
Evaluation of an IPS² delivery planning approach in industry – limitations and necessary adaptations

Henning Lagemann*, Thomas Dorka, Horst Meier
Ruhr-Universität Bochum, Chair of Production Systems, Universitätsstraße 150, 44801 Bochum, Germany
* Corresponding author. Tel.: +49-234-32-29848 ; fax: +49-234-32-29848. E-mail address: lagemann@lps.ruhr-uni-bochum.de

Abstract

After having been planned, developed and implemented, Industrial Product-Service Systems (IPS²) enter the operation phase of the IPS² lifecycle. During the operation phase, the IPS² provider is facing the challenge to effectively and efficiently schedule IPS² delivery processes and assign available resources from the IPS² network. IPS² delivery planning is an optimization problem of great complexity which is subject to various constraints within a large solution space. Computational support is needed to systematically exploit IPS²-specific planning flexibility options and find close-to-optimum planning solutions. For this purpose, an IPS² planning method has been development and prototypically implemented in an IPS² Execution System. In this paper, a first evaluation of the implemented planning method in an industrial setting is presented. The results indicate that the planning method for IPS² delivery planning generally satisfies the requirements of the industrial evaluation partner. Possibilities for further development as well as limitations of the IPS² delivery planning approach are presented.

Keywords: Industrial Product-Service Systems; operation; delivery planning; execution system; case study

1. Introduction

The lifecycle of Industrial Product-Service Systems (IPS²) consists of the phases planning, development, implementation, operation and closure. Throughout their lifecycle, IPS² are socio-technical systems and have a highly dynamic nature. This is particularly apparent in the operation phase, in which the organization and management of IPS² delivery takes place. Several partners collaborate in a network to deliver product and service shares in order to generate the required customer value. The partners provide resources which are needed to execute the various delivery processes. These delivery processes have been designed for the customers’ specific needs during the development of the IPS².

The organizational challenge of IPS² operation is to assign the available resources in the provider network to the delivery processes for each IPS². Furthermore, the IPS² delivery processes have to be scheduled considering optimized route planning with regard to the timeframes of availability for service for both the IPS² product share and the technical and human resources. The complexity of this planning problem lies in the multidimensional solution space. Globally distributed customers have potentially multiple IPS² which require repeated executions of various delivery processes with varying requirements. These resource requirements need to be matched with the diverse qualifications or specifications of many heterogeneous resources at different locations. Both long-term strategic as well as short-term operational planning have to be considered. Hence, systematic planning approaches are needed.

The difficulty of finding solutions for the planning problem can be alleviated by the application of IPS²-specific optimization potentials. These provide additional flexibility options and thus enlarge the amount of feasible planning solutions when applied systematically. However, until now little research has been conducted on the topic of IPS² capacity...
Due to the complexity of the machine tools and the resulting systems as well as control and automation technology [9].

In order to deliver field service processes, most importantly machine installation as well as preventive and corrective maintenance activities, TRUMPF has more than 1,000 service technicians worldwide and is cooperating with external service providers. These technicians need to be highly skilled in various types of technology since the machine tools consist of mechanical, hydraulic, electrical and laser-optical sub-systems as well as control and automation technology [9].

Due to the complexity of the machine tools and the resulting requirements concerning technician skills and experience, it takes a long time to find, hire and train technicians. In combination with the great variety of different machine tool types and variants this leads to the necessity for technicians to specialize in certain machine types. Consequently, according to their specialization, field service technicians usually have very heterogeneous skill sets and experience with the various machine types.

Hence, the overall challenge for TRUMPF’s service organization is twofold: Firstly, for each machine type within each technology, there need to be enough specialists in order to be able to provide time critical service delivery processes. It is the aim of strategic capacity planning to make sure that the available resource capacity in terms of expert service technicians is capable of matching future demand situations. Secondly, TRUMPF as a large service organization needs a multitude of dispatchers for the scheduling of service tasks and the assignment of service technicians. Usually, each of these dispatchers is using a planning table with a disjoint set of resources, i.e. service technicians. These have individual periods of availability, different locations and heterogeneous skill sets and experience. Due to the complexity of the operative planning task, the number of field service technicians which can be planned by each dispatcher is limited.

The user requirements for an efficient planning approach, which result from the described challenges, can be summarized as follows:

R1: The planning approach should provide the functionality to support the service dispatcher by automatically generating initial schedules for the service delivery based on existing customer requests.

