Integrating Transportation in a Multi-Site Scheduling Environment

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Abstract

Multi-site scheduling deals with the scheduling problems of an enterprise with several distributed production sites, where sites are using the intermediate products of other sites to manufacture the products of the enterprise. Therefore the transportation of the raw materials and the intermediate products to the plants is an important task within the whole process of manufacturing. Scheduling problems are treated on two levels. On the global level a global schedule is generated including the requirements for the local level schedulers which then have to transform the global schedule into a local schedule for manufacturing. Since transportation is a vital task in the multi-site scenario, we will view it as a scheduling task on the local level as well. Besides the "classical" objectives of transportation tasks such as finding shortest paths or minimizing costs the temporal restrictions of meeting the delivery dates here are the most important goals. In this paper we describe how transportation tasks can be modeled as a scheduling problem and which kind of solution strategies are appropriate.

1. Introduction

The main task of scheduling is the temporal assignment of activities to resources where a number of goals and constraints have to be considered. Scheduling problems can be found in several different application areas, e.g., the scheduling of production operations in manufacturing industry, computer processes in operating systems, aircraft crews, etc. Scheduling covers the creation of a schedule of the activities over a longer period (predictive scheduling) and the adaptation of an existing schedule due to actual events in the scheduling environment (reactive scheduling) [1, 2]. However, scheduling also has a very important interactive dimension because we always find humans involved in the scheduling process who have to decide, interact or control. Among the decisions to be taken by the human scheduler (the user of the scheduling system) are, e.g., introducing new orders, canceling orders, changing priorities, setting operations on specific schedule positions. These decisions have to be regarded within the scheduling process [3].

The complexity of real-world scheduling scenarios is mainly determined by

- the requirements imposed by numerous details of the particular application domain, e.g. alternative machines, cleaning times, set-up costs, etc.,
- the dynamic and uncertain nature of the manufacturing environment, e.g. unpredictable set-up times, machine breakdowns, etc.,
- conflicting organizational goals, e.g. minimize work-in-process time, maximize resource utilization, and
- the need of interaction with a human scheduler.

Additional tasks and problems arise if one looks at a multi-site production environment where hierarchical coordination and distributed scheduling is necessary. This will be described in more detail in sections 2 and 3.

Because most of the scheduling problems to be optimized have been proven to be NP-hard and due to the dynamic character of the scheduling environment the solutions proposed for real world scheduling problems rather look for feasible than optimal solutions.

Transportation problems as the other area of interest classically deal with finding cost optimal routes to deliver goods from depots to customers. Therefore the problems are formulated as combinatorial optimization tasks with a depot and a set of demands of delivery points with known distances and capacities of a fleet of vehicles. This problem is known as vehicle routing problem (VRP) and stresses the geographical aspects of transport. The vehicle routing problem with time windows (VRPTW) is an extension of the problem introducing time windows to define intervals in which the demand has to be satisfied.

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Here the temporal aspect and its constraints are emphasized but the capacity restrictions of the vehicles are neglected or simplified.

If we look at transportation tasks within supply chains or in a multi-site scheduling environment with just in time demands we have transportation orders like: "load amount A1 of product P1 at location L1 between time t1 and t2 and deliver it at location L2 between t3 and t4". Now the temporal constraints are the most important constraints, but the capacity and cost constraints are valid as well in order to create economically feasible solutions. Additionally, like the scheduling tasks mentioned above, the transportation tasks have to cope with a highly dynamic environment and uncertain information.

In this paper we will look at the transportation problem from a scheduling perspective. First the transportation problem within a multi-site scheduling scenario is described. Afterwards our solution approach to transport scheduling and related approaches are presented.

