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Manipulating the Decision Behaviour of a Subordinate Service Centre by a Closed-Loop Cost Accounting Scheme Control

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Abstract

We investigate a supply chain decision problem that encompasses three challenges, which cannot be managed satisfactorily nowadays with computerized decision support: dynamic, islands of planning autonomy and hierarchically coupled planning goals. We combine the existing online optimization framework by a closed-loop optimization control circuit that allows a subordinate service centre agent to carry out the necessary process decisions but adapts the used incentive scheme so that the subordinate agent is enforced to process decisions which comply with the desires of a superior supply chain coordinator. The concept is verified into simulation experiments.

1 Introduction

The supply chain of a product describes the sequence of activities to be carried out in order to create the desired output from one or several inputs factors. Procurement is responsible for the purchasing of the input factors, production transforms the input factors into the demanded output, distribution comprises the forwarding of the completed product to the retailing places by means of (physical) transport and the customer receives the product in the retail stage. Supply Chain Planning (SCP) aims at achieving the highest possible efficiency of a supply chain by coordinating and consolidating the necessary material flows so that economies of scale are exploited to the largest possible extend.

Recent trends in the management of supply chains compromise the successful application of SCP-concepts like hierarchical planning. The explicit consideration of unexpected events, so called dynamics, is propagated as significant competitive advantage. However, only basic methodological support has been investigated so far for SCP if data, requirements or desires unpredictably vary over time. A supply chain is built by several partners who agree to a temporary cooperation. They are not willing to give up the responsibility and self reliance for the material flow decisions in their part of a supply chain. Consequently, a centralized and supply chain-wide top-down material flow determination is impossible. Although a supply chain is built by independent partners, one of them has the power (or right) to define the supply chain-wide goals. This so-called supply chain leader or coordinator must persuade the independent partners to behalf in the sense of the superior supply chain goals instead of the subordinate partner's aims by managing incentives and penalties. However, only generic methodological knowledge is available to support the relevant decision making.

In this contribution, we consider a dynamic disposition problem that demonstrates the challenges associated with the previously mentioned challenges for computer-supported supply chain planning. Two partners are considered. Both have conflicting goals. The superior coordinator wants to maximize the reliability of the overall supply chain but an independently deciding subordinate transport planner wants to maximize its own profit. Due to its superiority, the coordinator is allowed to decide about the applied incentive scheme determining the subordinate agent's profit. We propose an integrated approach that couples the two hierarchically ordered goals into a close-loop control circuit-like system. Section 2 describes the considered disposition problem, Section 3 introduces the decision making approach and Section 4 reports the results from computational experiments that verify the general applicability of the proposed concept.

2 Problem Description

2.1 Related Work

Brehmer (1992) discusses dynamic decision problems from a general perspective while Potter and Lalwani (2005) survey dynamics to the transportation tasks of a supply chain. Krumke (2001) gives a structured overview of online optimisation as the basis for model-based reactive decision making. Typical challenges and methods to cope with autonomy in complex value creation systems are compiled in Hülsmann and Windt (2007). Hierarchically organized operations and supply chain planning is investigated by Miller (2002). Schneeweiß (2003) surveys decentral decision making and Choi (2004) as well as Sauer and Appelrath (2002) propose a central coordinator of independently deciding service centres. Vecht et al. (2006) perform experiments in which the decision behaviour of subordinate agents adapts to the contribution to a superior common goal.

2.2 Order Fulfilment in Supply Chains

Fig. 1 outlines the order fulfilment in a supply chain. Customers express their demand in terms of external orders submitted to the supply chain coordinator. This coordinator receives the external customer orders as customer orders and overtakes the responsibility for their reliable fulfilment (Choi et al., 2004; Sauer and Appelrath, 2002). The coordinator splits each customer order into the necessary internal purchasing, production, distribution and retailing tasks. Tasks associated with different customer orders are combined into internal purchasing, production and transport requests. Then, each department involved in the supply chain is instructed to execute the specified requests according to their competencies in order to contribute to the fulfilment of the customer orders.

The supply chain including the coordinator as well as each department is considered as a group of agents who cooperatively fulfils a set of tasks (the external customer orders). None of the agents is able to fulfil the complete tasks without the support of the others. The coordinator agent has not the knowledge, resources and abilities to setup and execute the material flow processes, while neither the purchasing agent nor the production or the distribution can acquire customer orders. The coordinative task of the coordination agent implies a hierarchy among the agents. Actually, the coordinator agent has the right (by definition) and the power (by the acquired orders and money) to instruct the departmental agents. Consequently, each department acts as a service centre for the entire supply chain (subordinate agents).

The supply chain coordinator agent receives charges paid by the customers for the fulfilment of the customer orders. From the sum of earned charges, budgets are defined that are used to cover the material flow process costs specified by the service centre agents. In order to stimulate a service centre to determine processes of highest efficiency, the difference between the budget and the process costs remains in the service centre as its gain (profit).