R2: When assigning service technicians to specific service delivery processes, relevant constraints need to be taken into account. This includes the matching of technician skills with delivery process requirements, the matching of existing time windows of field service technicians with the periods of accessibility of the customer’s machine (external factor) and the time window of the delivery process. Besides respecting service technicians’ working hours, all service technicians should have approximately the same workload.

R3: The planning approach must provide an automated route planning module to calculate travel times between the resources’ locations and the site of service delivery. This is essential in order to select technicians based on their skills, experience and location, to find the best sequence of consecutive delivery processes and to determine the start times of delivery processes correctly.

R4: Urgent delivery processes as well as unexpected losses of capacity (e.g. illness of a service technician) necessitate the ability to quickly make changes to an existing delivery plan. Existing flexibility potentials should be utilized systematically to react swiftly to disturbances.

R5: In order to maximize planning efficiency by allowing for a high level of flexibility, all technicians should be planned within one aggregated planning table. The planning approach should support cooperation and the pooling and sharing of resources across organizational and national boundaries.

R6: The planning approach should conduct the scheduling of delivery processes automatically. However, manual

The user requirements for an efficient planning approach, which result from the described challenges, can be summarized as follows:

R1: The planning approach should provide the functionality to support the service dispatcher by automatically generating initial schedules for the service delivery based on existing customer requests.

R2: When assigning service technicians to specific service delivery processes, relevant constraints need to be taken into account. This includes the matching of technician skills with delivery process requirements, the matching of existing time windows of field service technicians with the periods of accessibility of the customer’s machine (external factor) and the time window of the delivery process. Besides respecting service technicians’ working hours, all service technicians should have approximately the same workload.

R3: The planning approach must provide an automated route planning module to calculate travel times between the resources’ locations and the site of service delivery. This is essential in order to select technicians based on their skills, experience and location, to find the best sequence of consecutive delivery processes and to determine the start times of delivery processes correctly.

R4: Urgent delivery processes as well as unexpected losses of capacity (e.g. illness of a service technician) necessitate the ability to quickly make changes to an existing delivery plan. Existing flexibility potentials should be utilized systematically to react swiftly to disturbances.

R5: In order to maximize planning efficiency by allowing for a high level of flexibility, all technicians should be planned within one aggregated planning table. The planning approach should support cooperation and the pooling and sharing of resources across organizational and national boundaries.

R6: The planning approach should conduct the scheduling of delivery processes automatically. However, manual
interventions by fixing delivery processes, which have already been agreed upon with the customer, should be possible.

R7: The planning approach should provide support in determining the long term capacity demand, i.e. strategic resource/capacity planning. An evaluation of the current performance of the service organization is required to determine whether the existing resource capacity is sufficient to fulfill the standards of the service organization. Key performance indicators (KPI) may help to identify discrepancies between existing and required resource capacity.

3. IPS² delivery planning approach

The focus of the present work lies on strategic capacity planning and operational resource planning. In [10] a perspective on resource planning for product-service systems (PSS) in general is presented. It is pointed out that the inherent complexity of PSS and the even more complex task of offering multiple PSS represent a challenge for resource planning. This is mainly caused by the fact that PSS also contain service or hybrid elements that are not taken into account in state-of-the-art resource planning.

Planning problems can be allocated at different planning levels according to the scope and impact of decisions taken on that level. Systematizations that can be found in management science, supply chain management, production and service operations science mostly differentiate between strategic (long-term) and operational (short-term) planning, which are often complemented by tactical (mid-term) planning in between (e.g. [3, 9, 11–13]).

This systematization between strategic and operational planning is also applied in the “adaptive IPS² delivery planning” approach described in [14]. The approach uses a genetic algorithm to solve the planning problem. The mutation operators of the algorithm use optimization potentials (described in detail in section 4.2) to alter existing solutions to generate new schedules for the delivery of IPS². Route planning is used to determine travel times of resources, thus solving the embedded travelling salesman problem. Consecutively, the newly generated plans are evaluated with respect to the punctuality of the processes, costs and utilization of resources. [14]

In [15] an extensive literature review was conducted showing that the existing approaches (including the preliminary studies that lead to [14]) are not sufficient to provide a satisfactory resource planning approach for IPS². Hence, a new resource planning for service delivery in PSS is described. The planning approach is based on a data model developed in [15]. The data about a service assignment are extended to identify which resources are needed. With this information and through lead time scheduling, the required resource capacities are determined. The resulting requirement and utilization profiles are matched with the available capacities. For the matching of requirements and capacities, a heuristic planning approach is suggested, yet not further described. However, different types of measures to overcome capacities that are either too high or too low are presented.

