How to Consider Supply Uncertainty of Renewable Resources in the Basic Data Structures of ERP-Systems

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Abstract Production planning in companies often assumes that resource flows are constant. This idealized assumption does not reflect the problem of uncertain procurements. Especially renewable resources are underlying natural influences which result in uncertainties of the quality and quantity of the resource as well as an uncertain time of harvest and delivery. In this paper we analyze how procurement uncertainties of renewable resources can be taken into account in the basic data structures of ERP-systems, namely bill of materials (BOM), work schedules and time schedules. Therefore we describe certain variations methods as general possibilities to handle uncertainty. As a result it can be stated that not every type of BOM can consider uncertainties well enough. The work and time schedules cannot represent every kind of variation which is needed. Overall, a combination of both structures is a good possibility to gain a more flexible and thus a more certain planning.

1 Introduction

There are many uncertainties in business planning: sales numbers on the client side cannot be predicted safely, production may be delayed or come to a standstill and resources may be hard to obtain due to unforeseeable events. The area of marketing and sales is well researched both with respect to practical and scientific aspects. There are many adequate forecasting methods and explanatory models.

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The same holds true for intra-corporate uncertainties, where concepts such as decentralized control centers enable adequate handling of problems.

With regard to procurement, however, one still assumes constant streams of resources, which is an idealized assumption. Examples, such as the impact of the earthquake and tsunami in Japan or the flooding in Thailand on the automobile and electronic industries, show that this is already the case with conventional commodities. This problem increases within the industrial use of renewable resources. Thus, it is not possible to accurately predict when goods will be ready for harvest or variations may occur regarding the quality and quantity, e.g. through humidity or droughts [1]. At the same time, the German Federal Government demands an increase of renewable resources in the industry in its national resource efficiency program [2]. Adequate planning is needed with regard to possible uncertainties when using these renewable resources and it is therefore necessary to model them in an easy and flexible way in ERP-systems. This problem will be discussed in the following by analyzing how these uncertainties in procurement can be taken into consideration in the basic data structure of the production planning, on which all further production steps are based on. Flexibility in this basic data and planning level can ensure that all functions and processes that build upon it will gain more flexibility, too. Corporations consider this flexibility in production and procurement to be very important [3]. The process of planning will be demonstrated in an exemplary use case of a company which uses renewable resources for the production of natural fiber reinforced plastics.

The specificity about renewable resources and their uncertainties will be described in Chap. 2. Chapter 3 deals with general IT-independent methods, which enable a consideration of the uncertainties in the planning process. In Chap. 4 is shown how procurement uncertainties can be considered in production planning and controlling systems (PPC). The article closes with a conclusion and an outlook on further possible areas of research.

2 Background Information

2.1 Uncertainties in the Procurement of Renewable Resources

Uncertainty is defined as the absence or incompleteness of information [4]. Uncertainties can be categorized according to different characteristics, which are presented in Table 1. Sourcing uncertainties include both uncertainties caused by direct suppliers, as well as sub-suppliers, and the logistics [3]. The focus in this paper lies on external uncertainties in the source process.

Many authors stress that it makes sense to clearly differentiate between the uncertainties according to cause and effect [5]. The *cause-related analysis* focuses on the uncertainty source, in order to prevent or eliminate it [5, 6]. The

Table 1 Ways of differentiating between uncertainties

Object of observation	Characteristics
Business	Internal, external
Cause	Operational, disruptions
Operational activity	Sourcing, production, sales, logistics, (IT, organization)
Process	Plan, source, make, deliver and return
Production process	Internal, external

effect-related analysis examines the uncertainty effects, in order to minimize these [7]. In order to measure an effect, ex-ante defined plans, goals and expected values have to exist, with the possibility of deviation due to the uncertainty [5, 8]. Thus, an effect can only exist if it can be objectively identified and/or measured. The effect in terms of this paper is an impact on production plans.