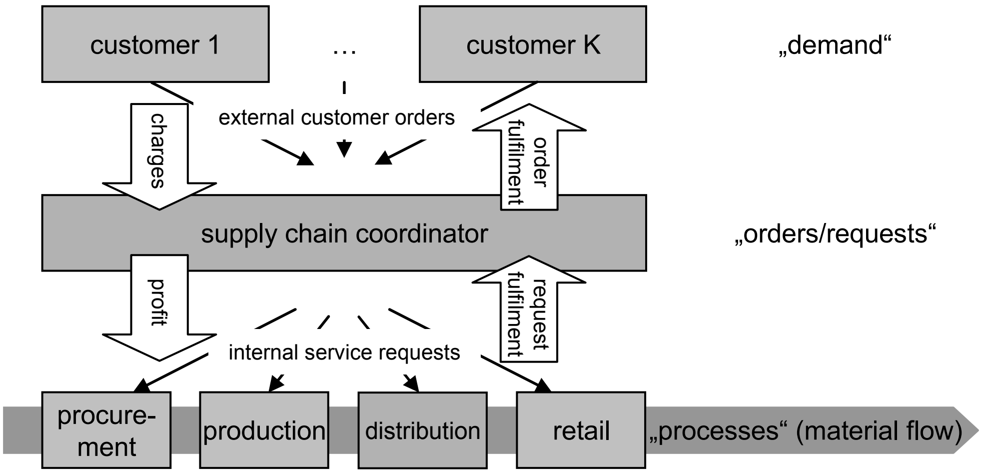

Figure 1: Customer demand fulfilment in a Supply Chain

An accounting scheme describes how expenses of a subordinate agent are accounted to the given budget.

Each service centre agent decides independently about the planning of its processes (resource deployment, etc.) but the coordinator agent (as the superior agent) modifies the accounting scheme in order to make specific process decisions more attractive for the subordinate service centre agent. Consequently, the process determination carried out by the service centre agent is biased by the coordinator agent by means of the accounting scheme variation. This forces the subordinate agents to adopt its process decisions to the guidelines of the superior coordination agent.

2.3 Variation of the Accounting Scheme

The modification of the accounting schema allows the correction of the service centre agent's behaviour. It can be applied if the specifications of the generated processes do not comply anymore with the intentions and specification of the coordinator agent, e.g. if the system input has varied (load peak) and the process reliability decreases (less punctuality).

We consider the interaction between the coordinator agent and the distribution agent. A budget of 25 monetary units (MU) is available. In the self entry (SE) mode, a request is served by a vehicle that is fully controlled by the distribution agent who compiles routes for the vehicle by combining several requests. If the subcontraction mode (SC) is selected for the execution of a request then the distribution agent books some capacity from a logistic service provider (LSP). The LSP overtakes the responsibility for the request fulfilment and guarantees a completion without delay. The distribution scenario comprises one depot at location (0|0) and two customer sites A_1 situated at location (0|5) and A_2 situated at location (5|0) that must be delivered. We assume that the distribution agent can deploy one vehicle, so that one route has to be generated. The route starts at time 0 and the velocity of the vehicle is one distance unit per time unit. Dwell times are not considered. Each travelled distance unit is accounted by 1 MU and if the vehicle arrives late at a customer site then each time unit delay is additionally accounted by 1 MU. The vehicle is late if it arrives later than time 10 at a customer site. The incorporation of an LSP charges the budget with 2.2 MU for each booked distance unit.

A1: Both customer sides are served in the SE mode. The secondly visited site is reached not before time 12.1 so that it is late and produces penalty costs. The travel distance is 5+7.1+5 = 17.1 and the penalty sums up to 2.1 MU. A1 charges the budget with 19.2 MU leading to a gain of 5.8 MU.

A2: One customer site (e.g. A_1) is served in the SE mode and the second request is fulfilled in the SC mode. The travel distance of the own vehicle is 10 and 5×2.2=11 MU are charged to the budget for the LSP incorporation. Overall, A2 reduces the budget by 21 MU. A gain of 4 MU is left for the distribution service centre. No delays occur.

A3: Both customer sites are served in the SC mode. This charges the budget by 5×2.2+5×2.2 = 22 MU, so that a gain of 3 MU is obtained for the service centre.

The distribution agent selects A1 because it tries to maximize its own profit. One request is late because the applied accounting scheme reduces the budget for a delayed SE-served request less than an SC-served non-delayed request. The ration $\alpha_I = \frac{c_{SC}}{c_{SE,D}} = \frac{2.2}{1+1} = 1.1$ between the costs of SC-fulfilment c_{SC} and delayed SE-completion charges $c_{SE,D}$ is larger than 1 so that a delay is preferred from the subordinate agent's view. In order to give the distribution agent an incentive for the selection of the SC mode and to serve a higher number of requests in time, the charges accounting the budget should be re-determined. A request served in the SC-mode should lower the budget by a smaller amount than a delayed request served in SE-mode does, e.g. the associated ratio α_{II} should fall below 1. Here, the accounting scheme is adjusted and in case of a delay two instead of one additional MU is charged for each time unit a request is served after the time window has closed at time 10. Now, it is $\alpha_{II} = \frac{c_{SC}}{c_{SE,D}} = \frac{2.2}{1+2} \approx 0,73 < 1$ and the following alternatives are distinguished

A4: Both customer sides are served in the SE mode. The secondly visited site is reached not before time 12.1 so that it is late and produces penalty costs. The travel distance is 5+7.1+5 = 17.1 and the penalty sums up to 4.2 MU. A4 charges the budget with 21.3 MU leading to a gain of 3.7 MU.