2. Transportation in a multi-site scheduling environment

Usually, scheduling problems are treated in a single plant environment where a set of orders for products has to be scheduled to a set of machines [1, 4-6]. In other systems single resources, e.g., the Hubble telescope, or a set of specific transportation orders, e.g., the DITOPS system [7, 8], are tackled. However, within many industrial enterprises the production processes are distributed over several manufacturing sites, which sometimes are spread over several countries. The sites themselves are responsible for the production of various parts of a set of final products. Therefore the in time transportation of intermediates from one location to another becomes a key issue in the whole manufacturing process and thus also in the scheduling process.

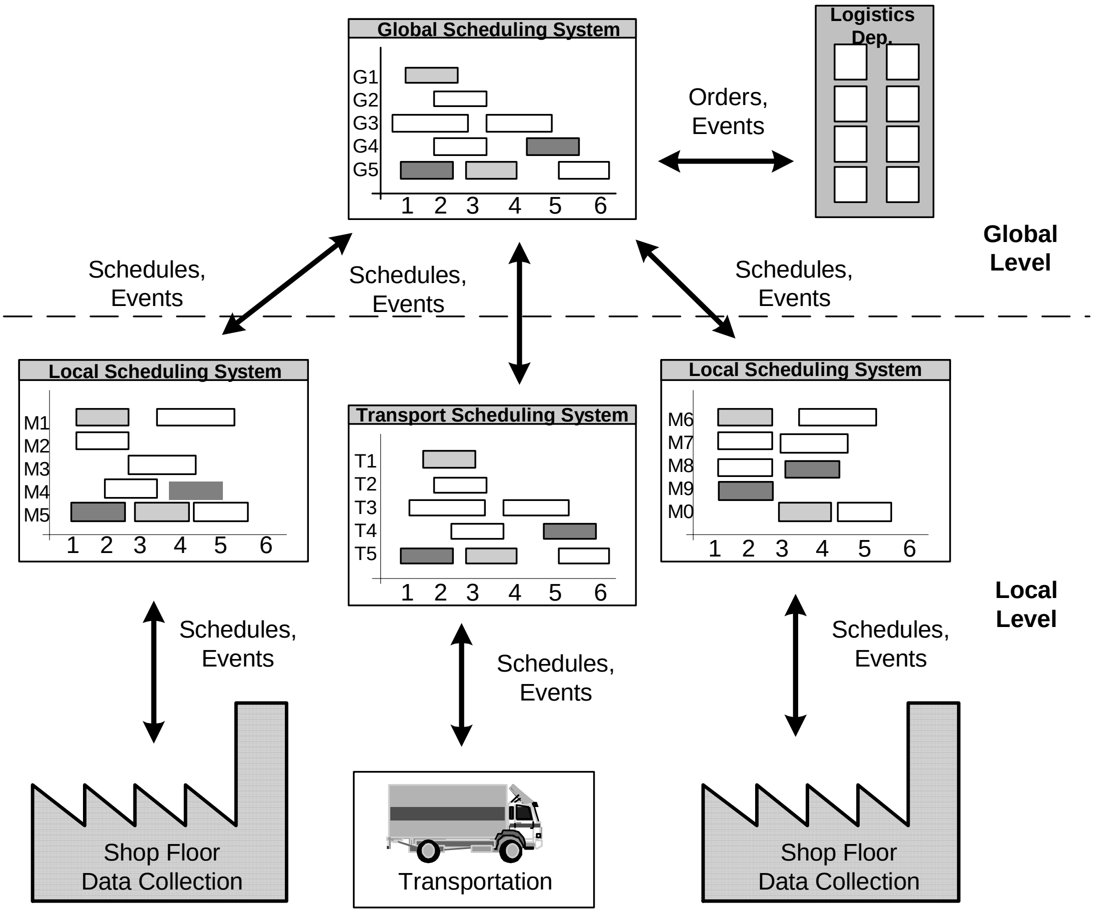

Figure 1. Multi-site scheduling with transportation scheduling

Due to the distribution of production processes to different plants and the need for coordinated scheduling some specific problems arise which have to be regarded in the scheduling algorithms. Among them are:

- production processes that are performed in different plants are related, e.g., by temporal or precedence relationships. The production process may have different costs at different sites.
- on the global level cumulative and imprecise (estimated) data are used.
- coordination and communication between the participating systems is necessary.
- different, often contrasting goals have to be regarded on the different levels, e.g., meeting due dates on the global level and minimizing work in process on the local level.
- the transportation of the intermediate products from one plant to another respectively to a depot used as intermediate stock becomes one of the important tasks in order to guarantee short lead times of production.