In the area of renewable resources there are some special uncertainties in comparison to conventional resources. Due to natural growth processes it is difficult to ensure exact times of harvests as well as the qualities and quantities of the resources [9–11]. Non-influenceable factors like precipitation, solar radiation or infestation by pests are not taken care of in actual production planning [12]. It is rare that complete harvests are lost through natural disasters, droughts or pests. But it is more likely that parts of the harvests are lost, have differences in size, material defects, divergences from defined requirements or damages. These factors can cause qualitative or quantitative uncertainties. A postponed harvest results in uncertainties of time. We do not regard cost uncertainties, which play an important role during procurement, but which only slightly affect production planning. We will demonstrate that it is possible to substitute a resource that is not delivered or to substitute an expensive resource with a cheaper one, so that cost uncertainties are equal to quantity uncertainties with regard to possible reactions. Furthermore location uncertainties are excluded from analysis, as they result in quantity uncertainties in two locations. In conclusion, we will only examine quantity, quality and time uncertainties.

In order to show the practical relevance, a reference to a study shall be made: This study among companies in German-speaking countries, which use renewable resources as an input, was conducted in 2010 [13]. Overall, 28 % of the companies perceive uncertainty in their supply chain. Most of the companies do not use advanced information technology like RFID to handle this uncertainty, but the demand for simple planning concepts which can be integrated easily into existing systems like Enterprise Resource Planning (ERP) is nevertheless present. Four qualitative interviews with companies which mainly use plant fibers are almost confirming these results: The companies typically use storage to hedge against uncertainty, as they obviously feel a lack of easy planning concepts. Only one participant said that information systems are not needed, as they know how to handle uncertainties due to their experience even without IT. We will use a company that uses fibers as an input for natural fiber reinforced plastics as an example in the following. The fibers can be used interchangeably in certain ratios [14], which means that for example hemp fibers can be substituted by flax fibers to produce flower pots.

2.2 Production Planning

In the following, the term PPC-system is understood as a software that supports and automates the production planning (and controlling) in line with the concepts of Material Requirements Planning (MRP I) and Manufacturing Resource Planning (MRP II). These concepts are an elementary component, as they led to the implementation of PPC-Systems over time. PPC-systems can also be modules within integrated standard software like ERP-Systems. Special emphasis lies on the focal production planning and control of an individual business. The areas of material planning, capacity planning and manufacturing controlling are also supported. Shop-Floor scheduling can be integrated.

3 General Possibilities of Considering Uncertainties in the Production Planning

In this chapter, different scenario planning methods and resource substitution will be evaluated in line with the uncertainties shown above. Scenario planning does not offer a direct decision on the production plans during the development of the scenarios. Instead, different alternatives are developed which are decided on later with the aid of a decision criterion. Thus, the decision on the alternative is made when information is complete, i.e. when the criteria becomes known, and is therefore postponed. This makes planning more flexible [15].

3.1 Quantity Variation

Quantity variation is a method that applies to quantity-related uncertainties. The production quantity is adapted to the actually delivered quantity, e.g. when shortfalls occur due to droughts or pests. It is also possible to split up the ordered quantity by increasing the number of suppliers, or to switch to alternative suppliers if uncertainties arise [3]. These suppliers should be distributed locally to avoid natural influences by the factors already mentioned in Sect. 2.1 and thus reduce the uncertainty of renewable resources. Scenarios can be developed prior to the adaptation of production plans, which include the actual delivery quantity as a decision criterion for choosing a scenario on delivery. Thus, one anticipates quantity variations and addresses these to a certain extent in the planning. The information can become known in the time of delivery or before when the supplier or carrier sends notifications during the transport.

3.2 Time Variation

It is also possible to develop scenarios on the time of delivery and in this way to consider time uncertainties. Changes are made to the order scheduling [3]. Planning occurs at a fixed point for a future delivery time. When the actual time of delivery becomes known, an alternative will be chosen with the point of time as the criterion. The delay of deliveries should become known when uncertainties arise; e.g. when a pest occurs and renewable resources are affected, which results in a later delivery. After harvesting the delivery time is announced by the carrier.