A5: One customer site (e.g. A_1) is served in the SE mode and the second request is fulfilled in the SC mode. The travel distance of the own vehicle is 10 and 5×2.2=11 MU are charged to the budget for the LSP incorporation. Overall, A5 reduces the budget by 21 MU. Again, the gain for the distribution service centre is 4 MU and no customers are visited late.

A6 is the same as A3 since the account of an LSP service is not modified.

Now, the distribution service centre agent would select A5 instead of A4 due to the relatively higher achievable profit (after the scheme has varied). The distribution centre agent has varied his decision behaviour. We learn from this example that an external modification of the accounting and incentive scheme forces the revision of decisions made autonomously by the subordinate distribution agent. This agent has to adapt its decisions to the modified benefits in order to keep its gain as large as possible. Due to the subordinate position the distribution agent has to accept the modification of the accounting scheme. Otherwise, if both agents where independent, the coordinator agent must transfer a side payment to the distribution agent in order to compensate the loss of profit and to convince the distribution agent to adapt its disposition behaviour (Sucky, 2006).

In the remainder of this article, we investigate the automatic adjustment of the accounting scheme, which, as seen above, bias the decision making of the subordinate agent. Actually, we propose to define a function that maps the currently observed punctuality into the subsequently applied accounting scheme. The suitability of this approach is tested in computational simulations of the following (simplified) scenario. Regularly, the coordinator agent receives 50 additional customer orders every 100 time units. Each customer order is transformed directly into an internal transport request (procurement and production orders are not considered here).

Let f_t be the number of requests that have been completed into the passed interval [t-500,t] or that are expected to be completed in the next 500 time units. The number of timely served requests in the interval [t-500,t] is f_t^{comp} and the number of requests scheduled for a punctual completion within the interval [t,t+500] is f_t^{expec}. The coordinator agent requires that the portion $p_t := \frac{f_t^{comp} + f_t^{expec}}{f_t}$ of requests completed within the last 500 time units and scheduled to be fulfilled in the next 500 time units is at least 80% ($p_t \geq 0.8$). A punctuality rate of 100% is not realistic (and proposed by the coordinator towards the customers) since hedging all imponderabilities leads to exploding costs if the covered risk converges to 100% in most of the realistic probability distributions used (Thonemann, 2005).

The distribution centre agent can select either the mode SE or SC for each request. An own fleet of 25 vehicles is available for the SE-related operations and an LSP is available for the SC operations which guarantees the timely request execution. In this investigation, all parameters are adjusted to values which enable the distribution centre agent to provide a least cost request fulfilment at a punctuality rate above 80%.

We apply a disturbance that pushes the balanced interaction between the two agents away from the stable state: A temporary demand peak increases the number of requests to be fulfilled timely. Using the so far applied accounting scheme ends in a decrease of the punctuality rate below 50% for a long time period so that an adaptation of the accounting scheme becomes necessary.

2.4 Outline of the Distribution Service Centre's Disposition Problem

We map the dynamic disposition task of the distribution centre agent into an online optimisation model (Krumke, 2001) consisting of a sequence of complete optimisation problem instances which are solved consecutively. A once generated solution (set of processes) is executed until additional requests arrive. Then, the distribution service centre agent interrupts the execution of the so far followed processes, sets up a new optimisation model instance, solves this instance and replaces the so far not executed process parts by the recently generated processes. Krumke et al. (2002) investigate such a decision situation for the dispatching of service vehicles to support motorists as soon as possible after a vehicle break down has happened.

Each instance can be described verbally describing the requirements of the output of the dispatching tasks, e.g. each set of processes must fulfil the following premises. (P1) Each vehicle is assigned to exactly one path, which represents the ordered set of customer sites to be visited. This path might be empty expressing that the vehicle is not set in operation. (P2) The vehicle must be able to execute the paths it is assigned to. It is especially necessary that the starting point of the selected path coincides with the current position of the considered vehicle. (P3) Each so far not completed request is either covered by a path of a vehicle (SE) or given to the LSP (SC). (P4) A request assigned to an LSP in a previous dispatching instance is not allowed to be served in the SE mode. (P5) If the on-site work for the fulfilment of a request has already been started but not yet finished then this request is not allowed to be shifted away from this vehicle or LSP.