Additionally, in the scheduling procedures used for multi-site scheduling today there is no immediate feedback from the local plants to the logistics department and communication between the local schedulers takes place without any computer-based support.

Within our multi-site scheduling project [9] we cope with these problems and introduce a hierarchically layered system with coordinated scheduling systems for the specific scheduling tasks on the different levels. Figure 1 illustrates a hierarchical two-level structure of multi-site scheduling reflecting an organizational structure often found in business.

On the global level requirements are generated for intermediate products manufactured in individual locations. On this level the generation of a robust global schedule is very important. That means, that a schedule should be generated that gives enough flexibility for a local scheduler to react to local disturbances without affecting the other sites. This can be achieved among others by heuristics using buffer times in the time windows for local production and trying to optimize the load balancing on the machine groups or by using fuzzy techniques. Additionally, it is important to detect capacity problems as early as possible and in case of reactive scheduling, to preserve as much as possible of the existing global schedule in order to minimize the subsequent effort on the local level.

Local scheduling (at individual locations) deals with the transformation of the global schedule into concrete local production schedules which represent the assignment of operations to machines. On both levels predictive, reactive as well as interactive problems are addressed, not only to generate schedules but also to adapt them to the actual situation in the production process.

Additionally, the coordination between these tasks has to be supported in order to provide all components with actual and consistent information.

An important point within the production process is that the intermediates have to be transported between the sites. Normally, e.g., in ERP systems, only a time buffer is used to denote that the intermediate product has to be transported from one site to the other. But what if the transport fails or is delayed for any reason? The succeeding site has to know about the delay in order to reschedule its activities. And what if the product to be transported will not be ready for transport? The transport facility, too, needs information about such changes in order to reschedule the transportation tasks. Therefore it makes sense to look at transportation tasks as if they were activities to be scheduled and use the representation and problem solving techniques from scheduling to solve this problem. This also means that transportation is an integrated feature in multi-site scheduling systems and should be interpreted as a local (scheduling) site. Figure 1 shows the extended scenario with a transportation facility as a local scheduling site.

3. Solving the transportation scheduling tasks

If we look at transportation as an integrated local scheduling task in multi-site scheduling systems we can formulate the problem similar to those of the other local production schedulers. First, some of the tasks and problems will be described using a simple example.

The transportation scheduler receives a set of transportation orders with information about the intermediate product to be transported, the amount of the product, the earliest pick up date, and the latest delivery date (due date).

Table 1. Transportation orders

Order/ Product	from	to	amount	pick-up	deliver
1	A	B	100	3	5
2a	B	C	100	7	10
2b	B	C	100	7	10
3a	A	C	100	6	9
3b	A	C	100	6	9
4	B	A	100	2	4

Table 1 shows a set of four orders for the transportation of 4 products between three locations A, B, C. The time window within which the orders should be scheduled is given by "pick-up" and "deliver". The resources are the transportation vehicles which can transport a specific amount of products of a specific type, e.g., liquids or palettes. In the example we have two trucks with a capacity of 100 each. As the maximum capacity of the trucks is 100, orders 2 and 3 have been splitted to 2a, 2b, 3a, 3b. As transportation costs we use the duration of the transport:

- from A to B (B to A): 2
- from B to C (C to B): 2
- from A to C (C to A): 3.