3.3 Quality Variation

A product is specified during its development and its characteristics are defined. Tolerance levels may also be set for these characteristics, in which the product can be developed with the desired quality. One refers to quality variation if these characteristics, which consist of primary and secondary characteristics, are changed [16]. Different levels of change are possible. Thus, a quality variation is a deviation from the original product specifications, resulting from a change in resource quality or other parts integrated into the product [17–19]. It is important to note that quality variation is not always deliberate, but can occur through unwanted characteristics or environmental impacts [17].

It is therefore possible to transfer the described variations onto quality-related uncertainties. Different scenarios for the values of one or more quality characteristics are determined during planning. A scenario can then be chosen at the time of delivery or, in the best case, when the delivery quality becomes known before that time. The decision criterion is a quality trait, which can for example be hardness, flexibility, viscosity, water content or something else in renewable resources [19]. Depending on the scenario, products with different qualities are produced, as one assumes that lower quality resources result in lower quality product characteristics and vice versa. In the extreme case, the choice of which product can be produced at all is made at the time of decision, depending solely on the quality criterion [19].

3.4 Renewable Resource Substitution

Besides the mentioned variations, it is also possible to vary the utilized renewable resource or their proportions [3]. This structural variation depends on the used resources, their substitutes and the production process. Examples are compound material that can be substituted by renewable resources and varying compositions [14]. For example, the wood fibres in Wood-Plastic-Components can be replaced by plant fibres to some degree. The same applies to the already mentioned natural fibre reinforced plastics, where plant fibres can be replaced by each other. The substitute resource has to be included in production planning in order to enable substitution. First, possible substitutes have to be determined and substitution options have to be analyzed with regard to time, amount, composition and material properties. The substitute resource should be deposited within the data structures of the production planning. One can chose between different alternatives when planning the amount of resources that are to be ordered:

- The substitute is always in stock and available for production during an emergency.
- Prior experience allows an estimate of a deficit in the primary resource and an adequate amount of the substitute can therefore be included in the order.
- The substitute can be obtained within a short time and no storage is needed.

It is important to consider that extra costs may arise through storage or prompt procurement. Summing up, the structural variation ‘resource substitution’ seems like a good option if the resources and production process allows it, which is often the case with compound material which includes renewable resources [14].

3.5 Summary

Flexible resources such as machines, equipment and personnel are needed for nearly all variations, because even though scenarios are planned in advance, the actual plan can only be chosen shortly before production begins. The variation methods are a good way to predefine potential alternatives and to delay deciding on a plan to a time when information is complete or better. Rolling planning enables updating scenarios and adaptation to changing external factors and environmental impacts [20]. These variation methods should therefore be updated regularly to improve planning. Forecasts are available for many characteristics of renewable resources: Beside the well-known weather forecast modern agricultural machinery or aerial observation can measure plant characteristics [21]. Farmers and forestry workers can also measure these data manually. When these data are made available, a rolling update of the production planning with actual (and thus more certain) data is possible to change or refine the plans. Related to our example, this means that the plans for the ratio of different fibers can be planned in advance and afterwards chosen regarding the quality, quantity and time points of the deliveries. The ratios of the fibers can be changed easily according to these plans. At the same time, early consideration of uncertainties is advantageous, as it forces planers to think about possible variations, their impacts and influences (e.g. the environmental factors mentioned above).

4 Consideration of Uncertainties in PPC-Systems

Basic data are the master data in PPC systems, i.e. those data that are independent of concrete orders or plans [22]. The basic data for PPCs include for example bill of materials (BOM), work plans, parts master data, operating materials and other data structures of the production process. Parts master data describe a certain part (i.e. a final or intermediary product, raw material or assembly groups) in more detail and include e.g. terms, descriptions or measurements [22]. As these data are merely descriptive and find entry into the planning of other structures, such as work plans, they are not discussed explicitly in this context. Instead, the focus lies on those product structures which are typically stored as BOMs and on work plans.

