A conceptual framework for cloud-based advanced planning systems

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ABSTRACT

In the last decade, Cloud Computing (CC) and Advanced Planning Systems (APS) are two emerging topics in research and practice. However, no comprehensive and general model that considers both topics at a conceptual level exists. Therefore, the purpose of this article is to provide a conceptual framework for cloud-based APS that merges the essential capabilities of both. Within the framework, we propose a generic structure of fundamental services and components to fulfill different consumer requirements from the area of supply chain planning. In addition, we elaborate appropriate service, deployment, and pricing models and introduce the 'Result-as-a-Service' model explicitly providing the functionality to solve planning problems. The research is generally based on the design science research approach by extending CC to the problem domain of supply chain planning and comprises a structured literature search and expert knowledge acquisition. Based on the framework, several findings concerning the potential of cloud-based APS but also caveats like security issues and planning capabilities are elaborated. Furthermore, several of the most important research topics (e.g. process and object reference models or ontologies for planning domains) are formulated and form an initial agenda for the research and further development of cloud-based APS.

KEYWORDS

Cloud computing; advanced planning systems; conceptual framework; research agenda

1. Introduction

In recent years, Cloud Computing (CC) is an emerging topic in the fields of Information Technology (IT) and Information Systems (IS). Here, the CC paradigm can be best described as 'a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction' (Mell & Grance, 2011, p. 2). The basic purpose of this 'model' is to offer IT outsourcing possibilities in the business-to-business sector (cf., e.g., Lacity et al., 2010; Leimeister et al., 2010; Hoberg et al., 2012; Schneider & Sunyaev, 2016 or Su et al., 2016) as well as new services in the business-to-consumer sector. A recent analysis shows that a company's adaptation to the Software-as-a-Service model (cf. section 2.1) positively affects operational and innovation benefits (Loukis et al.,

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2019). In this context, CC represents a substantial change in the way IT is invented, developed, deployed, scaled, updated, maintained, and paid for (Marston et al., 2011) and 'promises to provide on demand computing power with quick implementation, low maintenance, fewer IT staff, and consequently lower cost' (Yang & Tate, 2012, p. 36). Regarding the business-to-business sector, the greatest advantages of such on-demand IT solutions compared to on-premise IT solutions are lower (up front) costs, the high flexibility for business and technology innovation as well as the possibility to focus on core activities for the consuming organisation. Particularly the pay-per-use pricing model (also called pay-as-you-go) makes CC (cloud services) predestined to complement on-premise IT resources in a cost-efficient way (Henneberger, 2016). Because of these advantages, CC offers the chance 'to make more of the potentially lucrative SME enterprise application market' (see Sharif, 2010, p. 133). Also M. Li et al. (2012), Lee et al. (2013), and Friedrich-Baasner et al. (2018) document these advantages for Small and Medium Enterprises (SMEs). Nevertheless, Friedrich-Baasner et al. (2018) also state that the acceptance and diffusion of cloud-based services is low among SMEs.

Another prominent topic in recent years is Advanced Planning (AP), one of the building blocks of Supply Chain Management (SCM). Hereby, SCM can be best described 'as the task of integrating organizational units along a SC [supply chain] and coordinating materials, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving competitiveness of the SC as a whole' (Stadtler, 2005, p. 576). In this context, the notion 'Advanced Planning' can be best described as the fulfilment of supply chain planning tasks by 'advanced' planning concepts and methods. These concepts and methods are embedded in a special type of Decision Support Systems (DSS) called Advanced Planning Systems (APS), the technical implementation of AP. Generally, APS 'do not substitute but supplement existing Enterprise Resource Planning (ERP) systems' (Stadtler, 2008, p. 18) and enhance their limited planning capacities. Regarding SMEs, it must be emphasised that DSS at all and APS in particular are rarely in use (mostly due to the lack of financial as well as technological resources) and that although SMEs represent a large part of producing companies (Dimopoulos et al., 2015) and DSS, for instance, for production scheduling (Schmidt, 1992) or physical distribution planning (Langevin & Saint-Mleux, 1992) are available at the market (cf. also the literature discussed in section 2.3).

In contrast to the fact that both CC and APS are emerging topics in practice and research, as far as the authors are concerned, there only exists a single scientific article that addresses the integration of CC and DSS on a conceptual and general manner. Furthermore, APS providers like 'Oracle (SCM Cloud)', 'Acteos (SaaS)', 'infor (CloudSuite)', 'SAP (Integrated Business Planning)' or 'Viewlocity', as well as optimisation software providers like 'AIMMS', 'FICO', 'FrontlineSolvers', or 'Gurobi', offer products in cloud computing environments but their interpretation of CC, provided services, addressed planning tasks, and planning capabilities is very heterogeneous. This complicates the comparison and acquisition of appropriate services by supply chain planners.