At time t_i the set of uncompleted requests is denoted by $R(t_i)$, the set of available paths is named $P(t_i)$ and the deployable vehicles for the SE-mode operations are collected in the set V. Let $p \in P(t_i)$ be a path, then $C^1(p)$ denotes the travel costs of p caused by the vehicle that serves this p (SE-mode). Furthermore, $C^2(p)$ contains the penalty costs caused by delayed services according to p. Finally, let $r \in R(t_i)$ be a request, then $C^3(r)$ gives the subcontraction costs associated with r. We use the binary decision variable x_{pv} to code whether path p is assigned to vehicle v or not and the binary decision variable y_r is 1 if and only if request r is served in the SC-mode. The distribution centre agent now selects values for the decision variables so that the sum of values given by (1) reducing the given budget is minimized.

$$\underbrace{\sum_{p \in P(t_i)} \sum_{v \in V} \left(C^1(p) + C^2(p)\right) \cdot x_{pv}}_{\text{SE-mode costs}} + \underbrace{\sum_{r \in R(t_i)} C^3(p) \cdot y_r}_{\text{SC-mode costs}} \tag{1}$$

3 Feedback-Driven Closed-Loop Accounting Scheme Control

The challenge of the introduced dynamic dispatching problem is the determination of an accounting scheme that, depending on the current time t and the currently achieved punctuality rate p_t that respects the least punctuality rate of 80%. As seen in the example given in Subsection 2.3 it is necessary to adapt the ratio between the costs of the SC-mode and the costs of the delayed SE-service of a given requests. Consequently, it is sufficient to determine coefficients for the summands "SE-mode costs" and "SC-mode costs" given in the objective function (1) and to adjust the coefficients so that at time t_i the distribution centre agent uses the objective function (2) to evaluate its process decisions.

$$H_1(t_i, p_{t_i}) \cdot \sum_{p \in P(t_i)} \sum_{v \in V} \left(C^1(p) + C^2(p) \right) \cdot x_{pv} + H_2(t_i, p_{t_i}) \cdot \sum_{r \in R(t_i)} C^3(r) \cdot y_r \tag{2}$$

We define the accounting scheme used at time t_i now as the ordered pair $\left(H_1(t_i, p_{t_i}) \mid H_2(t_i, p_{t_i})\right)$. The dependence of the accounting scheme from the currently observed punctuality rate p_t causes the adaptation of the scheme to the current punctuality. After additional requests have arrived at time t_i, two decision tasks require an answer.

The **coordinator agent** has to specify the accounting scheme $\left(H_1(t_{i+1}, p_{t_{i+1}}) \mid H_2(t_{i+1}, p_{t_{i+1}})\right)$ to be applied for solving the forthcoming instance of the process update model. Therefore, the agent is reported about the last observed punctuality rate p_{t_i}. He compares this value with the externally given referential punctuality p^{target}=0.8. Depending on the deviation of p_{t_i} from p^{target}, he decides about the necessary variations of the so far used accounting scheme. The modified scheme is implemented into the process control, represented by the distribution centre agent. The existing processes are updated and the punctuality rate is update from p_{t_i} to $p_{t_{i+1}}$. Based on the observed value of $p_{t_{i+1}}$ the next accounting scheme is determined as described before. Since the observed control variable influences the determination of the next applied accounting scheme, this iterative procedure for the scheme determination is a close-loop control circuit which controls the decision model used by the distribution centre agent.

The **distribution centre agent** has to revise the so far executed processes. Therefore, he solves automatically a decision model that represents the decision problem he is faced with. The previously specified accounting scheme is used to evaluate the process update alternatives so that the distribution centre agent can compare the available alternatives. Finally, he selects a solution that maximises its profit. The model-based process update is a control loop that is executed reactively after additional requests have arrived. However, it is an open control circuit because it does not exploit any process quality indicators to adjust its process update premises. Independently from the current process punctuality and the current workload it follows the goal to maximize its own profit.

From the coordinator agent's view it seems promising to integrate both control loops in order to keep the punctuality of the generated processes close or even above 80% independently from any disturbances even if the distribution centre agent independently performs its profit-oriented disposition. The coordinator agent specifies the valid accounting scheme and thereby influences the distribution agent's decision preferences.

Fig. 2 shows a generic close-loop control circuit. At time t_i, the current control variable $o(t_i)$ is compared with a given reference input $r(t_i)$. The error signal $e(t_i)$ calculated from the deviation between $o(t_i)$ and $r(t_i)$. Next, $e(t_i)$ is processed by the loop controller K to the control value $s(t_i)$ which is used to re-determine the controlled system. For evaluating the controlled system, the control variable subject to variation by external disturbances $d(t_i)$ is stored in the control variable $o(t_i)$. Now, the feedback $o(t_{i+1})$ is compared with the recent reference input $r(t_{i+1})$ and so on.

In the remainder of this section we describe how the generic closed-loop control-circuit can be configured for the process control that has the superior goal of an 80% process punctuality but that allows the maximisation of the subordinate service centre agent's profit to the highest possible extend as long as the superior goal remains achieved.

In the following, we first present a concept to derive an error signal e(t) from the comparison of the target punctuality and the recently reported punctuality (Subsection 3.1). Next, we define a controller that transforms the error signal e(t) into an update intensity (Subsection 3.2) and propose a procedure to update the so far valid accounting scheme using the current value of the update intensity (Subsection 3.3).

