Available-To-Promise (ATP) Systems: A Classification and Framework for Analysis

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Abstract

Available-To-Promise (ATP) systems deal with a number of managerial decisions related to Order Capture activities in a company, including order acceptance/rejection, due date setting, and resource scheduling. These different but interrelated decisions have been often studied in an isolated manner, and, to the best of our knowledge, no framework has been presented to integrate them into the broader perspective of Order Capture. This paper attempts to provide a general framework for ATP-related decisions. By doing so, we 1) identify the different decision problems to be addressed, 2) present the different literature-based models supporting related decisions into a coherent framework, and 3) review the main contributions in the literature for each one of these. We first describe different approaches for Order Capture available in the literature, depending on two parameters related to the application context of ATP systems, namely the inclusion of explicit information about due dates in the decision model, and the level of integration among decisions. According to these parameters, up to six approaches for ATP-related decisions are identified. Secondly, we show the subsequent decision problems derived from the different approaches, and describe the main issues and key references involving each one of these decision problems. Finally, a number of conclusions and future research lines are discussed.

Keywords: Available-To-Promise, Order Capture, Due Date Management

1. Introduction

This paper deals with Available-To-Promise (ATP) systems. ATP systems refer to a number of managerial decisions related to Order Capture activities in a company, including order acceptance/rejection, due date setting, and order scheduling. Clearly, the efficient handling of these decisions is of utmost importance for nowadays companies.

While the importance of ATP systems is widely recognised in the literature, there are a number of problems that one faces when approaching existing research in the topic. First, there is no consensus on which decision problems are included under the labels of 'order promising', 'order fulfilment', 'Order Capture', 'ATP', or 'advanced ATP'. While it is not practical to try finding exact borders for such a dynamic and evolving topic, it is clear that this heterogeneity in the scope is problematic to establish a research framework. Probably, the variety of situations and hypotheses does not help to unify the theory. On the other hand, it has been stated that, while there are general papers discussing the needs and potential features of ATP systems, there are few contributions dealing with their underlying decision models (Chen et al., 2002). However, since there is a wealth of literature on related topics, being perhaps the most notable case due date scheduling and due date assignment models, one wonders that there is a lack of quantitative models, or maybe the case is that the different but interrelated decisions have been often studied in an isolated manner. To the best of our knowledge, no framework has been presented to integrate them into the broader perspective of ATP systems. Finally, the lack of such a framework is likely to be the cause that there are hardly works on developing mechanisms to ensure flexibility and/or to reinforce the consistency among the different decisions.

This paper attempts to provide a general framework for ATP-related decisions. By doing so, we integrate the relevant decisions into a coherent scheme and discuss them. Given the huge extension of the related literature, it is not feasible to provide a comprehensive review of the plethora of existing models and solution procedures for the underlying problems. Instead, we discuss the key references and, when possible, point the reader to the corresponding state-of-art reviews.

The remainder of the paper is organized as follows: In Section 2 we discuss the concept of Order Capture and the activities to be carried out in this process. From these activities, we infer the main decisions to be supported by ATP systems, and in Section 3 discuss the context in which these decisions are to be taken. Section 4 presents the different approaches to ATP-related decisions depending on the consideration of the information on due dates, and on the level of integration of the different decisions. These approaches are then discussed and the corresponding decision problems are identified. Section 5 is devoted to a detailed discussion of these decision problems, while Section 6 contains the conclusions and future research lines.

2. Activities related to Order Capture

Activities related to customer orders in a company may be classified into three categories (see Veeramani and Joshi, 1997; or Kingsman, 2000 for a similar approach):

- Order Capture. Order capture starts when a customer places a Request For Quotes (RFQ). Typically, a RFQ consists of a list of required products and the quantity required for each one of these. It may also contain information about expected due dates, either in the form of indications that may be negotiated, or as strict dead-lines (later on we discuss variations of these with respect to input data). A response to the customer is given in terms of how many of these requirements can be fulfilled, at which dates, and at which prices (see below for details and variations on this response). From this response, a (firm) order is agreed upon customer and supplier, perhaps after an iterative process of negotiations about the quantities, dates, and prices initially provided by the supplier and/or the customer. The detailed activities involved in this process are shown e.g. in Kingsman et al. (1996).
- Production Planning (Order Planning). Production Planning encompasses all activities carried out until the initiation of the Production Orders (PO). This includes manufacturing process planning, production planning, and material acquisition, among others. PO are the result from customer orders (from Order Capture), planned demand (obtained by a demand forecast), or a mix of both. Note that, in a strictly pure Make-To-Order environment, most of these activities will be carried out right after Order Capture. In practice, however, at least some of these activities (i.e. raw material purchase) overlap in time with those of Order Capture.
- Order Execution. Order Execution refers to the set of activities (such as e.g. shop floor control) carried out after the initiation of the manufacturing of the process customer order until it is completed.

In this paper, we focus on Order Capture, also labelled by some authors as Customer Enquiry stage (see e.g. Kingsman et al., 1996; or Xiong et al., 2006). Even if traditionally considered of great importance, Order Capture has become even more prevalent due to a number of factors, including:

- The move from Make To Stock (MTS) to Make To Order (MTO). Increasing individuality of customers' requirements tend to replace Make To Stock (MTS) systems by Make To Order (MTO) systems. The most important point in MTO systems is the point in which jobs are accepted and due dates are promised to the customer (Yeh, 2000).

- Dramatic changes in the Order Capture process. While traditional Order Capture process typically involves some negotiation between sales personal and the customer over a relatively long period of time, new channel sales (i.e. e-Business) may require companies to fully automate the Order Capture process and to provide quotes in real-time.
- The rise of the customer-driven manufacturing, in which manufacturing is driven by customer orders (Parente, 1998). Customer-driven manufacturing is seen as a key concept for the factory of the future (Wortmann et al., 1997).

Broadly speaking, ATP (Available-To-Promise) systems can be defined as the decision making tool to efficiently support (some/all) related Order Capture activities. ATP is essentially a software system, usually embedded in Enterprise Resource Planning (ERP) systems and/or Advanced Planning Systems - APS (Pibernik, 2005). Although the functional scope of ATP systems may vary significantly from one vendor to another, we will try to determine which functions these systems should ideally cover regardless their implementation on currently available software packages.

Traditionally, the functionality of ATP systems has been confined to determining the availability of finished goods at certain points of time in the future. This traditional view of ATP is supported by the APICS definition (APICS, 1987): "ATP is the uncommitted portion of a company's inventory and planned production at a designated location". This is also called 'availability check' (Zschorn, 2006), or labelled 'ATP check' in some commercial packages (Dickersbach, 2004). The term CTP (Capable-To-Promise) adds some functionality to the availability check if the result of the latter is negative and production is required (Zschorn, 2006). In this regard, ATP may be linked to existing products while CTP is linked to capacity to produce. However, CTP is often included into the functionalities of ATP (Kilger and Schneeweiss, 2000).