4.1 Variable Bill of Material

BOMs are at the core of all production planning processes, because they reflect all those structures that describe the composition of a product such as raw materials, other materials, assembly groups or intermediary products [20, 22–25]. There are several kinds of variable BOMs differing in the way they store and represent data. The *type parts list*, sometimes also called *identical parts list* or *variant parts list*, provides a comparison of parts and types of the final product [22, 23, 25, 26]. The total amounts of all parts contained in the product are entered into the rows. The variations of the product are entered into the columns. The cells of the intersections contain the amount of a part for a certain product. In order to avoid redundancy of data, a column of identical parts can be introduced, where the amount of parts is entered which is identical for all variations [22, 24, 27, 28]. Table 2 shows an example. The column of identical parts reduces the complexity of parts lists and increases the processing speed. If there are few variations, these parts lists are also easy to read as all variations can be shown in one list due to the single-step structure [22, 24, 28]. A disadvantage here is the increased work load if the amounts of the identical parts for different variations change [24]. Furthermore, it is not possible to assign the general parts lists to a certain order, so that individual order parts lists have to be produced for each variation [23]. It is possible to produce variations according to quantity or according to structure and thus to handle quantity and quantity variations as well as substitutions.

Table 2 Type parts list

	Identical parts	Variation A	Variation B	Variation C	Remark
Part 1	3				Identical parts
Part 2		1	2	3	Varying quantities
Part 3		1		1	Varying structures

The *complex parts list*, also called *selection parts list*, is quite similar to the type parts list, as all variations of a product are included [26, 27]. It is different because it contains all potentially required parts and leaves only the option to select whether or not a part is included in the configuration. Therefore the configuration may be changed (i.e. structural variations are possible), but not the quantities [25]. The discussion in Sect. 3.1 showed that variations of quantities are useful, so this type of list will be excluded from further discussion.

A *plus-minus parts list* differentiates between standard parts (identical parts) which are used for all variations and stored in an independent basis parts list and a specific parts list for each variation [22, 23, 26]. The specific parts list includes all changes against the basic parts list in negative or positive quantities [24, 25, 27, 28]. Table 3 shows an example. Geitner defines the plus-minus parts list only as variations of the variable parts - not of the identical parts - and introduces the additional term of identical parts list [25]. We do not follow this separation here, as it is possible to enter the identical parts directly into the plus-minus parts list which provides sufficient differentiation and avoids creating an additional type of parts list. This type of parts list has the advantage that the data of the parts list can be managed separately, meaning that for example in case of change of identical parts in the basis parts list, the specific variation parts list will not have to be changed [24]. Data redundancy, more precisely the repeated listing of identical parts in each variation, is avoided. This has the disadvantage that the relationship of basic configuration and different variations is not immediately visible and that data management is made more difficult by the duplication of listings. The representation of plus-and-minus quantities makes it possible to show quantity as well as structural variations, which means that also quality variations and substitutions can be handled.

The *complementary parts list*, where only additions to the basic parts list are entered into the specific parts list, is a sub-type of the plus-minus parts list. This kind of list only makes sense for products that require more of certain materials. It is therefore not suitable for products where less or different kinds of materials are required. Theoretically a negative change would be possible by adapting the basic

Table 3 Plus-minus-parts list

Basic parts list	Identical parts	Specific parts list	Variation A
Part 1	3	(Part 1)	
Part 2		Part 2	+1
Part 3		Part 3	+1

parts list (in this case the amount of a specific part would be reduced) and all variation parts list are also adapted (i.e. increasing the amount where applicable) [24]. However, the processing effort is so high that instead the plus-minus parts list should be used in these cases.