Some additional information is not used in the example, e.g., the products to be transported can vary in size, type and weight, orders may be merged, products may be stored, there may be more technical requirements, e.g., a specific kind of transport vehicle is needed, or a specific sequence of orders is necessary.

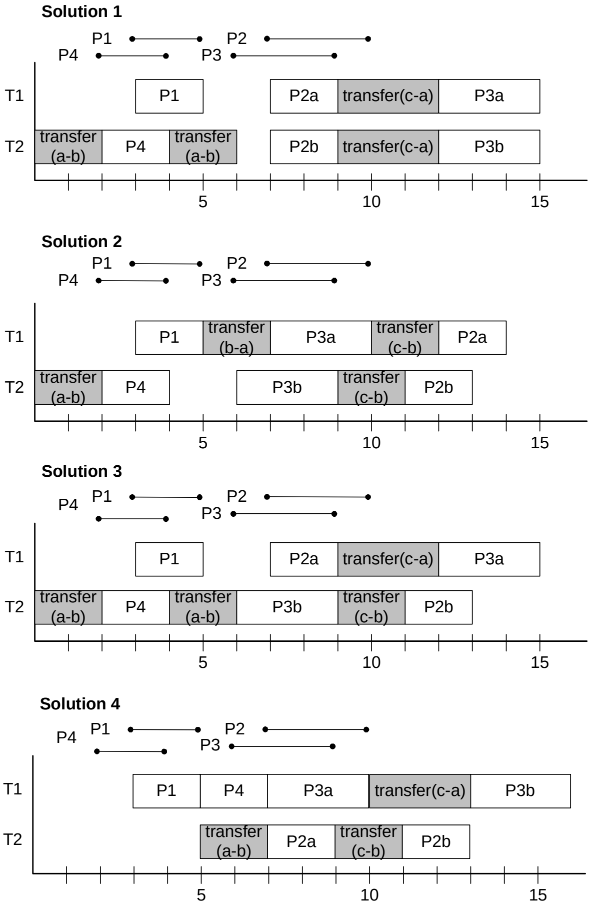

Figure 2. Example solutions

Figure 2 shows four possible solutions. We assume that the trucks are located in A at time 0. The first two solutions are calculated using an order-based approach (see below), solution 3 tries to deliver as much as possible of the products in time, solution 4 tries to minimize the transportation costs. The transfer is necessary to bring the trucks to the next location for pick up. There is no solution which fulfils all the temporal constraints. Table 2 shows some results of objective functions for the solutions, the number of late orders (products), the sum of the latenesses of the orders and the sum of the transportation costs for the schedule. The table illustrates one important problem not only of this kind of scheduling, i.e. what is the best solution and how can one find it? Solution 2 is the best one if we look at lateness, solution 3 is slightly worse but part of the products will be delivered in time. Is it therefore better than solution 2? Solution 4 is the best when considering transportation costs, but 4 of the six products will be late. Experience shows that it mainly depends on the problem situation and the user of the system what will be accepted as the best solution. Additionally, if we have to cope with reactive scheduling then feasible solutions and user interaction will become more important.

Table 2. Evaluation of the results

solution	late orders	lateness	transport costs
1	2 (1 product)	12	24
2	3 (2 products)	8	22
3	2 (2 products)	9	23
4	4 (3 products)	14	21

For a solution approach it is necessary to describe what information is needed to model the problem and how it is used. Therefore the following information should be available at the local level for a transportation order to determine a detailed transportation schedule:

- a set of transport activities for products. Each activity is accompanied with information, e.g., about the type of product, appropriate vehicles, the estimated duration and route of the transport.
- a set of vehicles as resources. For each vehicle we know, e.g., the capacity, the type and the range. Coupled with the vehicles are the drivers who can also be seen as resources.