While the above functionalities are covered by what some authors describe as 'conventional' ATP systems (Pibernik, 2005; Zhao et al., 2005), these are judged insufficient to cope with nowadays firms' requirements. To do so, one must place ATP functions into the global scope of Supply Chain Management Systems. According to the Supply Chain Matrix (see Stadtler, 2005), Demand Management activities are included into three 'blocks', i.e.: Strategic Network Planning, Demand Planning, and Demand Fulfilment & ATP (DF & ATP). Broadly speaking, this distinction refers to the time-decision range (long, medium, short). Strategic Network Planning includes (among other non-customer related activities) product program and strategic sales planning. Then, Demand Planning and DF & ATP activities are differentiated depending on whether they occur before or after the decoupling point see e.g. (Ball et al., 2004). As a consequence, Demand Planning basically includes forecasting-related activities, while DF & ATP would include the following activities:

- Order Promising. Order Promising includes activities related to the acceptance/rejection of jobs (Order Acceptance or Order Selection), and to setting the delivery date (Due Date Assignment, Due Date Determination, or Due Date Quotation). Since there are many contributions in the literature dealing with the two topics separately, in the following we substitute the topic of Order Promising by these two components[1].
- Order Scheduling and Control. This includes the short-term allocation of component stock to production orders (or finished product stock to delivery orders), the release of production/delivery orders, and the scheduling of production orders. Order Promising and Order Scheduling and Control are sometimes collectively known as 'Order Fulfilment', a term which is not uniquely used in the literature (see remark before).
- Shortage Planning. This refers to the activities to be accomplished in case of unavailable (component or finished products) stock. The activities include decisions on supply alternatives (outsourcing, substitutive products), and negotiation with the customer (late supply, partial shipments, etc.). From a modelling viewpoint, shortage planning deals with relaxing some constraints that have been previously considered in Order Promising or Order Scheduling decisions, and that lead to a non-acceptable solution. Since in this paper we basically deal with ATP models, Shortage Planning activities will be considered in the corresponding decision models (see Section 3.3. on types of flexibility).

According to these definitions, we can conclude that the main decisions in ATP systems refer to:

- **Order Acceptance/Selection (OAS)**, i.e. decide whether a RFQ or set of RFQs are to be accepted as firm orders. When several RFQs are involved in the decision, then it typically consists of selecting a subset of RFQs for acceptance, henceforth in this case the problem is denoted as Order Selection. Note that this decision can be taken: a) in the absence of explicit customer due dates in the RFQs (and then the decision may involve economic benefits of order acceptance/rejection in view of the actual workload, set up costs, capacity reservations for forecasted orders, among others), b) according to due dates in the sense of indications provided by the customer (which usually involves consideration of penalties associated to deviations from these due dates as well as economic considerations as in the previous cases), or to dead lines provided by the customer (which leads to feasibility/unfeasibility problems along with previous economic issues).

[1] Additionally, the terms 'Order Promising' and 'Order Fulfilment' are not clearly defined in the literature. For instance, while Zhao et al. (2005) state that '… and ATP must include both order promising and order fulfilment capabilities' (indicating them as two separate aspects), others (e.g. Pibernik, 2005) consider 'order promising' as a part of 'order fulfilment', while others identify order fulfilment with order capture and order execution (Lin and Shaw, 1998). Finally, for other authors, order promising encompasses due date assignment plus the periodic control of the fulfilment of the so-promised due dates (Grant et al., 2002).

- **Due Date Assignment (DDA)**, i.e. establishing a due date for each accepted RFQ. This decision makes sense if the customers do not provide expected due dates in the RFQs, or these may be subject of negotiation. If the customers provide due dates (being these strict deadlines, or indications of expected completion time), there is no proper decision problem for due date assignment. Of course, from the subsequent scheduling decisions, completion times (and consequently, delivery dates) different from the due dates could be derived, but this is not a result of a DDA decision problem, but of the subsequent scheduling problem.
- **Order Scheduling (OS)**, i.e. planning the usage of the resources, raw materials, and starting and finishing times of the accepted RFQs, so economic considerations involving resource usage, set-ups, and due dates, are optimised.

This definition is consistent with most ATP (or advanced-ATP) literature: Zhao et al. (2005) state that "… the ATP function … provide a response to customer order request based on resource availability …, must insure that the quantity promised can be delivered on the date promised …, should be able to dynamically adapt resource utilisation and to prioritize customer orders". Pibernik (2005) states that "advanced ATP provides … order quantity and due date quoting on the basis of available supply chain resources and alternative measures in case of an anticipated shortage". According to this approach, ATP decision problems would be identical to those of Due Date Management (DDM), at least as it is understood by Keskinocak and Tayur (2003), although DDM is another term for which it seems that there is no unique definition, as some authors exclude/include acceptance/rejection decisions from it. Finally, note that the term CATP (Capacity-ATP) is also employed by some authors (e.g. Wu and Liu, 2008), to label the according set of functionalities.

3. The context of ATP-related decisions

The decisions identified in the previous section can be taken in different business contexts, as the Order Capture process may vary substantially from one type of business to another. Of course, since each company may establish unique relationships with its customers/providers, it is not possible to cover all situations. Nevertheless, our intention is to identify some patterns of the Order Capture process to understand the requirements of the decision models in ATP systems. By analysing the related literature, we have identified a number of factors (or dimensions) determining the context in which ATP-related decisions are taken. These are discussed in the following subsections.

3.1. The Timing of the Order Capture Process

Regarding the timing of the Order Capture process, the following types can be identified:

a) Real-time process. The customer expects an immediate response from the provider after posing the RFQ, and the provider expects an immediate confirmation of the RFQ (or its rejection). If the provider fails to provide an immediate response, the potential customer is lost. If the provider fails to provide an immediate confirmation, the response of the provider is not binding anymore. This type of process occurs in many e-Business settings.

b) Real-time quotation. The customer expects an immediate response from the provider after posing the RFQ. However, the provider does not expect an immediate confirmation of the RFQ. Usually, the quotation given by the provider becomes less and less binding (or even not binding at all) as the time for the confirmation becomes longer. Also, a deadline for customer confirmation can be issued by the company.

c) Off-line quotation. Neither the customer expects an immediate response from the provider, nor does the provider expect an immediate confirmation from the customer. Usually, one (several) round(s) of negotiations are accomplished before a confirmation is agreed.

In the literature, it is common to distinguish between real-time ATP and batch ATP (Chen et al., 2002), two concepts which are closely related to some of the previous definitions. In a real-time ATP, order quantity and due date quoting is completed immediately after the customer places the RFQ. In order words, the ATP module is activated after receiving a RFQ. In a batch mode, the ATP module is activated at regular intervals (batching intervals). During a batching interval, RFQs are first collected and then processed together.