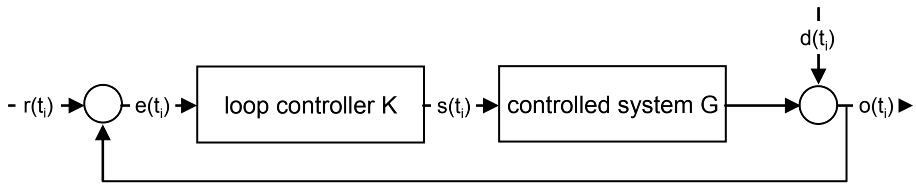

Fig.2: Generic closed-loop control circuit.

3.1 System Development Corridor

At first, we define the error signal e(t) (the "distance") between the desired and the observed punctuality. Therefore, a clear definition of "desired values" for the control variable o(t) is necessary in order to decide whether the current instantiation of p_t requires an adjustment of the so far used accounting scheme or not.

General setting. Let $\vec{o}(t)$ be a real-valued vector consisting of the M components $o_1(t),\ldots,o_M(t)$. Each single component is a real-valued function that maps the current time t to a given process quality indicator value. The image set of $o_i(t)$ is denoted as IM_i.

The ordered pair $(t\,|\,\vec{o}(t))$ is called the *system performance at time t*. All accepted, desired and high evaluated control variable values for time t are collected in the set $F_r(t) \subseteq IM_1 \times \ldots \times IM_M$. If and only if $\vec{o}(t) \in F_r(t)$ then $\vec{o}(t)$ fulfils the requirements of the reference input r(t). The set $S_r(t) \subseteq F_r(t)$ contains only those control variable values that cannot be shifted out from $F_r(t)$ by the next external disturbance.

The system development corridor valid at time t is defined by D(t):= $[t;\infty)\times F_r(t)$ and contains all performance instantiations which are desired for the future. The core of D(t) is defined by C(t):= $[t;\infty)\times S_r(t)$.

We define the error signal e(t) as a real-valued non-negative function of the time that assigns the current system performance $\left(t\,|\,\vec{o}(t)\right)$ the value 0 for all performances $(t|\,\vec{o}(t)\,)\in C(t)$.

Configuration for the investigated problem. We use only the one performance indicator $o(t)=p_t$ with the associated image set $IM_1:=(0,1)$. The reference input r(t) is defined by the interval $r(t):=(p^{target};1)$ and we define $F_r(t):=r(t)=[p^{target};1]$. This leads to the system development corridor D(t):= $[t;\infty)\times[p^{target};1]$ and its core C(t):= $[t;\infty)\times[p^{target}+0.1;1]$. Since $p^{target}=0.8$ we get the system development corridor $[t;\infty)\times[0.8;1]$ and its core $[t;\infty)\times[0.9;1]$. As long as $p_t\geq 0.8$ the current system performance (t,p_t) belongs to the core C(t). If p_t falls below 0.9 and if the distance of p_t from 0.9 increases then the system's performance gets more and more off the core C(t) and finally leaves the system development corridor D(t). This leads to the following error signal definition: $e(t):= -\min(p_t-(p^{target}+0.1);0)$. The error signal prematurely indicates that the performance runs into danger to leave the system development corridor, e.g. by the next external disturbance like a peak in the work load.

3.2 Definition of the Controller

The controller transforms the previously calculated error signal e(t) into a control value that manipulates the controlled system afterwards. Therefore, it is a mapping h that assigns the error signal e(t) to the control value h(e(t)).
By construction, only slight adaptations of the controlled system are required if the error signal is small, but if the error signal increases then substantial variations of the controlled system are necessary. Consequently, the controller function h should be strictly increasing
For the decision problem described in 2.3 we define h as a piecewise linear function with $h(e(t))=0$ if $e(t)\leq 0$, $h(e(t))=1$ if $e(t)\geq 0.2$ and $h(e(t))=5e(t)$ as long as $0<e(t)<0.2$. We interpret h(t) as percentage of the maximal possible adjustment of the accounting scheme. If the error signal is 0, then no adjustments are required, if the error signal is maximal then the most severe variation of the accounting scheme is triggered. The percentage of adaptations of the accounting scheme increases smoothly with increasing error signal.

3.3 Instantiation of the Next Applied Accounting Scheme

The control value h(e(t)) is exploited to manipulate the processes. Since the arrival of additional customer orders requires the revision of the so far followed processes, the process update procedure is affected so, that the control value is considered in the forthcoming process revision. The decisions to update the processes are made according to a mathematical optimisation model which consists of a constraint set representing the premises (P1)-(P5) described in Subsection 2.4 and the objective function (2).
Fig. 3 shows the information flow from outside the considered system through the control components (error signal generator and controller) into the subsystem "process control". The control value h(e(t)) is sent to the objective function of the process control model and updates