Of importance is also information about stocks at the production sites or elsewhere because this allows or forbids delays. This and other necessary information may be represented by hard and soft constraints, e.g.,

- as hard constraints
    - meet user requirements, e.g., orders already scheduled by the user,

    - meet the technical requirements, e.g. the capacity of the vehicles, the need for a specific kind of transport vehicle, or existing capacity restrictions for some routes.
- as soft constraints
    - realize a just in time delivery,
    - meet the due dates respectively time windows of the transportation orders,
    - use preferred routes,
    - optimize the vehicle (capacity) usage,
    - optimize transportation costs.

We should keep in mind that the last two goals are even goals of the classical vehicle routing problems. If we look at the predictive scheduling task it seems to be possible to include features of the problem solving approaches from transportation research, e.g., from vehicle routing problems with time windows [10]. But if we look at the dynamic environment in which the transportation scheduling is integrated, it seems likely that reactive scheduling will be often the case in transportation scheduling, too. The environment consists of imprecise global schedules where new orders are introduced dynamically and several local scheduling systems that have to react to all kinds of events. The events one has to deal with in the transportation domain are amongst others:

- changes of local resources, e.g., breakdowns, maintenance,
- delays in transport due to traffic conditions such as deviations, traffic jams,
- changes in orders for transportation activities,
- user interactions.

Additional characteristics of the transportation tasks that have to be handled when solving the problem include the division of orders into suborders, a dependence of the number of necessary vehicles on the order amount and several routing decisions, e.g., if and when a vehicle should be rerouted or which orders can be handled by one vehicle.

Thus, we will have to look for good heuristics that will produce feasible solutions or proposals for schedules in a short amount of time. The solution does not need to be optimal in terms, e.g., of production costs, but feasible especially regarding the temporal constraints. Additionally, user interaction should be possible, e.g., for fixing some activities to specific vehicles or time intervals, and the system has to deal with the events of the dynamic environment. This functionality has to be incorporated in the scheduling system (not only for the transportation problem). Therefore we favor an approach that produces feasible solutions and checks constraint violations by the user. The approach bases on AI techniques for modeling and problem solving and will be presented in the remainder of this section starting with the modeling of the problem, then presenting a heuristic for the creation of a schedule and some remarks on other features of the system like rescheduling and user interaction.

Table 3. Modeling global, local and transportation scheduling

	Local Scheduling	**Transportation Scheduling**	**Global Scheduling**
R	machines	transportation vehicles with capacity and other restrictions	groups of machines
P	intermediate products consisting of several production steps (operations)	transport of intermediate products using specific transportation vehicles	final products consisting of several intermediate products
O	internal orders for intermediates	internal orders for intermediates	external orders for final products
HC	schedule all orders, regard production requirements (one variant, precedence constraints)	schedule all orders, regard technical requirements (type of vehicle, transport capacity)	schedule all external orders, regard production requirements (one variant, precedence constraints, capacity)
SC	"optimal" machine utilization, meet due dates, minimize work-in-process costs.	meet due dates, "optimal" vehicle utilization, minimize costs.	meet due date, minimize transportation times/ costs, use production equally, reduce inventory costs.

Global, local and transportation scheduling problems can be modeled similarly by the five-tuple (R, P, O, HC, SC) [11], where R denotes the set of required resources, P the set of producible products, O the set of actual orders, and HC and SC stand for the sets of hard and soft constraints, respectively. Table 3 shows this model applied to global, local and transportation scheduling with examples for the items.

The actual data of the R, P and O sets are typically stored in a database, the constraints have to be handled by the problem solving component. In the rule-based approach presented below the constraints are incorporated in the selection rules and the control constructs of the algorithm.