In the following, the “adaptive IPS² delivery planning” approach presented in [14] is evaluated for application in industry. In contrast to [15], this approach provides a detailed description of an operational planning algorithm and a prototypical implementation already exists. These factors make this approach the most suitable solution for evaluation at TRUMPF.

4. Evaluation of the IPS² delivery planning approach

The planning approach under examination has been developed in TR 29 for IPS² providers [14, 16, 17]. In the case of IPS² providers, capacity and delivery planning is based on predefined data input in the form of the IPS² model [7]. In this model, detailed information is available concerning delivery processes and process requirements. Resources with specific capabilities are provided by network partners, which are represented by virtual organization units as part of the IPS² network [18]. The IPS² model is the output of the IPS² development phase, in which these specifications are determined. Within the IPS² model, several IPS²-specific potentials for optimization are included, providing the means to react flexibly to disruptions in capacity demand and resource availability [2].

In the following, the preconditions for the successful application of the IPS² delivery planning approach will be discussed, including data requirements and data availability as well as the applicability of IPS²-specific potentials for optimization. Based on this, required adaptations and limitations of the IPS² planning approach will be identified by comparing the practical requirements of the industry partner with the features and functionalities of the IPS² delivery planning approach.

4.1. Data requirements and data availability

Various types of data are needed for the effective scheduling of delivery processes. The required data can basically be categorized into process information and resource information. Process information includes process times, process requirements and possibly also process alternatives. Resource information includes location, availability and utilization, quality or qualification of resources and in some cases even resource-specific process times, if processes are not completely standardized. These types of data are managed by the provider, who is responsible for the scheduling and delivery of service processes. External network partners or subcontractors need to share relevant resource information in order to be considered for service delivery.

At TRUMPF, most delivery processes are initiated by the customer. In that case, additional information as to where and when the service delivery should take place is required. This includes a problem or demand description based on which the type of delivery process is determined. This information is usually collected during telephone support. After determining the delivery processes which need to be conducted, resources are selected and assigned based on their availability, qualifications and location.

In case the delivery process is not initiated by the customer but triggered condition-based, further information regarding the state of the operating equipment (i.e. the machine or tools)
is required [19]. Alternatively, predetermined maintenance can be scheduled according to predefined maintenance intervals. At TRUMPF, the latter is the case for those customers who have a preventive maintenance contract.

For the application of the described IPS² planning method at TRUMPF, most of the relevant information is available or can be obtained with reasonable effort. For example, process times either exist in the form of target or standard times or can be calculated with the help of an extensive database with information about previous delivery processes.

One of the greater challenges is that, at TRUMPF, resource requirements of delivery processes and resource qualifications are not available in a formalized way. Nevertheless this is required input for the evaluated planning approach. Most of this information which is needed to match delivery processes with resources is in the minds of the service dispatchers, who know which technicians can deliver services to which machine types. Therefore, distinct skill requirements need to be generated for each type of delivery process and for each machine type. Similarly, technician skills have to be formalized based on absorbed trainings and/or based on the history of past delivery processes.

In other cases, simplifications will have to be accepted in order to be able to apply the planning approach to service planning at TRUMPF. For example, the complete availability periods of the customers' machines are not collected systematically. In practice, TRUMPF service dispatchers either simply inform the customer about the date and time of the delivery process or come to a bilateral agreement. Therefore, when applying the IPS² planning method, some assumptions might have to be made, e.g. that machines are available during usual working hours.

Hence it can be concluded that the required information and data for service delivery planning are either available at TRUMPF or can be obtained from other existing data or by way of making reasonable assumptions, as in the case of the machines' availability for service. These data can be transformed into the form of the IPS² model, based on which IPS² delivery planning is conducted.

4.2. Applicability of IPS²-specific planning flexibility options

Systematically exploiting existing flexibility options is one of the most important requirements the planning approach must fulfill (R4). The concept of IPS²-specific potentials for optimization has been first brought up by MEIER and KRUG [2, 3]. The basic idea is to increase the planning flexibility by systematically utilizing variance in time, variance of resources, variance of processes, variance of allocation time and by partially substituting product and service shares [17]. For example, the dispatcher can choose between different redundant resources which are available for the same delivery process. Likewise, different substitutive delivery processes (e.g. exchanging a defect component instead of repairing it) might have different implications for the duration, the costs and the resource requirements of a delivery process.