the coefficients $H_1(t, p_t)$ and $H_2(t, p_t)$. If the fed back punctuality rate $p_{t_{i+1}}$ has decreased compared to p_{t_i} then the quotient of $H_1(t_{i+1}, p_{t_{+1i}})$ and $H_2(t_{i+1}, p_{t_{+1i}})$ should be increased compared to the quotient of the components $H_1(t_i, p_{t_i})$ and $H_1(t_i, p_{t_i})$ of the previously used accounting scheme. It is aimed to make the so far not attractive enough SC-mode relatively cheaper compared to the delayed SE-mode request execution. As soon as a re-increase of $p_{t_{i+1}}$ is detected then the ratio between $H_1(t_{i+1}, p_{t_{+1i}})$ and $H_2(t_{i+1}, p_{t_{+1i}})$ should be lowered compared to the accounting scheme used in the last update run at time t_i. Doing so, the profit of the distribution agent is kept as high as possible. Bierwirth (2000) calls the adaptation of the internal decision model of the subordinate agent *image modification*.

We set $H_2(t, p) := 1$ for all subsequently generated accounting schemes and vary only the coefficient $H_1(t_i, p_{t_i})$ immediately before the process revision at time t_i. Let α denote the average quotient of the SE-costs and the SC-costs for the fulfilment of a request. We assume that $\alpha>1$ so that a delayed SE-service of a request is averagely cheaper than an SC-fulfilment of this request. Now, we update $H_1(t, p_t)$ according to formula (3) exploiting the previously calculated control value h(e(t)).

$$H_1(t_i, p_{t_i}) = \begin{cases} 1, & i = 0 \\ 1 + \alpha \cdot h(e(t_i)) & i \geq 1 \end{cases} \qquad (3)$$

The generated sequence of accounting schemes is adapted to the current punctuality. If the control value h(e(t)) is equal or close to 0 then no variation of the relation costs associated with the two fulfilment modes is carried out. As soon as the control value takes a value close to its maximum 1 (in case that the punctuality is very small) then the value of $H_1(t_i, p_{t_i})$ is so large that the selection of the SC-fulfilment mode is cheaper for most of the requests from the point of view of the distribution centre agent. Consequently, the number of subcontracted requests is increased and the number of timely served requests might re-increase or the decrease of the punctuality rate is at least stopped or deferred.

Since the variation of the objective function of the distribution centre agent redefines the fitness landscape of the optimisation problem outlined in Subsection 2.4, it affects the direction of the optimisation algorithms' search trajectory. For this reason, we call this adaptation of the controlled subsystem Search Direction ADaptation (SDAD).

The Memetic Algorithm described in Schönberger and Kopfer (2007) is called to find a high quality process update for the current problem instance.

4 Computer Experiments Report

4.1 Setup of the Experiments

In order to verify the theoretical conception of the closed-loop control circuit we have performed comprehensive numerical simulation experiments. The general setting is as described at the end of Subsection 2.3. Streams of incoming requests are taken from the request sets introduced in Schönberger and Kopfer (2007). A spontaneous increase of the number of arriving requests from time 1500 until time 1700 simulates an external disturbance.

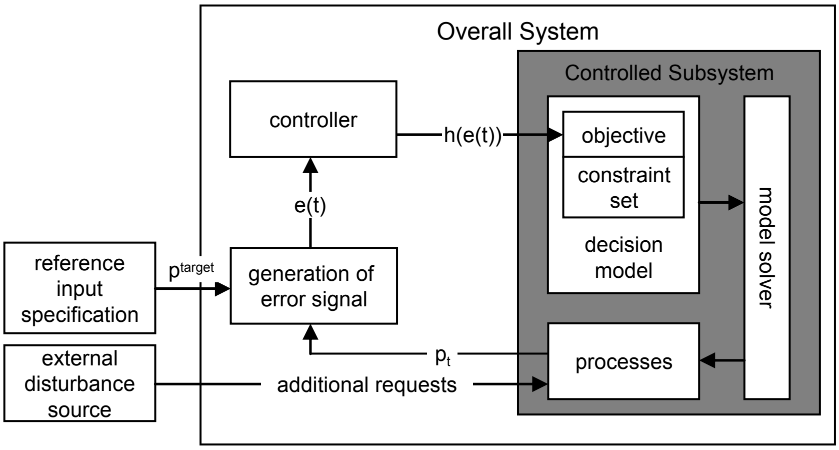

Fig 3.: Closed-Loop Process Control

Experiments with three different scenarios have been performed. The first group of experiments is labelled by E(1,NONE). Here, a comparable SC-mode tariff (α=1) is available and the coordinator agent does not intervene into the disposition subsystem of the distribution centre agent. In the remaining two groups of experiments, the SC-mode is discriminated by an SC-mode tariff that is higher then the SE-mode costs (α=3). We have performed experiments with (E(3,SDAD)) and without (E(3,NONE)) the application of SDAD-based interventions of the coordinator agent. Four different requests sets have been deployed in all three scenarios and each single simulation experiment has been executed three times (because the disposition algorithms deployed some random-based decisions). Overall 3×4×3=36 simulation experiments contribute to the subsequently presented results.