Similar to the representation it is also possible to transfer algorithmic approaches from knowledge-based production scheduling to the domain of transportation scheduling. Because it will not be possible to find the one and only algorithmic solution for all the features of the transportation scheduling problem described above, several strategies have to be checked and an appropriate one should be choseable by the user together with manual scheduling. To describe (and implement) several strategies we adopt an approach from [11] with which scheduling algorithms can be built dynamically by combining strategies represented as skeletons with selection rules, e.g., heuristics for orders, resources, intervals etc. A simple order-based heuristic strategy similar to those used in scheduling production could be as shown in figure 3. Resource-based or time-based strategies are possible as well.

```
BEGIN
WHILE transportation orders to
      schedule
       select order
       select possible transportation
            vehicle
       select time interval
       IF possible THEN schedule it
       ELSE solve_conflict.
END WHILE
optimize schedule
END
```

Figure 3: Order-based heuristic for transportation scheduling

Heuristic knowledge of the domain as well as approaches from knowledge-based scheduling [12] and operations research like the savings-heuristic [13] can be used within the *select* statements and the *solve_conflict* statement. Possible rules for selection and conflict resolution are:

- **select orders** by earliest due date or slack rule or importance (user given priority)
- **select vehicle** by first fit or best fit regarding capacities or by using bottleneck resources first or by looking at the route already scheduled (looking for the nearest route passing the start/ destination)
- **select time interval** in a just in time manner (backward from due date) or forward from earliest pick up
- **conflict resolution** may incorporate looking for alternative intervals, alternative transport vehicles or user driven decisions like outsourcing of transportation orders to external carriers.

In the optimization phase (*optimize schedule*) it should be possible to use one or more strategies to improve the schedule in order to optimize other goals like minimal costs. This could be done, e.g., like in DITOPS by splitting and merging routes [8]. Iterative improvement techniques may also be a promising approach [14].

In the case of a necessary reaction due to events like vehicle breakdowns, parts of the strategy presented above can be used to find alternatives, e.g., as in *conflict resolution*. Important is the possibility of user interaction, e.g., for proposing alternatives or changing orders or capacities.

The system architecture is based on the common architecture of all the local and global scheduling systems within our MUST project (see figure 4). The user interface is adopted from the global scheduling area presenting two views of the transportation schedule, an order based perspective showing the orders and the resources used for transportation, and a resource based view showing the resources and the products they have to transport. Because communication is an important feature of the multi-site scheduling system it is provided also for the transportation scheduling system, which is located on the local level.

The following events can be communicated between the levels:

- the global schedule showing the transportation orders,
- changes in the global orders,
- the local realization of the global orders,
- events of the local level important to the global scheduler because they need rescheduling effort, e.g., breakdowns of resources.