However, most real-time ATP literature (implicitly or explicitly) assumes 'real-time process' and not 'real-time response'. Consequently, real-time ATP models perform a detailed scheduling calculation based on current shop-floor conditions. However, if the confirmation does not occur in real-time, such a detailed schedule may be useless, as shop floor conditions may have substantially changed. In such 'real-time response' process, perhaps it is more interesting to submit a quick approximate quotation as an estimate response to the customer which will be refined by a detailed scheduling only when the confirmation is issued by the customer. Indeed, in Ball et al. (2004) a two-step approach is described which is employed by computer retailers in the Internet consisting first of giving a soft (and coarse) commitment to the customer in real time, and after a few days giving a hard (and more accurate) commitment after collecting several RFQ.

Real-time ATP decisions have been also labelled in the scheduling literature as job-insertion problem (Roundy et al., 2005), as the decision is to insert a new job into an existing schedule (or, alternatively, rejecting it in case of no feasible solution can be found). However, here we make a clear distinction between 'order' (or RFQ) and 'job', as a single customer order usually consists of several jobs from the scheduling perspective. Therefore, job-insertion models would be a particular case of real-time ATP for such cases in which orders are made up of individual jobs.

3.2. Scope and integration

A key issue defining the scope of the decision problems is whether production management-related decisions are integrated or not. If they are not integrated, then it is clear that quantity and due date quoting must be performed on the basis of finished goods inventory (FGI), or on the basis of supply chain resources (SCR), including raw material, work in process, finished goods, and production and distribution capabilities (Pibernik, 2005). Therefore we can distinguish between FGI-ATP and SCR-ATP.

From a business perspective, an important distinction should be made between push-ATP systems and pull-ATP systems (Ball et al., 2004). Push-ATP systems pre-allocate resources based on demand forecast. In this regard, these systems are very similar to traditional production planning and inventory control systems (the main differences between these are discussed in Ball et al. 2004). Push-ATP systems provide very reliable order promise, however, since the decisions are based on forecasts, they may get intro trouble if these are not accurate. Pull-ATP systems perform dynamic resource allocation in direct response to actual customer orders. Such pull-ATP system will use a greedy algorithm, which can be myopic. This myopic nature can be mitigated by batch-ATP. But, as the length of the batching interval increases, the customer service degrades. Both types of systems do not have to be mutually excluding each other in practice. For instance, in Zhao et al. (2005) a real-life ATP system is described which mainly operates under a pull strategy, but, in order to anticipate future demands from high priority customers, some 'pseudo-orders' are booked into the system. Finally, it is to note that, from a modelling viewpoint, there is no difference between both types.

3.3. Flexibility

When a RFQ (or a set of RFQs) cannot be fulfilled according to one or more of its (their) dimensions (i.e. quantity, due date, prices), several options may be available to the company. These are based on the flexibility of the constraints imposed to the problem (usually by their integration into the objective function), and can be classified as follows:

- Product flexibility. In certain cases, substitute products can be delivered until the due date instead of the product originally ordered by the customer. Indeed, it has been observed that customers are often indifferent to certain aspects of product features, and that they are willing to make compromises with respect to trade-offs concerning different attributes (Zhang and Tseng 2008).

- Volume flexibility. As the whole quantities specified in the RFQs may not be delivered at the due date, a RFQ can be fulfilled by several partial shipments (see e.g. Pibernik 2005). In this view, the first partial shipment offered to the customer would represent the maximum part of the RFQ that can be fulfilled at the requested due date.
- Delivery flexibility. In some cases, the due dates may be subject to negotiation, i.e. they are not considered as dead-lines that cannot be violated. One extreme case may be that the customer does not provide due dates within the RFQ. Another case may be that, if no feasible due dates are found, then the ATP system proposes alternative due dates beyond the one suggested by the customer (this is a common practice in some companies, see Zhao et al. (2005).
- Resource flexibility. In this case, alternative sources of FGI or manufacturing capacity are available. In the case that these sources are located at different places, transportation planning becomes an additional issue. This case includes the so-called multi-location ATP (Pibernik, 2005). While some authors claim that ATP systems operate on a short-term basis and therefore capacity cannot be adjusted (e.g. Zhao et al., 2005), others claim that short-term capacity planning is one of the most powerful tools of due date management (e.g. Ragatz and Marbert, 1984). Regardless the flexibility of human resources, in Christou and Ponis (2008) a real case of an ATP system with manpower flexibility in the beverage industry is described.
- Price flexibility. The price of the delivery can be accommodated, so orders that could not be accepted (due to e.g. high set-up costs) could now be profitable and therefore be processed. Despite of its importance, in this paper we do not address pricing decisions. References on this topic include (Cakravastia and Nakamura, 2002; Easton and Moodie, 1999; Geunes et al., 2006; Merzifonluoglu and Geunes, 2006; Moodie, 1999; Moodie and Bobrowski, 1999).

From all options presented here, resource flexibility is the only type of flexibility that does not require discussion and agreement with the customer. Therefore, we may classify it as 'internal' flexibility whereas the others can be denoted as 'external' flexibility.

3.4. Representation of resource/capacity usage

Apart from naïve approaches that address OAS and/or DDA without considering the capacity of the plant (open-loop approaches), these decisions are taken in view of the capacity and resource usage of the plant. To do so, a prediction of the completion times of the potential orders (in the case of OAS) and of the orders whose due date is to be assigned (in the DDA case) should be made. Two different options can be adopted in this regard:

- Estimation of completion times of the jobs according to some (aggregate) considerations of workload and resource configuration.
- Generation of a detailed schedule, from which the completion times of the jobs are obtained.

Note that, in practice, differences between these two options may blur, as the schedule could be obtained e.g. by aggregating the different resources into a single machine and therefore, from this viewpoint, what it is obtained is also an estimation of the completion times. However, even in this case, a usable schedule is obtained, while in the first option, no decision has been taken with respect to scheduling and, consequently, subsequent problems involving scheduling decisions should be addressed.

The main issue here is to determine under which conditions one option is more suitable than another. Extending the related literature concerning this topic (Ivanescu et al., 2002), we can define the ex ante (ex post) completion times as the completion times obtained when a schedule based on expected (actual) processing times is constructed. In a deterministic situation, the ex ante completion times of a constructed detailed schedule are identical to the ex post completion times, and they are therefore the best possible estimate. Therefore, one indicator of the suitability of each option would be the adherence of the real shop floor to the deterministic assumption.

3.5. Consideration of committed orders

There are a number of different constraints in the decision problem, depending on how already committed orders are considered in the shop floor:

A) Empty. There are no committed orders to be considered. Consequently, all resources are available from time zero.