All variations include implicit opportunities to deal with uncertainties. Thus variations for possible scenarios can be formed well ahead as described in Chap. 3 and used when needed. If renewable resources are missing, it can be checked whether they may be substituted by other parts, which is a structural variation of the parts list and the resource substitution mentioned above. The complex parts list is an exception, where this substitution is only possible by using explicit and non-contradictory alternatives instead of a direct substitute as in the other parts list. This makes the representation of a substitution very difficult here. Therefore the question is whether there are parts lists for the same product assembled without the missing renewable resource. It would also be possible to search the order queue using the parts lists with varying quantities for possible products without the missing renewable resource. This is equivalent to the quantity variation mentioned above. Here the question is whether there are open production orders for a product which needs less or none of the actual missing renewable resource.

The same is true for the consideration of quality-related uncertainties. If parts lists are developed well ahead containing the renewable resources in varying qualities as variation, it is possible to decide flexibly which of the parts lists is actually to be used. This is equivalent to the quality variations described above. Thus it is possible to develop e.g. two type parts lists for the same product, of which one variation contains 'renewable resource 1 in good quality' and another one 'renewable resource 1 in bad quality'. Once the quality of the material delivered is known, the adequate parts list can be selected. This parts list may also include more amounts of the renewable resource to balance the quality, e.g. in compound materials [19]. This is equivalent to the structural variation of the parts list, which is possible with all variations described above. Table 4 shows an example. It is also possible that simply using higher quantities of material counterbalances bad quality. This can be taken care of by an adapted parts list with a variation for good quality and smaller quantities and a variation for bad quality and higher quantities [18, 19, 29]. This is equivalent to a quantity variation, an

Table 4 Structural variations of a parts list according to varying quality of material

	Identical parts	Variation A: bad quality additions[a]	Variation B: bad quality substitution[b]	Variation C: good quality
Part 1	3			
Part 2		2		1
Part 3: compensate bad quality		1		
Part 4: Substitute			1	

[a] In this case, the bad part is used anyway (2 pieces of part 2) and an additional part 3 is added

[b] The bad part is not used but substituted by another part 4

Table 5 Quantity variation of a part list according to varying quality of material

	Identical parts	Variation A: bad quality	Variation B: good quality
Part 1	3		
Part 2		2	1

example of which is shown in Table 5. The increase of part 2 shall counterbalance the bad quality.

Parts list cannot take account of time-related uncertainties. The early or late delivery of renewable resources does not change the composition of the product and postponement of delivery dates has no impact on the product structure. This issue is solved by variable work plans or processing plans, which will be discussed in the following chapter.

4.2 Configurators for Variable Bill of Materials

Parts lists variations have been used for some time to represent the variability of final products. Customers' increasing demand for individualisation is often quoted as a reason for this [23, 27, 30]. In production processes with many variations, such as automobile production, the sales departments or customers may use (product) configurators to check the feasibility with respect to technical and functional aspects and to select or, in the case of dynamic composition to develop, the appropriate parts list [20, 22, 31]. A configurator can also be used to take account of uncertainties in planning the production process. Instead of making the selection of the required parts lists dependent on customer request, the selection can be done according to the decision criterias described in Chap. 3. When these become known, in the best case before arrival at the place of production, in the worse case only at the point of delivery, information about quantities, quality and time of delivery are available. These data make it possible to let the configurator select a parts list which is feasible under the given restrictions. Flexible parts list selection makes it possible to postpone the production process if the delivery of a certain renewable resource is delayed and to push the orders for which the renewable resource is required to a period after the planned date of delivery. It is also possible to substitute the missing renewable resource or to use alternative materials. In this case all order parts lists have to be searched for the renewable resource in question and a variation of the parts list has to be selected. The same is true for uncertainties in quantities and qualities. As explained above, alternative part lists for different material qualities can be created, which can be selected according to the existing data on the quality of a material. Thus variable parts lists lead to flexible production processes. In our example the configurator could choose the ratios and substituting materials automatically according to predefined requirements, which were set by the production planner.