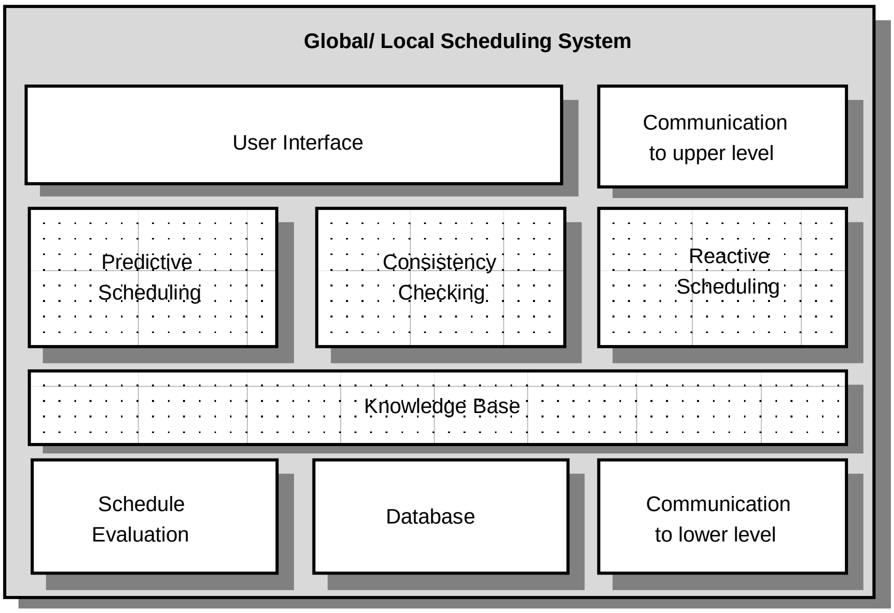

Figure 4: Common architecture of scheduling system

4. Related work

In Operations Research most of the approaches presented deal with vehicle routing problems, where optimal solutions regarding some cost function have to be found. Thus the techniques used only look at the geographical aspects of the problems. Extensions using time windows for delivering and uphauling products are called vehicle routing with time windows or vehicle scheduling problems. Here the approaches concentrate on the temporal constraints often neglecting the capacity restrictions of the vehicles and the distances between the locations. As most of the problems belong to the NP-hard problems newer solution approaches are using constraint programming [15], heuristics [16], and genetic algorithms [10] to find near optimal solutions.

Using the approaches from above the dynamic nature of the transportation problems as well as the changing environment can not be taken into consideration. They seem to be better suited for the predictive case of finding routes or schedules for specific or standard problems.

Solutions inspired by the work in AI can be divided into two categories. One consists of systems that use an agent based paradigm where a set of cooperating agents is used to model the transportation problem and to solve the transportation scheduling tasks. Among these are the MARS system [17], a system using partial intelligent agents [18] and the TELETRUCK system [19]. Important differences are in what the agents are representing and what kind of responsibilities they have, e.g., in the MARS system two groups of agents - truck agents and transportation company agents - are cooperating via an extension of the contract net protocol to solve the transportation tasks. The companies do not have scheduling facilities, the actual schedule for the whole company is spread over the truck agents and maintained by them. Thus the agent based paradigm provides a more control oriented, reactive view of the problem and its solution.

The second group of systems are intended as decision support systems and use heuristics to find initial and reactive solutions for specific transportation tasks, e.g. the DITOPS system [20]. In the DITOPS system a mixed initiative approach is used including a constraint-based scheduling system and user interaction for proposing alternatives whenever the problem is overconstrained and no valid solution can be found. The approach presented here belongs to this second category.

5. Conclusion and future work

It has been shown that, especially within a multi-site scheduling environment, it is possible to treat transportation problems as scheduling problems. A representation formalism and a heuristic strategy for solving transportation scheduling problems have been presented.

The work is included in the distributed knowledge-based scheduling system MUST [9] which has been designed to support the human experts in the management of the dynamic distributed manufacturing environment, in particular in scheduling the appropriate distribution of the orders to the different manufacturing plants as well as in coordinating the decentralized scheduling activities for all plants within one enterprise. The objective of this approach is the reduction of complexity of distributed scheduling and improving the quality of the solution at the same time. The MUST system consists of one global scheduling subsystem and several local subsystems, one for each individual production site. Common features of all subsystems of the multi-site approach are:

- All components are based on knowledge-based techniques, i.e. problem-specific knowledge is identified, represented, and applied for the solution of the addressed problem.
- Several problem solving techniques have been investigated for use in the scheduling components.
- The reactive scheduling components on both scheduling levels are realized as a leitstand with a sophisticated graphical user interface allowing interactive scheduling.
- The user interfaces are window-oriented and most functions are mouse-sensitive.
- Each subsystem contains two communication interfaces for the information exchange within MUST and the integration of the MUST system into an existing organizational environment.

An early prototype was implemented in PROLOG. We now work on a redesign using object oriented features and JAVA as implementation language.

Within the transportation scheduling system several strategies shall now be implemented and evaluated using example or benchmark problems if available. Another approach investigated in our working group uses agent-based technology to solve the multi-site scheduling problem with a multi agent system including an multi agent approach for the transportation problems. This approach will also be compared with the "simple" heuristic one presented here.

The results of the work on multi-site scheduling can be adapted to the whole supply chain or to other application areas, e.g., distributed software development or project management. This will be one of our future research areas.

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