B) Frozen. The schedule of committed orders cannot be changed. Then, from a modelling viewpoint, the problem is equivalent to schedule a set of jobs (i.e. the jobs to be committed) with limited resource (i.e. machine) availability, which represents the frozen schedule of the already committed jobs. Obviously, the 'empty' case above stated would be a special case of this one, where all resources are available. The 'frozen' case for a real-time ATP (one job) with no flexibility always yields a trivial solution. In most schedulers, the schedule of the existing work orders is not changed for both complexity reasons arising in computation, and because of the so-called domino effect: slight changes in one operation may imply a big rescheduling in order to keep feasibility (Akkan, 1997). Other reasons for considering frozen orders are discussed in Frederix (2001) in the context of the extended enterprise.

C) Constrained. The schedule of already committed orders can change, but committed due dates cannot be violated. This hypothesis is adopted e.g. in Zhao et al. (2005) and in Unal et al. (1997).

D) Bounded. The due dates of the committed orders have, in general, lower and upper limits. The schedule of the already committed orders can change, as long as the due-date bounds are respected. The upper bound ensures that committed orders are not postponed beyond a reasonable time period, while the lower bound establishes the earliest time that the customer is willing to receive the order. Clearly, the 'constrained' case is a particular case of this one, when both lower and upper bounds coincide.

E) Unconstrained. The schedule of committed orders can change, and the committed due date can be violated. Usually, in this case, penalties for due date violation should be included in the objective function, weighting the deviation of committed jobs from their due dates higher than those for the un-committed jobs.

It is expected that, in a real life setting, not all committed orders are considered in the same way. Indeed, some of them may fall in a certain category while others do not. For instance, a differentiation between committed orders may be based on order characteristics (such as customer hierarchy, priorities, etc.). Even in the uncommitted case, it is likely that, at the time the decision is made, some orders are already being processed in some stages, so their schedule cannot be changed. However, in some cases, their processing may be interrupted right after finishing these stages. Again, the 'frozen' set or orders can be excluded from the decision problem while considering limited availability of the resources.

Most of the scheduling literature considers that the shop floor is empty when the new set of jobs should be scheduled. Although there is a (growing) body of literature on scheduling with machine availability constraints (see e.g. Wang and Cheng 2007 for a recent paper), in most of these models, the unavailability is not restricted to the beginning of the processing period, but it is more oriented to include maintenance considerations into scheduling decisions. An approach that can be identified as the 'unconstrained' case is the one presented in Hall and Potts (2004). Finally, contributions from rescheduling literature (see e.g. Vieira et al. 2003) could be applied to all non-empty cases. Nevertheless, it has to be noted that many of these methods focus on repairing existing schedules due to disruptions in the shop floor and thus consider specific objective functions related to the minimisation of the disruption.

4. Approaches to ATP-related decisions

In this section, we classify the different approaches that may be adopted when addressing Order Capture. The classification is based on two parameters:

- The consideration of information about due dates in the decision model, and
- the level of integration of the different decisions regarding Order Capture.

The first parameter refers to whether information about the due dates is integrated (or not) in the decision models. The non-inclusion of this information can be either due to the fact that the customer did not provide due dates in the RFQ, or these due dates can be subject of negotiation. When due dates are stated for each RFQ, they can be provided as indicators of what the customer expects (but nonetheless a deviation from these due dates is allowed), or as strict dead lines. For a discussion of the differences between these two approaches, we refer to the 'delivery flexibility' concept in section 3.3. If due dates are provided in the form of strict dead lines, then the different decision problems may be regarded as 'feasibility versions' of the corresponding due date decision problems.

The second parameter refers to how the different decisions to be taken are integrated. In general, there are three decisions to be taken, i.e.: OAS, DDDA, and OS, as described in section 2. However, when due dates are provided, due date assignment decisions do not have to be taken[2]. The integration of the different decisions poses a number of problems with respect to the complexity of the underlying models and the corresponding solution procedures. Additionally, the decomposition of Order Capture in two or more sub-problems poses a number of issues with respect to the feasibility of the solutions obtained at different decision levels (e.g. it is possible that the accepted orders then cannot be scheduled on time). Therefore, all non integrated approaches should provide some mechanisms for coordinating the different decisions.

Apart from the obviously higher simplicity of the problem, there may be several reasons for not to address the decision problems in an integrated manner, e.g. if the RFQ process is of the 'real-time quotation' type discussed in section 3.1. I.e.: an immediate due date has to be sent to the customer, who will eventually confirm (or withdraw) the order request after some time period. Since the shop floor situation may have been substantially changed from the time that the RFQ was posed until the (non-) confirmation of the order, it may be useless to perform a detailed schedule of this potential order. If such detailed scheduling is performed, the locking of the resources and materials to perform that potential order would not be done until the order is confirmed. By that time, since the shop floor situation may have changed, the information provided by the detailed scheduling would be of little help. Therefore, performing a detailed

[2] Note that, even when due dates are provided, different due dates could be established after Order Scheduling. However, here we regard this result as an output of Order Scheduling decisions and do not include it as Due Date Assignment, which can be accomplished (as we discuss later) without developing a detailed job schedule.

schedule based on such shop floor volatile conditions may not be the best option, thus favouring the consideration of DDA decisions without addressing job scheduling. In addition, the adoption of the different options may also have consequences from an organisational viewpoint. We do not discuss these aspects and refer the reader to the paper by ten Kate (1994).

According to the two parameters mentioned above, up to six different approaches can be identified (see Figure 1). These are:

- **Approach I.** Upon the reception of the quantities requested by the customers, all three decisions (OAS, DDA, and OS) are taken simultaneously. We are not aware of papers describing applications of this approach.
- **Approach II**. In this approach, the overall problem is decomposed into job acceptance/selection decisions (where the set of jobs to be accepted is obtained as output), and DDA and OS decisions are taken simultaneously. The DDA & OS decision problem receives the accepted jobs as input, and produces a quote and a schedule for them. This approach encompasses a variety of scenarios, including those for which acceptance decisions are carried out by a different functional unit (e.g. sales) while subsequent decisions on the jobs are coordinated with another functional unit (e.g. operations). This approach is present e.g. in Soroush (1999), and a simulation experiment showing the advantages of the integration of DDA and OS decisions is presented in Alfieri (2007). In addition, application scenarios where the customary policy is that of never denying an order unless it is technically or economically unfeasible and the subsequent Order Capture decisions are jointly taken, are also included in this approach (se e.g. Chen et al., 2002). For instance, in Zhao et al. (2005) an application case is described in an OEM's (Original Equipment Manufacturing) electronic product supply.
- **Approach III**. In this approach, the three decisions are handled separately. First acceptance/selection decisions are taken, then due dates are quoted, and, in a later stage, jobs are scheduled. As in the previous approach, here the case is included where OAS activities are either carried out by a different functional unit, or all RFQs are accepted. This corresponds to a traditional scenario described e.g. in Weng (1999) for a factory producing lighting fixtures where (prior to the developments described in the paper) orders were accepted without checking the efective capacity to manufacture them and due dates were quoted adopting naïve approaches that ignored the current situation of the shop floor.
- **Approach IV**. In this approach, OAS and DDA are simultaneously solved. The accepted jobs and their corresponding due dates are scheduled in a subsequent stage. This approach is adopted e.g. in Chatterjee et al. (2002), Sawik (2008), and in the already mentioned case in Weng (1999).