4.3 Variable Work Schedules/Time Schedules

Work schedules (task lists) are another structure of the basic data in production planning. They include instructions for the production process as well as processing steps of producing elements [22, 25]. Every produced element thus has its own work schedule. The work schedule is therefore a summary of all steps and needed resources. *Alternative work schedules* are one way of considering uncertainties. Different work schedules are developed which differ in the determinants of their usage. Unit based work schedules are a typical example, in which it is possible to integrate different process steps or times for some ranges of quantities. This corresponds to the variation in quantities. However, it is also possible that a work schedule is chosen according to the resource quality [22]. The condition characteristics and possible value (ranges) then have to be added to the work schedules. These characteristics have to be evaluated during planning, so that a plan can be chosen based on the conditions. This corresponds to the variation in quality.

Time schedules are the time plan for producing an element. They display the chronology of steps, including possible periods of waiting, setup and processing. During shop-floor scheduling, the final resources are assigned, e.g. machines and personal. The lead time scheduling of a production process is planned during the rough-cut scheduling, including the starting and ending time for every individual step as well as possible *buffer time in the work and time schedules*. The buffer time is the time by which the beginning or ending or a step can be delayed without postponing the project end [32]. This is a first possible reaction against uncertainties, at which buffers are only short periods that prevent idle times and thus enable full economic capacity utilization. It is therefore possible to bridge short time uncertainties, with quick decisions being made either during material planning or rather during production control. Buffer periods do not safeguard against longer delays of delivery dates of necessary renewable resources. However, prolonged processing times caused by low quality resources can be compensated, which addresses an internal area of process uncertainty with the external source of the uncertainty in bad resource procurement. In summary, work and time schedules can have buffer times to hedge against time uncertainties.

The time schedules, which are developed from the alternative work schedules, are another way of considering uncertainties. *Alternative operations* can exist within the time schedules [22]. Thus, it is possible to include steps for preprocessing or postprocessing when faced with quality variation. These steps are integrated into the standard work plan as optional steps, which possibly delay the process when they are used. An operation “preprocessing” could be included in the work plan, which is only carried out when a characteristic does not pass the quality control. Otherwise, this step is disregarded and the standard process is chosen, so that two alternative working sequences in the time schedule emerge. This case is illustrated in Fig. 1. The same applies to optional postprocessing steps. This shows that possible additional or alternative steps already have to be known during the development of work and time schedules, in order to include them. The actual decision is made during the shop-floor scheduling.

In addition to alternative work schedules, it is also possible to implement *different sequences* in work plans. Even though interdependencies will always exist, making a specific order of processing steps indispensable, specific operations may be changed [22]. Thus, time or quantity uncertainties can be counteracted by shifting operations either backwards or forwards either in the phase of material planning or shop-floor scheduling (depending on when it becomes known). This also influences the release of production steps in shop-floor scheduling: depending on the availability check, orders can either only be released prior to production (static availability check) if all resources are available or even when resources are (partly) unavailable (flexible availability check). A flexible availability check thus is necessary to adapt the sequence and to release production steps under the condition that not all resources are available (as it is the case in time and quantity uncertainties). Alternatively, availability can already be checked prior to individual steps (dynamic availability check). Thus, other steps can be processed first, while those for which resources are missing can be postponed. This approach is illustrated in Fig. 2.

When switching a sequence it makes sense to determine the earliest and latest points for the beginning and end of an operation within the time schedule, so that the planned delivery deadline is not exceeded. For example, if an operation cannot be carried out because the renewable resource is unavailable or being preprocessed to solve quality problems, the part to be produced can pass through other operations, which do not require this resource. If quality is low, it is also possible that an operation takes longer than usual, e.g. if the renewable resource is wet or hard to handle. Besides buffer periods, one could also do other operations concurrently. Operation time might also be shortened if fewer renewable resources are delivered than needed or planned for. Quantitative uncertainties can also be indirectly addressed by moving forward subsequent operations, because fewer units require less time than planned. All of these variations require a flexible way of postponing subsequent process steps and a flexible machinery setup in order to prevent undesirable downtimes.