A simulation run is stopped after 5000 time units resulting in 50 repeated process update revisions. We have recorded the used accounting schemes (H_l-values), the current punctuality rates p_t and the percentage i_t of requests fulfilled in the SE-mode throughout each simulation run. Within each of the three scenarios, we calculated the average observed values for these three performance indicators for each revision time. In order to get a better understanding of the online variations over the simulation time, we calculated the relative variations of the punctuality rates p_t and the SE-mode usage i_t by computing $\tilde{p}_t := \frac{p_t}{p_{1000}}$ and $\tilde{i}_t := \frac{i_t}{i_{1000}}$ respectively. Finally, we computed the averagely observed marginal costs m_t by dividing the additionally realised costs between the two directly succeeding process update runs at time t_i and t_{i-1} and the number of meanwhile completed requests.

4.2 Results Report

The continuous line in Fig. 4 shows the relative punctuality $\tilde{p}_t$ observed in the E(1,NONE) scenario. During and after the peak of the incoming workload (starting from 1500), no significant decrease of the punctuality is detected. Here, the equal costs of the SC- and the SE-mode allow a cost-neutral mode-shift for so much requests, that no blockage of the capacitated own fleet is achieved. The profit-maximisation goal of the subordinate agent complies with the least punctuality requirement of the superior coordinator agent.

A quite different development of the punctuality rate is demonstrated in the E(3,NONE) scenario, where the higher SC-mode costs prevent the intensification of the SC-mode usage. Consequently (as shown by the dotted line), the punctuality breaks down to 40% below the initially detected punctuality. Furthermore, it lasts nearly 1800 time units until it re-achieves the value observed before the load peak started.

In the third scenario, the SDAD-based accounting-scheme adaptation is alive. The dotted-lined curve presents the usage-percentage of the maximal possible control value for h(e(t)) submitted into the controlled subsystem in order to adapt the accounting scheme to the current punctuality rate. Whenever the punctuality falls down, the control value is lifted for a certain period and pushes the SC-mode costs closer to the SE-mode costs in the used accounting scheme. With the modified objective function, the distribution agent get enough incentives to use the SC-mode to a larger extend and finally, the punctuality rate declines online slightly and for a short period below the required least punctuality rate (dashed-line). These simulation results verify the general applicability of the accounting-scheme adaptation concept.

The variation of the percentage of SE-fulfilled requests is compiled in Fig. 5. In the E(1,NONE) scenario (continuous line) strong variations of $\tilde{i}_t$ are observed because the comparable costs of the two fulfilment modes allow the cost-neutral selection of the most appropriate fulfilment mode so that both the coordinator agent's as well as the distribution centre agent's goals are achieved simultaneously.

If the costs of the SC-mode usage are increased and if the coordinator agent does not intervene by adjusting the accounting scheme (E(3,NONE)) then the load peak does not induce a variation of the percentage $\tilde{i}_t$ (dotted line). The consideration and usage of the accounting scheme modification convince the distribution centre agent to select the more expensive SC-mode (dashed line) often to the same extend observed in the E(1,NONE) scenarios.

So far, we have observed positive impacts of the accounting scheme variation. Nevertheless, the torsion of the objective function means a deviation from the striving for least cost transport operations (processes). If the objective function misleads the search trajectory of an optimisation algorithm, then the achievement of this goal will fail. The continuous curve in Fig. 6 shows the incremental (or marginal) costs m_t of the fulfilment of one additional request. If the costs are comparable then the workload peak does not affect the marginal costs. Delays are prevented by the intensified SC-mode utilization. The marginal costs m_t oscillates around 15 monetary units. The increase of the SC-mode costs in the E(3,NONE) scenario prevents the intensification of the LSP incorporation after the demand peak. Instead, delays are accepted which causes penalty payments, so that m_t increases after the demand peaks establishment and it takes a long period until its re-achieves its initial value (dotted line).