IPS²-specific potentials for optimization are included in the evolutionary planning algorithm (compare section 3) in the form of mutation operators, which all occur with a specific probability [14]. Hence, an important precondition for the fulfillment of R4 is satisfied. However, in order to be fully applicable, the IPS²-specific planning flexibility options need to be matched by corresponding flexibility potentials within the service organization, which is discussed in the following.

Making use of the flexibility potential variance in time by rescheduling delivery processes within the process and resource time window is the main strategy of flexibly adapting the delivery plan at TRUMPF. All required data are available.

Likewise, variances of resource are standardly applied by the service dispatcher. Often there are several service technicians available who have the required qualifications to perform a delivery process. In practice, the service dispatcher usually chooses the technician who is closest to the customer’s location and has the most experience with this particular type of equipment. The required information for the utilization of this optimization potential is included in the planning data in form of qualifications that are possessed by several service technicians.

If no technicians with the required qualifications within the specified time window are available, the dispatcher uses external service providers. These are often less trained and less experienced than TRUMPF’s technicians and therefore cannot be assigned to all types of delivery processes, which is a minor limitation of this strategy. This is equivalent to the IPS² network organization, where the IPS² network can be extended by partners from the provider network [20, 21].

Another possibility of utilizing external resources is to make use of the customer’s staff. Practically, this is the case whenever malfunctions or defects can be solved with the help of the telephone support without any technicians in the field. In the terminology of IPS², this would be considered to be a process substitution, combined with alternative resources. However, this possibility cannot be regarded as a true optimization potential which can be applied systematically. In practice, usually it is not possible to know in advance if a customer’s problem can be solved remotely or if a field service mission is required. Therefore, the telephone support is to be understood as a supplement rather than a substitute for the field service delivery process.

A possible variance of processes, which is applied occasionally, is the assignment of varying numbers of service technicians. Mostly, one single service technician is sent to the customer to deliver the service processes. However, in some cases, the regular service technician might be supported by (i) an assistant, i.e. another technician who is not trained for this type of process or less experienced; (ii) a specialist, i.e. another technician who has received special trainings and many years of experience with that particular type of machine; or (iii) another technician with equal qualification and experience. At TRUMPF, information about resource requirements and process duration in the case of delivery processes with multiple technicians is available in the experienced dispatcher’s mind, but not in a formalized form.

The variation of the allocation time, i.e. selecting different means of transportation for the resources, is almost exclusively applied to spare parts. These are usually shipped to the customer by regular parcel service, but in some cases
might even be sent by express courier. In most countries, service technicians travel by car and have their tools and equipment with them. Only in very large service organizations, such as the United States of America, service technicians travel by plane. Consequently, at TRUMPF, alternative types of transportation for service technicians are hardly ever applied, because the disadvantages (e.g. difficult or impossible transportation of equipment or significant additional costs) outweigh marginal savings of time.

The substitution of product and service shares is not applied explicitly at TRUMPF as a systematic flexibility option during delivery planning. In the planning algorithm, it is not implemented as an explicit optimization potential in the form of a mutation operator but included implicitly in the form of alternative processes. Similarly, at TRUMPF, it could be applied in the form of alternative processes with remote service equipment for visual online support, for example.

4.3. Applicability and required adaptation of the IPS² planning approach

According to R6, manual user interventions should be possible. This necessity has already been considered in the planning algorithm [14]. However, the possibility of freezing scheduled delivery processes and thus preventing them from being rescheduled has not been integrated explicitly. Hence the planning approach should be extended to be able to support two different types of freeze points: In case the customer has already been notified about the date of service delivery, the process should not be moved to a different time slot (freeze point 1). Similarly, in case resources have already been assigned and undergone some specific preparations (e.g. spare parts or other materials have been sent to the place of service delivery) neither the service process nor the resources should be altered (freeze point 2).

In line with R2, constraints in the form of delivery process requirements and time window constraints for all internal and external resources need to be respected. This is an integral part of the planning approach, hence R2 is fulfilled entirely. However, as specified in section 4.1, distributed data and implicit information (such as skills and requirements) within the service organization need to be formalized in order to allow automated processing.