It is also possible to reorganize operation sequences over several orders. If a time schedule is changed due to such a reorganization, resources that were originally reserved become available now. Operations from other orders could be

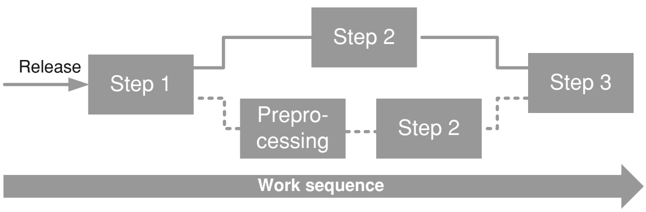

Fig. 1 Alternative operations in work and time schedules

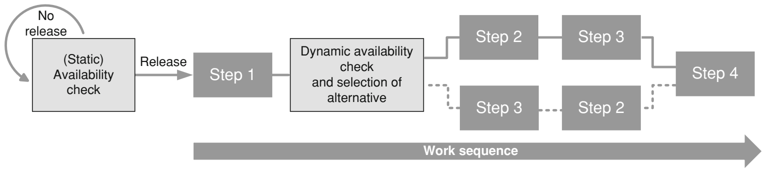

Fig. 2 Different sequences in work and time schedules

processed during this time. Thus, it is possible to develop alternative sequences and operations of several orders. This makes also sense when quantitative variations occur: Processing times are reduced if delivery shortfalls or degraded material occur because fewer resources have to be processed. Subsequent steps can therefore be carried out earlier than planned. This frees up resources which can be used by other orders. Otherwise it is possible that resources needed for the next step are not yet available because they are being blocked by another order. Idle periods then occur. This also shows that it is important to coordinate between alternative sequences across several orders and resources. If the mentioned delivery shortfall is taken into account at an early stage, it is easier to be flexible, as it is possible to define several alternative sequences for different orders and resources. This planning would be carried out within the material planning phase. The final scheduling of work plans and resource utilization can be carried out when the actual delivery shortfall becomes known. If problems suddenly occur or information becomes known too late, planning is carried out within the sequence or operations planning at the stage of shop-floor scheduling, which results in a weak planning result and system nervousness.

For the shown methods it is necessary to expand the conventional standard work plans in such a way that they are able to include the following data: earliest and latest points for individual operations, if–then conditions for sequences, if–then conditions for the choice of work plans, exchangeability of operations (sequence conditions), alternative operations, optional operations and finally simultaneous operations. One also has to consider that process-related time frames, steps and sequences are determined during the conversion into concrete order related schedules, which cannot be revised later on [22]. This excludes other flexible methods which are well suited. Kurbel refers to optional paths through the network of possible operations which are no longer available [22]. Nevertheless, there are these alternatives that were planned for individual operations beforehand and that can actually be carried out later on.

A long-term option for safeguarding against uncertainties is through variable capacities within the rough capacity planning. The actual planning of capacity changes would then be carried out in the requirement planning. Thus, it is not only possible to integrate time but also capacity buffers into work schedules. This enables a spontaneous increase in the workload, for example for the pre- or postprocessing of bad quality renewable resources (which means for example drying) or additional work, which would reduce this uncertainty. It is then necessary to *increase the offered capacity*, which can happen through overtime, additional shifts, adjustments in the intensity of machinery, quantitative staff adjustments or use of additional (reserve) machines [32]. It is also absolutely necessary to ensure flexibility in resource capacities [33]. Furthermore it is possible to provide certain resources as backups that can be used during emergencies. As we assume that not more renewable resources are delivered than ordered, we will not go into the impacts this will have on quantity uncertainties (increased quantities). Capacity adjustments however are a way of reacting to reduced quantities. If material delivery shortfalls result in a reduced production, then *the offered capacity is decreased* so that only the needed resources are used. A decrease can be achieved by reducing staff, adjusting machinery intensity or reducing machinery runtimes. The released capacities can then be used for other orders or to process the delivery of the missing quantities at a later time.