- **Approach V**. In this approach, there is no DDA, as it is assumed that the RFQs consist of quantities plus due dates. The remaining decisions (order acceptance/selection) and scheduling are taken separately. Analogously to approach II, this approach also encompasses the case when all orders are accepted. References considering this approach (which is widely employed in industry) are e.g. Corti et al. (2007), Raaymakers et al. (2000a), Sawik (2006), or Xiong et al. (2006). An application of this approach for the chemical industry is shown in Ivanescu et al. (2002),
- **Approach VI**. As in the previous approach, there is no DDA, as it is considered that the RFQs consist of quantities plus due dates. The decision (jointly taken) is which jobs to accept according to the due dates provided exogenously, and how to schedule them. This approach is described e.g. in Luss and Rosenwein (1993), and Wester et al. (1992). An application case for the chemical batch industry is described in Raaymakers et al. (2000b).

[INSERT FIGURE 1 OVER HERE]

In total, the decision problems resulting from the different approaches are the following (see also figure 1):

- **Integrated Approach**. The basic input data provided by the customer(s) are the quantities requested (RFQ). The output is the set of accepted RFQ, together with their schedule and due dates.
- **Order Acceptance/Selection**. The input data provided to 'Order Acceptance/Selection' are the quantities requested by the customer(s). The output is the subset of accepted quantities. Other terms used for this task are 'order taking' (Weng, 1999). The corresponding decision problem and related models in the literature are discussed in section 5.6.
- **Order Selection and Scheduling**. No DDA is accomplished, since due dates are part of the RFQ. The decisions (taken simultaneously) are to select a set of jobs to be accepted, and to generate a schedule for the accepted jobs. The corresponding decision problem and related models in the literature are discussed in section 5.1.
- **Order Acceptance/Selection with DD**. In this decision problem, the input is a set of RFQ with due date information. The output is the set of accepted jobs. No schedule is generated with respect to the accepted jobs. The corresponding decision problem and related models in the literature are discussed in section 5.7.
- **DDA & Scheduling**. In these models, the set of accepted jobs is considered exogenously. The decision is to schedule these jobs and to set due dates which are related to the completion time of the resulting scheduling. The term 'Due Date

Assignment & Scheduling' is employed e.g. by Li and Cheng (1999). The corresponding decision problem and related models in the literature are discussed in section 5.2.

- **Due Date Assignment**. Here the problem can be described as follows: Given a set of (already accepted) jobs, establish a due date, but no attempt is done to generate a schedule. Usually, the due dates are established by certain job- and workload-related parameters, leaving the scheduling decision for the future (Ozdamar and Yazgac, 1997). The corresponding decision problem and related models in the literature are discussed in section 5.5.
- **Scheduling With Due Date Objectives**. In this problem, due dates are given (i.e. exogenous due dates) over a set of already accepted jobs. The decision is to find a schedule of jobs that either is feasible (i.e. due dates should be interpreted as deadlines or hard constraints that cannot be violated), or it optimises certain objective function which involves penalties for deviations from the expected due dates. The corresponding decision problem and related models in the literature are discussed in section 5.4.
- **Order Acceptance/Selection and DDA**. In this model, the decision refers to the set of RFQs (quantities) to be accepted and the corresponding due dates. No schedule is generated in this decision problem. The corresponding decision problem and related models in the literature are discussed in section 5.3.

In Figure 2 we classify the six approaches according to the two parameters considered: inclusion of due dates in the decision problem, and level of integration of the decisions. Regarding the level of integration, approaches I and VI correspond to companies in which there exists a high degree of integration of all relevant decisions and more specifically, there is full coordination between sales and manufacturing departments. Approaches II and IV correspond to a medium level of integration: In approach II, acceptance/rejection decisions are taken by a business functional unit (typically, sales department) which is different from the one in charge of subsequent decisions (Ebben et al., 2005). Approach IV typically represents the situation in which the sales department is in full control of all decisions involving order capture, leaving the execution of the orders to the manufacturing department. Finally, approaches III and V represent a low level of integration among all relevant decisions in the Order Capture process.

[INSERT FIGURE 2 OVER HERE]

5. ATP Decision Problems and Models

In the next subsections, we discuss the decision problems and models according to the above framework, with the exception of the integrated approach, for which we are not aware of related literature. (This aspect is regarded in the Conclusions section as a future research topic.)

5.1. Order Acceptance/Selection and Order Scheduling (due dates provided)

These models incorporate two (interrelated) decisions: which jobs to accept, and how to schedule them. Due dates are considered as exogenous data. The objective function incorporates all relevant costs and benefits of accepting each job. In its simplest case, it contains the sum of the weighted tardiness or lateness of each job (Ghosh 1997, Slotnick and Morton 1996, Slotnick and Morton 2006, Luss and Rosenwein 1993). For these cases, the two interrelated decisions can be decomposed under certain circumstances (see e.g. Slotnick and Morton 1996, and Slotnick and Morton, 2006). In other cases, the objective function captures additional information, as in Markland et al. (1990), where the objective is to minimise an objective function composed of a tardiness penalty, a coordination penalty (an indirect measure of inventory costs), and a penalty for rejected orders. In Robinson and Carlson (2007) a real-time ATP model minimises inventory holding costs, several administrative and production costs, as well as the cost of rejecting an order. In Kirche and Srivastava (2005) and Kirche et al. (2005), a model for OAS and OS with exogenous due dates is presented. The model seeks to maximize the profit (using an Activity Based Costing scheme), and rejects all orders that cannot be fulfilled on time.

Also in Akkan (1997), the costs of rejecting an order as well as the cost of early completion are considered. An interesting case is found in Lewis and Slotnick (2002), where the rejection of a customer order implies not to receive future orders from this customer. In Chen et al. (2002), the objective function considers the profit margin per unit and a number of costs: holding costs for raw material and work in process inventories, lost-sales costs, and an underutilization penalty.

A particular case of the Order Selection problem is the so-called Order Insertion problem. This problem involves accepting/rejecting a single job, and the corresponding feasibility version of the problem would check whether inserting a new job is feasible or not. Note that the two problems are not identical, as in the Order Insertion problem a job insertion resulting in a feasible schedule may not be accepted due to cost considerations. Examples of works addressing the Order Insertion problem are Roundy et al. (2005), and work prior to 1985 can be found in the survey by Cheng and Gupta (1989).

