of time intervals: (i) prediction intervals and (ii) redistribution intervals. A prediction interval is larger than a redistribution interval, i.e., during each prediction interval there is a number of redistribution intervals. Each consumer agent produces one prediction during a prediction interval and sends this to its redistribution agent, who sums the predictions of all consumer agents belonging to the cluster and informs the producer agent about this. The predictions made by the consumer agent must reach the producer at least $TP + TD$ before the resources are actually consumed. Typically, there is also a production planning time that also should be taken into account (i.e., added to the sum).

4.3. Simulation Results

The focus during the initial simulation experiments [18] was to see how the quality of service (QoS), measured in terms of the number of restrictions issued, varied with the amount of excessive production (in relation to the predicted consumption).

We found that the multi-agent system performed well, coping with faulty predictions (even though the discrepancy between the predicted and the actual consumption sometimes was quite large). We also discovered that in order to achieve the same QoS between the two sets of experiments, the centralized approach required an additional 3% excessive production.

Figure 7 shows the total number of restrictions to tap water and the number of restrictions to water for household heating (radiator) during one day for different degrees of surplus production in a cluster of ten consumer agents. We see that there is a clear trade-off between the quality of service (number of restrictions) and the amount of surplus production and that there are almost no restrictions of any kind when 4% more hot water than the predicted consumption is produced. Moreover, this approach allow large

fluctuations in customer demand, which is something that has been argued not to suit JIT approaches [13].

We have compared this approach to a more centralized approach without redistribution agents and where all computation is carried out at the producer side. The only task of the agents on the consumer side were to read sensor data and sent this to the producer agent. Simulation results showed that more than 7% overproduction was needed in order to avoid any restrictions/shortages. For more information about this approach and simulation results, see [18].

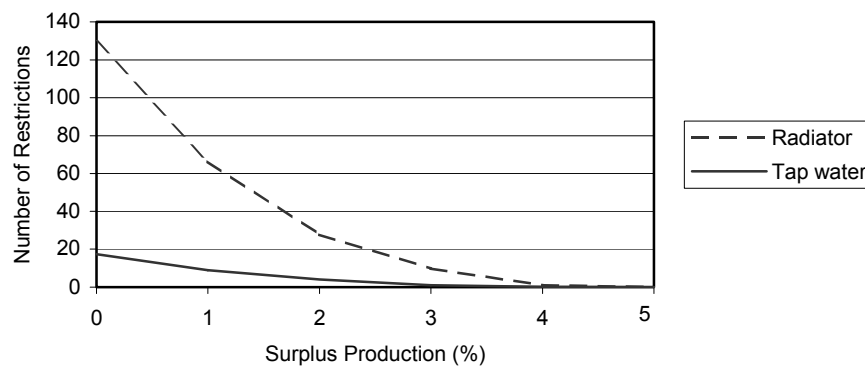


Fig. 7. Trade-off between quality of service and surplus production for the semi-distributed approach. The dashed line corresponds to the number of restrictions for the radiator water and the other line to the number of restrictions for the tap water.

5. Conclusions and Future Work

We have presented an outline of a general simulator based on a formal model of the distribution part of supply network. The long-term goal is to implement such a simulator and use it for systematical evaluation of both new and existing multi-agent approaches to supply chain management. We also described the first step towards this goal in the form of a case study.

In the near future we plan to generalize the current version of the simulator to cover more types of production and distribution domains. Also, we plan to implement other MAS approaches as well as improving the one presented here.

Acknowledgement. This work has been financially supported by VINNOVA (The Swedish Agency for Innovation Systems).

References

1. Anwar, M.F., and Nagi, R.: Integration of Just-In-Time Production and Material Handling for an Assembly Environment, *5th Industrial Engineering Research Conference*, Minneapolis, 1996.
2. Parunak, H.V.D., and VanderBok, R.S.: Managing Emergent Behaviour in Distributed Control Systems, Presented at *ISA-Tech.*, [<http://www.isa.org>], Anaheim, 1997.
3. Babanov, A., Collins, J., Gini, M.: Risk and Expectations in a-priori Time Allocation in Multi-Agent Contracting, To appear in *First International Joint Conference on Autonomous Agents and Multi-Agent Systems*, Bologna, 2002.
4. Fox, M.S., Barbuceanu, M., Teigen, R.: Agent-Oriented Supply-Chain Management, *The International Journal of Flexible Manufacturing Systems*, 12:165-188, 2000.
5. Chen, Y., Peng, Y., Finin, T., Labrou, Y., Cost, S., Chu, B., Sun, R., Wilhelm, B.: A negotiation-based Multi-agent System for supply chain management, *Third Conference on Autonomous Agents, Workshop on Agent based Decision-Support for Managing the Internet-Enabled Supply-Chain*, Seattle, 1999.
6. Carter, J., Ghorbani, A.A., Marsh, S.: Just-In-Time Information Sharing Architectures in Multiagent Systems, To appear in *First International Joint Conference on Autonomous Agents and Multi-Agent Systems*, Bologna, 2002.
7. Parunak, H.V.D., Savit, R., Riolo, R.L.: Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users' Guide, *Multi-Agent Systems and Agent-Based Simulation*, LNAI 1534, 10-25, Springer Verlag, 1998.
8. Wagner, T., Guralnik, V., Phelps, J.: Software Agents: Enabling Dynamic Supply Chain Management for a Build to Order Product Line, *International Workshop on Agents for Business Automation*, 2002.
9. Ganeshan, R., and Harrison, TP.: An Introduction to Supply Chain Management, [http://silmaril.smeal.psu.edu/misc/supply_chain_intro.html], 1995, 2002 (22 April).
10. Prajogo, N.H., and Johnston, R.B.: A Barriers Framework for Understanding Just-In-Time Implementation in Small Manufacturing Enterprises, *Asia Pacific Management Journal*, 6(2):175-195, 2001.
11. Monden, Y.: Toyota Production System: An Integrated Approach to Just-In-Time. *Industrial Engineering and Management Press*, Georgia, 1993.
12. Ohno, T.: *Toyota Production System: Beyond Large-Scale Production*, Productivity Press, Oregon, 1988.
13. Hall, R.W.: *Zero Inventories*, Dow Jones-Irwin, Illinois, 1983.
14. Arvastson, L., and Wollerstrand, J.: On Sizing of Domestic Hot Water Heaters of Instantaneous Type. *6th International Symposium on Automation of District Heating Systems*, 1997.
15. Holmberg, S.: Norrköpingsprojektet – en detaljerad pilotundersökning av hushållens vattenförbrukning, Technical report M81:5, Departement of Heating and Ventilation Technology, Royal Institute of Technology, Sweden., 1981 (in Swedish).
16. Ygge, F., and Akkermans, H.: Decentralized Markets versus Central Control: A Comparative Study, *Journal of Artificial Intelligence Research*, 11:301-333, 1999.

17. Wooldridge, M., Jennings, N.J., Kinny, D.: The Gaia Methodology for Agent-Oriented Analysis and Design. *Journal of Autonomous Agents and Multi-Agent Systems*, 3(3): 285-312, 2000.
18. Davidsson, P., and Wernstedt.: A Multi-Agent System Architecture for Coordination of Just-in-time Production and Distribution, *17th ACM Symposium on Applied Computing*, 294-300, 2002.
19. Wernstedt, F., and Davidsson, P.: An Agent-Based Approach to Monitoring and Control of District Heating Systems, To appear in *15th International Conference on Industrial & Engineering Application of Artificial Intelligence & Expert Systems*, 2002