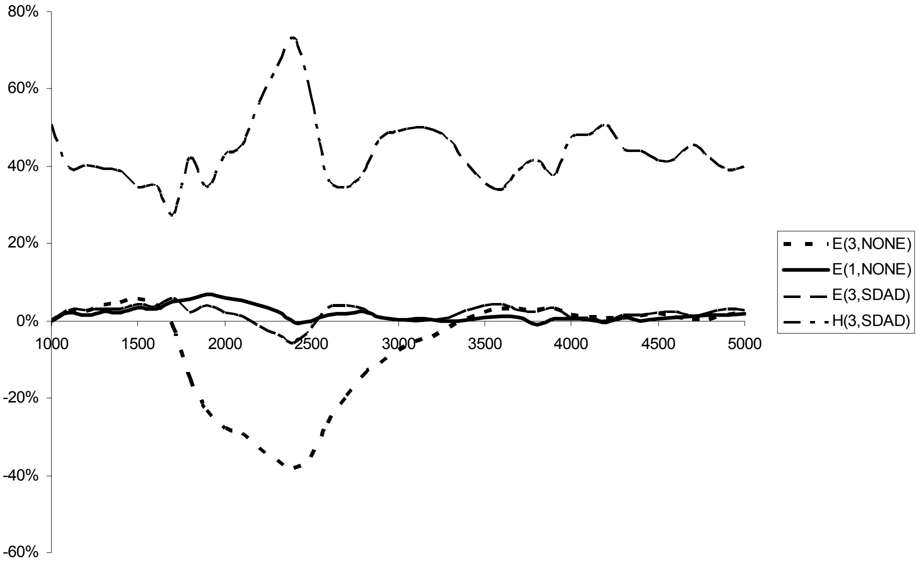

Fig. 4: *Variation of the punctuality* $\widetilde{p}_t$

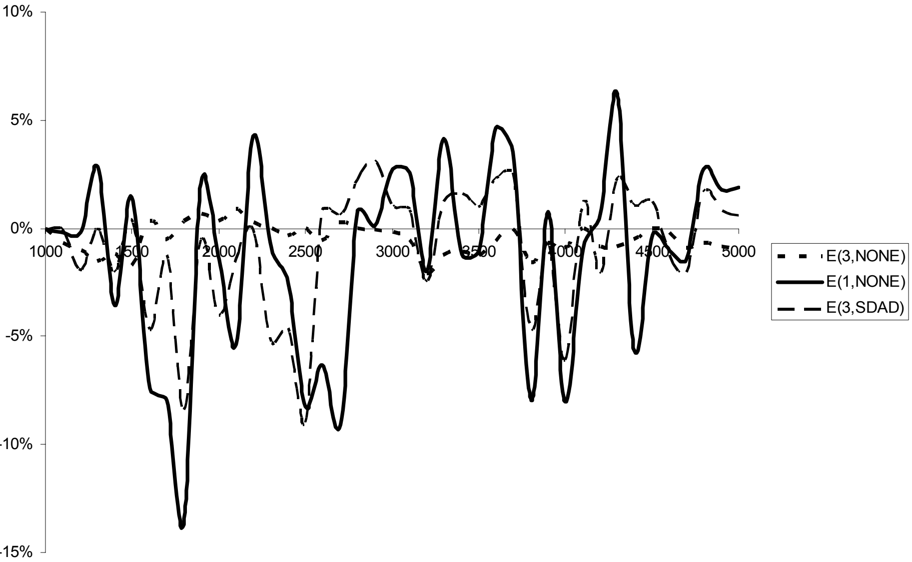

Fig.5: *Variation of the internalisation quote* $\widetilde{i}_t$

In the E(3,SDAD) scenario, the adaptation of the accounting scheme temporarily increases the LSP-service incorporation. The usage of the SC-mode causes costs but helps to keep the number of waiting requests (already scheduled but not yet finished) quite small. Consequently, the marginal costs are high immediately after a severe coordinator agent intervention but m_t falls below the marginal costs in the E(3,NONE) scenarios, if the control value is low (dashed curve).

5 Conclusions and Outlook

We have investigated a dynamic decision problem in which a superior agent observes the achievement of its own disposition goal and gives incentives to a subordinate agent to adapt its own decision making and the subordinate agent should contribute to the achievement of the superior agent's goal. The adaptation of the behaviour of the dominated agent is modelled as a close-loop control circuit and coupled with the open-loop process control circuit of the subordinate agent. We have proven the suitability and applicability of this integrated approach within numerical simulations. Future research efforts will be dedicated to the revenue control of the coordinator agent exploiting the knowledge about the current marginal request completion costs.

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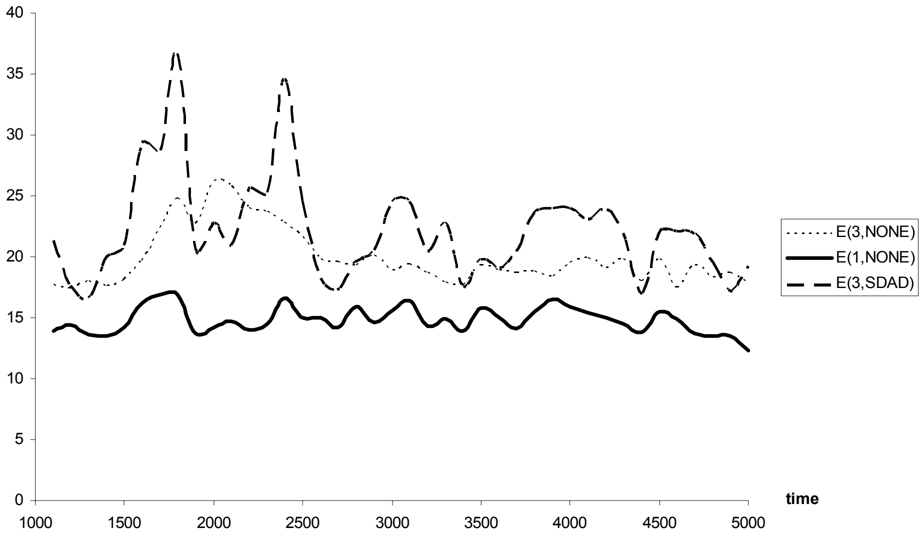

Fig. 6: Marginal costs

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