5.2. Due Date Assignment and Order Scheduling

In this case there is no external determination of due dates, so they must be generated endogenously, as part of the solution to the decision problem together with the corresponding scheduling decision. In this decision problem, scheduling decisions are explicitly taken into account either by developing a full schedule, or by obtaining a dispatching/sequencing/priority policy. Clearly, the latter case is a specific case of the former, as dispatching policies explore a subset of all possible schedules. When no scheduling decision is involved (even if an estimation of the completion times is carried out), we consider this problem to fall into the class of Due Date Assignment problems (this problem is discussed in section 5.5). In line with section 3.4.1., this somewhat arbitrary decision is motivated as follows: if a schedule is developed (even if it is a rough schedule based on a simplified plant layout model), then it can be executed in the shop floor. Thus, there is (in principle) no need of solving a subsequent scheduling problem. However, if no schedule is provided (e.g. because due date assignment is done e.g. by estimating the total workload of the shop floor), then subsequent scheduling decisions should be taken (i.e. the problem of scheduling with due date objectives should be solved).

There are two broad approaches for the problem under consideration (see e.g. Keskinocak and Tayur 2003):

a) Simultaneous approach. In this approach, DDA and OS are simultaneously solved as part of a single decision model. Indeed, setting a schedule includes determining completion times for each job. Therefore, from a pure deterministic viewpoint, these completion times can be employed as due dates to be offered to the customer, henceforth the decision problem would be reduced to a scheduling problem where some efficiency measure is optimised (e.g. machine utilisation, fast deliveries, etc.). However, since external and internal variability occur in shop floors, setting due dates very close (or equal) to the completion times of the jobs ('tight' due dates) may decrease the reliability of the promised due dates.

b) Sequential approach. In this approach, first due dates are set, and then these are employed to determine job schedules. In this case, some coordination/feedback mechanism should be set, as otherwise the due dates may not be feasible. The related literature where neither a joint decision is taken nor a feedback mechanism is provided is discussed in the corresponding sections (due date assignment in section 5.5, and scheduling with due dates in section 5.4).

The two approaches are discussed in detail in the next subsections.

5.2.1 Simultaneous approach

When both objectives are addressed simultaneously, despite the absence of due dates, since time-based competition is common in a growing number of industries (Weng, 1999), it seems reasonable to give priority to a fast delivery to the customer. This is equivalent to penalise slow deliveries and, since the delivery of a job is related to its completion time, the cost penalty function of each job will include some form of measuring its completion time:

- One of these objectives is the makespan, which seems particularly suitable when the customer(s) should be provided with a common due date. This typically represents the situation when a single customer with several jobs has to be provided, or an assembly environment in which all components should be ready at the same time to avoid delays (Baker and Scudder, 1990). The literature on scheduling with makespan objective is so vast that it is useless to give references. We instead refer the interested reader to any of the many good scheduling textbooks.
- Weighted completion time. This penalty seems to be appropriate when each job should be provided with a different due date, the weighting expressing the relative importance of each order. Some recent references addressing weighted completion time minimisation are Tang et al. (2006) for the hybrid flowshop, and Brueggemann et al. (2006) for the identical machine case.
- Deviation of completion times. This objective was first proposed by Kanet (1981), and it is measured as the sum of the absolute differences among the completion times of all pairs of jobs.
- Expected deviation (earliness/tardiness) from the due dates stipulated. Note that by the introduction of the earliness penalty, the two objectives assumed in due date management as contradictory are now aligned. I.e.: if only tardiness costs are considered, a (unpractical) due date assignment strategy will be to set very long due dates to ensure their fulfilment. However, with the earliness penalty, due dates should be set as tight as possible, but not too tight. This approach is presented in Soroush (1999). Note that this case makes sense only in a stochastic setting.

When all jobs have to be assigned a common due date, then additional objectives can be considered. Since the due date is common to all jobs, it is possible to compute the deviation (earliness or tardiness) with respect to this (to be determined) common due date. Cheng et al. (2002) adopt this approach for the case with common due dates and incorporating due date-related costs together with earliness and tardiness costs. Also Mosheiov (2001) and Birman and Mosheiov (2004) discuss the problem of simultaneous DDA and OS in parallel machines and for the two-machine flowshop in order to minimise the maximum (earliness and tardiness) costs among the jobs. Another paper considering the deviation from a common due date is Chen (1996).

While most scheduling models consider all jobs to be available, Unal et al. (1997) consider the problem of inserting a set of new jobs so that the flowtime of the new jobs is minimized while not violating the committed due dates of the existing jobs.

5.2.2 Sequential approach

Although the term is a bit problematic, most authors label this problem as Due Date Management (see Charnsirisakskul et al., 2004). A Due Date Management policy is a combination of a Due Date Setting Policy and Scheduling (possibly a Priority Sequencing) Policy (Wein, 1991). Clearly, the two sub-problems hold conflicting goals, as it is evident that the tighter the due dates obtained by solving the DDA problem, the more difficult it is to fulfil the due dates in the subsequent scheduling sub-problem. Due Date Management approaches usually consist of selecting a combination of due date assignment procedures (among a finite set) and scheduling rules that minimises (long-run) due dates while allowing only a given (exogenous) percentage of tardy jobs (Wein 1991, Miyazaki 1981, and Raghu and Rajendran 1995). A scheme for the coordination of these two sub-problems is described in Saad et al. (2004). Less common are approaches aimed to establish optimal parameters for a given policy (see e.g. Seidmann and Smith 1981, or Cheng 1984). An excellent review of the literature addressing this approach is Keskinocak and Tayur (2003).

5.3. Order Acceptance/Selection and Due Date Assignment

This problem analyses whether the RFQ is to be rejected or accepted, and to establish the corresponding due date in the latter case. Note that not all orders can be accepted (even if any due date is acceptable for the customer), as some jobs cannot be accepted regarding economic terms. Clearly, prices, costs, and benefits are the main variables involved. We are not aware of papers dealing with this problem, although some discussion on related problems can be found in Chatterjee et al. (2002). Regarding the order selection version of the problem, a linear programming model is presented in Sawik (2008) in order to maximize the number of orders that can be delivered within the expected over a production planning period.

5.4. Scheduling with Due Date Objectives

Since due dates are assumed to be exogenous, here the decision problem is to schedule the n jobs seeking to minimise some form of deviation from the desired due dates. A particular case is when these exogenous due dates should be interpreted as dead lines, being this a feasibility version of the aforementioned decision problem.