In general, the sooner uncertainties become known and are integrated into planning in the PPC, the better one is able to react. Thus, it is easier to integrate them during rough-cut scheduling to create absorbing buffers. The following steps and orders are postponed in order to make a realistic plan of resource allocations. It is harder to react if uncertainties become known too late during shop-floor scheduling. As this step focuses on target variables such as the delivery deadline or utilization rate and economic targets are neglected, postponement of the process steps would have a large impact [32]. In the worst case a new plan would be developed which cannot meet the deadline. One should therefore try to plan with information of supply chain partners like farmers, harvesters or forestry workers and companies as early as possible and to consider these data in the planning.

5 Conclusion and Further Research

In this paper we analyzed how procurement uncertainties can be considered in the basic data structures of ERP-systems. The general possibilities to consider uncertainties in planning were identified as methods for a variation of quantity, time and quality. Furthermore the substitution of renewable resources was described.

All of the methods are suitable to reduce the specific uncertainties of renewable resources. Finally we examined how the basic data structures can implement these variation methods and how suitable they are for doing so. The results are summarized in Table 6. It turns out that the type parts list or the plus-minus parts lists are well suited to implement the variation methods. The same is true for the complementary parts lists as a subtype of the plus-minus parts list. If these variable BOMs are supplemented with variable work schedules, all the mentioned variation methods can be implemented: While the BOMs cannot implement time variations, the time and work schedules can cover this aspect. Vice versa the time and work schedules cannot implement resource substitutions, but the BOMs can. Thus, a combination of both data structures can cover all the variation methods.

Table 6 Summary of the possibilities to consider uncertainties in the basic data structures

	Quantity variation	Quality variation	Time variation	Resource substitution
Bills of material				
Type parts list	Yes	Yes	No	Yes
Complex parts list	No	Yes	No	Limited[a]
Plus-minus parts list	Yes	Yes	No	Yes
Complementary parts list	Yes	Yes	No	Yes
Work schedules	Yes	Yes	Yes	No
Time schedules	Limited[b]	Yes	Yes	No

[a] By selecting the substituting renewable resources
[b] By order shifting

In our exemplary case, the production of natural fiber reinforced plastics, the production planner can use the mentioned parts lists to plan the substitution of the fibers in advance. For example a type parts list can be build up with two alternatives of a 50–50 %-mixing of two types of fibers or as an alternative a 60–40 %-mixing of these fibers. In this way the needed substitutes are planned, too. The used parts list with fitting ratios according to the deliveries is chosen when the true deliveries become known. This is an easy enhancement for existing ERP-systems and fits the needs of especially small and medium enterprises.

It was repeatedly pointed out that the exchange of information among the members of the supply chain is an important point. The early knowledge of the real values of scenarios' decision criteria is necessary to update and refine the plans and thus to get better and more realistic plans. In this context we recommend further researchers to focus on data collection and exchange in the supply chain of renewable resources. It has already been shown that, for example, Radio Frequency Identification (RFID) enables a more accurate and earlier data collection along the supply chain, resulting in a positive impact on reducing uncertainty in production planning and control [1]. The reaction of PPC systems to frequent changes of plans results in so called "system nervousness" [34–36], which has a negative impact on planning reliability and is itself a new intern source of uncertainty. Further research should examine the reactions of PPC systems and develop a model how the most valuable use of the data can be ensured. This includes the question which data are useful for the production planning with renewable resources.

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