In the considered planning approach [14], R3 is fulfilled insofar as there are different types of routing services which can be used for the automated route planning of resources, e.g. google maps routing service. This functionality needs to be provided in order to calculate the transportation time or travel time of resources between two subsequent delivery processes at different locations.

In order to automatically generate initial schedules for IPS² delivery (R1), the planning algorithm must provide the possibility to split long delivery processes into multiple sub-processes. This is due to the fact that a large percentage of the delivery processes cannot be completed within one working day. This has not been considered previously. In between the parts of a subdivided delivery process, the assigned technician(s) either travel(s) home or to a different overnight location, but should not be assigned to other delivery processes. Concluding, if this functionality can be implemented successfully within the planning approach, automated resource scheduling will be possible in order to fulfill R1 within the industrial setting at TRUMPF.

R5 is basically fulfilled by the planning approach as there is, theoretically, no limitation to the size of the planning problem which can solved. However, depending on the available computing capacity, there will be limitations due to increasing computing time. Further computational studies with planning problems of increased complexity will have to be conducted in order to find out if the planning approach can be used for IPS² delivery planning in large provider networks across organizational and national boundaries.

Within the industrial setting presented in this study, the existing approach is not suitable to support long-term capacity planning (R7). The main reason for this is to be seen in divergent interpretations of the purpose and the scope of long-term, i.e. strategic capacity planning. Strategic capacity planning at TRUMPF is conducted for a time period of one year and longer because most measures of strategic capacity adjustment take several months, e.g. hiring and training service technicians [7]. For such a long planning horizon, information regarding the timing and the amount of future IPS² delivery processes is not available at TRUMPF. Furthermore, the planning approach does not include the possibility of extrapolating future service demand and supply based on probability distributions and expected market growth.

5. Conclusion and discussion

In this paper, an IPS² delivery planning approach, which has been implemented prototypically in an IPS² Execution System, has been evaluated. Having compared functional requirements with functionalities and capabilities of the planning approach, it can be concluded that, subject to some adaptions, the IPS² delivery planning approach under consideration is generally suited to be applied in the industrial setting, namely the international service organization of TRUMPF machine tools. The functionality to split long processes into several sub-processes is a necessary adaption of the planning approach. The introduction of freeze-points, after which delivery processes should not be rescheduled or resources should not be reassigned, is recommended.

A major limitation of the approach is the insufficient support of long-term capacity planning as required by TRUMPF (R7). The planning approach does not provide the functionality to generate and incorporate expected but yet uncertain delivery processes on a stochastic basis. Consequently, no possibility of deriving differentiated conclusions or support in taking strategic capacity management measures can be provided so far by the IPS² planning approach.

The limitations and required adaptions of the IPS² planning approach might partially result from the fact that the planning approach has been developed for delivery planning within IPS² networks where all parties have access to the IPS² Execution System (IPS² ES). In that case, manual interventions might become obsolete, because the customer
has access to the IPS² ES, too, can define the availability of the IPS² in detail and can retrieve the time and type of service delivery from the IPS² ES at any time.

6. Outlook

Further research is needed in order to evaluate the performance of the IPS² planning algorithm with regard to the validity and quality of the operative planning solution. In particular, future studies should be conducted to evaluate the computational performance of the planning algorithm and to optimize the various parameters of the genetic planning algorithm. First test runs indicate that the planning algorithm might require large amounts of computation time, depending on the size of the planning problem and the computational resources which are available. In-depth studies are required to examine possible limits.

Furthermore, the evaluation should be extended to other industrial settings and scenarios in order to derive more generalizable conclusions. Quantitative studies in industrial settings with real-live data and quantitative and qualitative evaluation by operative planners are needed.

In order to support strategic capacity planning, a new approach is needed which takes the various dynamic influences on capacity demand and supply into account [22] and provides support in deciding which measures of capacity management should be implemented. Due to the possibility of anticipating future demand with the help of stochastic probability distributions, simulation modeling might be a promising approach that will be further examined.

Acknowledgements

We express our sincere thanks to the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) for financing this study within the Collaborative Research Center Transregio 29 (CRC/TR 29) on Industrial Product-Service Systems – dynamic interdependencies between products and services in the production area.

We further thank TRUMPF Werkzeugmaschinen GmbH + Co. KG for the fruitful cooperation in the transfer project T3 as part of CRC/TR 29.

References