Deterministic scheduling with due dates objectives has been subject of extensive research, and excellent reviews exist for the topic as well as for specific sub-cases. For instance, Sen and Gupta (1984) and Baker and Scudder (1990) review scheduling with due dates objectives, while the reviews by Gordon et al. (2002a) and Gordon et al. (2002b) are devoted to the common due date case. The review by Koulamas (1994) is devoted to the total tardiness problem. The Common Due Window (CDW) case (a generalisation of the common due date) has been recently addressed by Biskup and Feldmann (2005), who summarise recent contributions to the topic. Regarding the dead-line version of the problem, we are not aware of papers dealing with shop environments other than the single machine case. Some exact (i.e. branch & bound) approaches for the problem are due to Bansal (1980), Pan (2003), Posner (1985), and Potts and Van Wassenhove (1983). Park and Kim (2000) also address the problem with deadlines. The problem has been also formulated where objectives may involve earliness penalties, which is different to the tardiness-earliness problem in the sense that the tardiness penalty will be infinite, as strict due dates are observed. Examples of this problem are included in the review by Baker and Scudder (1990). The stochastic counterpart of the problem has not received similar attention, being Soroush (2007) a recent reference summarising previous findings.

The vast majority of the related literature considers that all the products must be manufactured within the company (fixed capacity). Only few references address other scenarios: In Jeong et al. (2002), it is checked that the demand can be satisfied from inventories located in different delivery centres. If not, the product has to be manufactured (with the subsequent 'traditional' scheduling problem with due dates). Another interesting contribution is given in Frederix (2001), where make-or-buy decisions (an alternative to consider flexibility in resource capacity) are integrated. In the context of collaborative manufacturing, Abid et al. (2004) present a model where customers give a due date window and jobs are allocated to resources in order to maximize customers' satisfaction. Finally, in Ozdamar and Yazgac (1997), a MIP model is developed considering the cost of overtime (resource flexibility), as well as backorder and setup costs.

5.5. Due Date Assignment (DDA)

In this case, the Decision Maker is only concerned with quoting the due dates, but not with the particular scheduling of jobs. A common approach to due date assignment is to promise a constant lead time to all customers, regardless of the characteristics of the order and the current status of the system (Kingsman et al. 1993, Vastag and Whybark 1993, Wisner and Siferd 1995). Despite its popularity in practice, the shortcomings of this approach are obvious

(Kaufman, 1996). Therefore, most DDA models set due dates according to the expected flowtime plus a time buffer to deal with uncertainty (Moses, 1999). Two key issues emerge in this problem, i.e. to estimate completion time (flowtime) of each job, and to determine the time buffer to be used. The vast majority of the related literature is devoted to the first problem, and we are aware only of a reference (Moses, 1999) presenting a method to control the size of this time buffer for a discrete manufacturing system.

Regarding the estimation of the completion times, one may distinguish two basic approaches, depending on whether the DDA must be performed over a set of accepted jobs (batch ATP), or every time a job arrives (real-time ATP). Usually, in the literature, the first case is denoted as static while the second one is called dynamic.

Regarding static due date assignment, three early reviews on the topic are due to Smith and Seidmann (1983), Ragatz and Marbert (1984), and Cheng and Gupta (1989). Two recent papers summarising the latest contributions to the area are Portougal and Trietsch (2006), and Sha et al. (2007). A particular case of due date assignment is described in Qi et al. (2002): the problem is to assign due dates (exogenous, but not yet assigned to specific jobs) to each job. The problem is somewhere at the border between the existence or non-existence of explicit due dates.

Regarding dynamic due date assignment, van Enns (1998) presents rules to dynamically assign due dates. Veral (2001), and Veral and Mohan (1999) address the problem of due date setting in a dynamic job shop. They evaluate a number of dispatching rules using simulation and statistical analysis.

5.6. Order Acceptance/Order Selection

In this type of problems, given one or more RFQ from one or more customers, the question is whether these orders would be accepted or rejected. If the decision involves one job, the output is an acceptance/rejection decision (Order Acceptance), while if a set of jobs is presented, the output is the set of jobs to be accepted (from zero to all RFQ). The latter problem is sometimes labelled as Order Selection, although this term and Order Acceptance are often used interchangeably. A distinctive characteristic of this problem is that no attempt of due date or order scheduling is done. This is a common situation at least in the scenario where due dates in the form of deadlines are given to the Decision Maker (see e.g. Philipoom 1992). Feasibility versions of the Order Insertion problem usually include considerations on augmenting short-term capacity through overtime or outsourcing. Some work on this topic can be found in Loerch and Muckstadt (1994), and updated references are given in Roundy et al. (2005).

5.7. Order Acceptance/Order Selection with Due Dates

In this case, acceptance/selection decisions are taken in the presence of explicit due dates set by the customers. References dealing with this problem are e.g. Chen et al. (2002), Ivanescu et al. (2002), and Wang et al. (2006). A particular case of this problem is presented e.g. in Luss and Rosenwein (1993), Raaymakers et al. (2000b), Sawik (2006), and Wester et al. (1992). Here, the authors perform OAS with due dates, but also assign the orders to a specific production period. The authors label this procedure as 'planning', as it does not involve decisions on the sequence of operations and resources involved to process the orders.

Park et al. (1999) propose a system for OAS with due dates which includes two types of due dates, depending on the order (strict due date and negotiable due date), and the possibility of adjusting short-term capacity. For the determination of the due dates, the completion times of the jobs are estimated according to the workload of the bottleneck process. Barut and Sridharan (2005) present a procedure for accepting or rejecting orders in view of the available capacity. Finally, Calosso et al. (2003) describe a system for OAS which includes a mechanism for negotiating due dates (as well as price and other product characteristics) with the customer.

6. Conclusions

In this paper, we propose a framework to accommodate Order Capture related decisions. The framework serves to integrate the different contributions in the literature. Despite the vast amount of research devoted to these topics, the following conclusions can be drawn in order to serve for potential research areas:

- Biased/Out-of-context research. While some of the sub-problems have been widely studied (see e.g. scheduling with due dates), the references for some others are scarce or even inexistent. Perhaps the most clear example is the absence of research devoted to the approach integrating the three main decisions in Order Capture (i.e. OAS, DDA, OS), despite the advantages shown in the integration of two of the decisions (OAS & DDA, or DDA and OS). Regarding the research context, even in some well-studied sub-problems, the approaches adopted do not suit well to the Order Capture problem. As a consequence, some reasonable hypotheses are not considered, so the applicability of the models and procedures can be questioned. An example is given by most scheduling research, where the shop floor is assumed to be empty, a situation which cannot be considered realistic for many scenarios.
- Mechanisms for coordinating/ensuring feasibility. For all approaches (except for the integrated one), it is possible that decisions adopted in some of the subproblems result in problematic or infeasible solutions for other subproblems. An example would be, in approach V, to obtain a set of committed orders in an OAS procedure that cannot be

scheduled on time in the subsequent SDD model. Therefore, some mechanisms to ensure feasibility and/or to reinforce the consistency of the different decisions are required. However, this topic is not addressed in most of the literature, probably due to the lack of a framework to integrate the different decisions, being one of the few exceptions the work by Raaymakers et al. (2000b), and Saad et al. (2004).

- Accuracy of the representation vs. complexity. For the decision problems arising from the different approaches, different abstractions (models) of the real scenario are possible. Perhaps the most obvious is the representation of the shop floor as an aggregate single resource, or as a detailed, multi-resource system. On one hand, relatively few of the referenced work refer to the latter representation. Despite the fact that some papers (e.g. Ebben et al. 2005) show that detailed representations are clearly better when due dates are tight. On the other hand, it is clear that, the more detailed the representation, the higher the complexity of the resulting decision problem. This may lead to problems regarding the computational performance of the different approaches. The trade-off of these two aspects is discussed in Robinson and Moses (2006) in a preliminary study, but there is need of additional research in this important topic, particularly regarding a comparison of the relative computational performance of the different approaches for realistic scenarios.
- Order Capture in a supply network context. In most papers, little attention is paid to the additional complexities arising when the process takes place within a supply network. Papers dealing with order capture in supply networks (see e.g. Huang et al. 2008) usually assume that, upon the arrival of a RFQ from a customer, information is exchanged between the company and its suppliers so the latter can determine whether they have capacity to provide the corresponding components, and to estimate the due dates. Once this information is gathered by the company, the order is either accepted or subject to a negotiation process that ends with the order rejection/withdrawal, or a firm order. In this regard, most approaches focus on showing the advantages of the information exchange (e.g. Lin et al. 1998), protocols for exchanging information on capacity and due dates among companies (see e.g. Huang et al. 2008, Thammakoranonta et al. 2008), or for handling product variety (such as Jiao et al. 2005). We are not aware of papers dealing with a coordination of the three main decisions in Order Capture. Indeed, the implementation of these approaches assume – implicitly or explicitly – a centralized planner (see e.g. Venkatadri et al. 2006) in a resemblance of the approaches adopted for a single company. Therefore, to fully encompass the complexity of a supply network, research in more flexible, decentralized approaches is needed.

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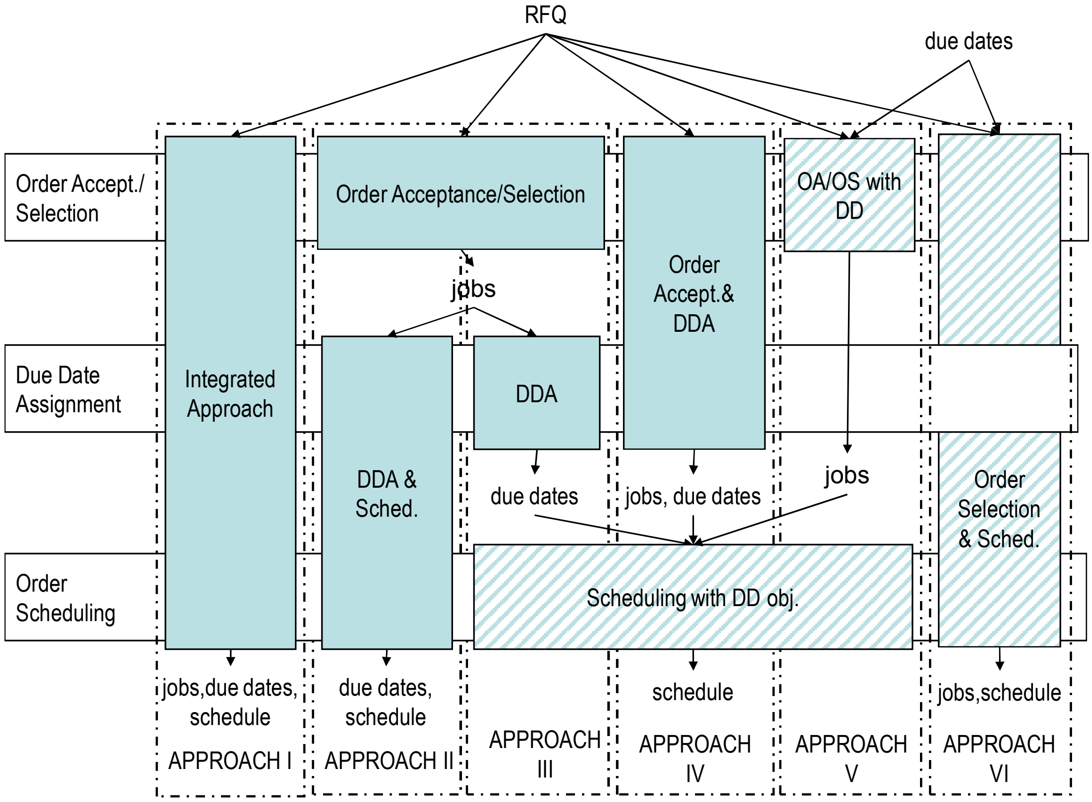

Figure 1. Main decisions, approaches and decision problems to implement ATP functions (decision problems in striped boxes involve explicitly due date considerations).

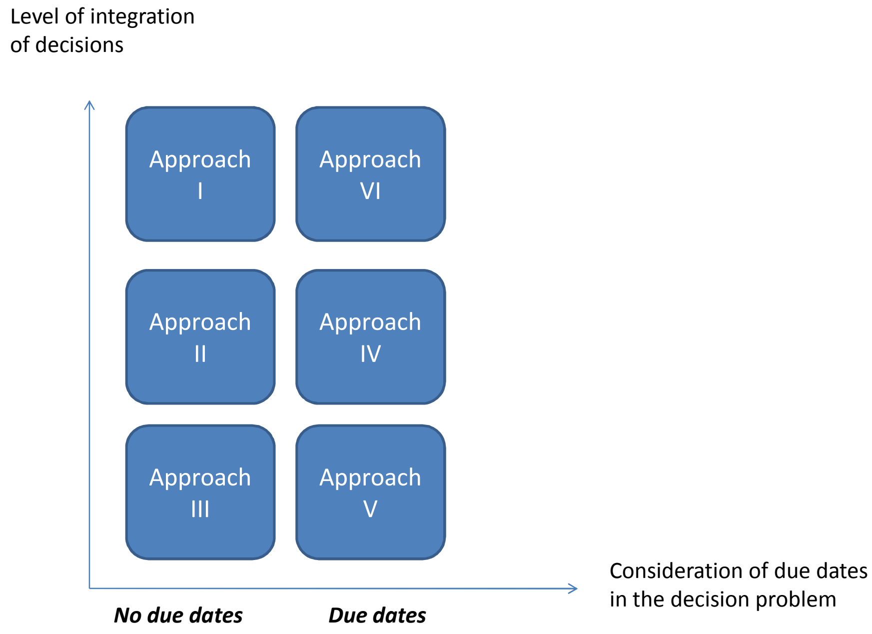

Figure 2. Application context of the approaches presented