Based on all these observations, we conclude that it is time to integrate CC and APS to 'cloud-based APS' at a conceptual level. Therefore, the purpose and contribution of this paper is to provide a conceptual framework for cloud-based APS, integrating the essential capabilities of CC and APS at a conceptual level. It describes a generic structure of different services, service components, and service, deployment, and pricing models. Furthermore, we introduce the new service model 'Result-as-a-Service – RaaS' to explicitly provide supply chain planning capabilities in CC environments. The framework is also developed to answer the question about which aspects, benefits, drawbacks, and challenges are meaningful for cloud-based APS. In addition, the framework creates a universal base and understanding for APS providers to support the development of services and also to describe and differentiate their services in a structured manner. This is also important for consumers to evaluate and adopt desired services more efficiently and for scientists to classify their research.

The paper is structured as follows. First, brief introductions on the topics CC and APS are given to provide a common understanding (sections 2.1 and 2.2). The following review of related work in section 2.3 carves out the research gap concerning cloud-based APS. The research methodology is described in section 3. Then, we present the new conceptual framework for cloud-based APS (section 4). The framework describes participating actors and their roles, consumer requirements and appropriate service models, basic service components to fulfill the consumer demands, the dependencies between participating organisations and deployment models as well as pricing models and accounting issues. In section 5, we discuss general implications and emphasise further research topics. The paper completes with the conclusions and limitations in section 6.

2. Background and related work

CC and APS have been established as a prominent topic in practice as well as research in recent years. Before presenting the concept to merge CC and APS, a general understanding (as used in this contribution) about both topics is given and a review of related work is presented.

2.1. Cloud computing

Several descriptions and definitions of CC, its characteristics, benefits, and drawbacks exist (cf. for instance, the articles of Weinhardt et al., 2009; Leimeister et al., 2010; Su, 2011; Azogu & Ryan, 2012; Hoberg et al., 2012; Repschlaeger et al., 2012, or Henneberger, 2016). Here, we basically use the broadly accepted model provided by the National Institute of Standards and Technology (Mell & Grance, 2011). Principally, the authors distinguish between 'Essential Characteristics', 'Service Model', and 'Deployment Model' and their main aspects are excerpted and summarised in Tables 1–3, respectively.

A further characteristic of CC is the 'Pricing Model' (cf. Hoberg et al., 2012), which can be divided into two general concepts (cf. Table 4):

A recent review on cloud computing research can be found in Senyo et al. (2018).

Table 1. Essential characteristics of CC (according to Mell & Grance, 2011).

On-demand self-service	'A consumer can unilaterally provision computing capabilities [. . .] as needed automatically without requiring human interaction with each service's provider.'
Broad network access	'Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms.'
Resource pooling	'The provider's computing resources are pooled to serve multiple consumers using a multitenant model, [. . .] dynamically assigned and reassigned according to consumer demand.'
Rapid elasticity	'Capabilities can be rapidly and elastically provisioned [. . .]. To the consumer, the capabilities [. . .] often appear to be unlimited and can be purchased in any quantity at any time.'
Measured service	'Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service.'

Table 2. Service models (according to Mell & Grance, 2011).

Software-as-a-Service (SaaS)	'The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g. web-based email), or a program interface.'
Platform-as-a-Service (PaaS)	'The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider.'
Infrastructure-as -a-Service (IaaS)	'The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications.'

Table 3. Deployment models (according to Mell & Grance, 2011).

Private cloud	'The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g. business units).'
Community cloud	'The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g. mission, security requirements, policy, and compliance considerations).'
Public cloud	'The cloud infrastructure is provisioned for open use by the general public.'
Hybrid cloud	'The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardised or proprietary technology that enables data and application portability (e.g. cloud bursting for load balancing between clouds).'

2.2. Advanced planning systems

General goal of AP in the context of SCM is '[…] the synchronization of constrained material and resources to independent demand. Its purpose is to create a plan that is feasible with respect to all resources required (machines, material, tooling etc.) […]' (Musselman & Uzsoy, 2001, p. 2045) or in other words, the fulfilment of supply chain planning tasks, incorporating long-term, mid-term and short-term planning levels (Stadtler, 2008). Hereby, all planning tasks together focus 'on supporting the material flow across a supply chain and related business functions: procurement, production, transport and distribution as well as sales' (Stadtler, 2005, p. 579). The two dimensions 'planning horizon' (also representing the planning level) and 'supply chain process' are used to classify the general supply chain planning tasks within the 'Supply Chain Planning Matrix' (Fleischmann et al., 2008). This approach is also used to classify software modules of APS. These modules represent a common structure that can be found in most APS products, whereby each module covers a certain domain of supply chain planning tasks (cf. Meyr et al., 2008). Figure 1 shows this general structure.

In the following, we will give short descriptions of the modules (details can be found in Fleischmann & Meyr, 2003; Meyr et al., 2008, or Stadtler et al., 2015). Strategic Network Design comprises all long-term (strategic) planning tasks, especially planning of plant locations, production systems, and the physical distribution structure. Also, some strategic sales planning decisions (e.g. which products should be placed in a market) are of interest. The module Demand Planning covers strategic and mid-term sales planning tasks (e.g. forecasting of potential sales per region) while the module Demand Fulfilment & ATP covers short-term (operational) sales planning. The basic purpose of Master Planning is the coordination of procurement, production, and distribution processes. Hence, the mid-term planning tasks of distribution, personal and capacity planning, and especially master production scheduling are supported by this module. In some APS architectures and

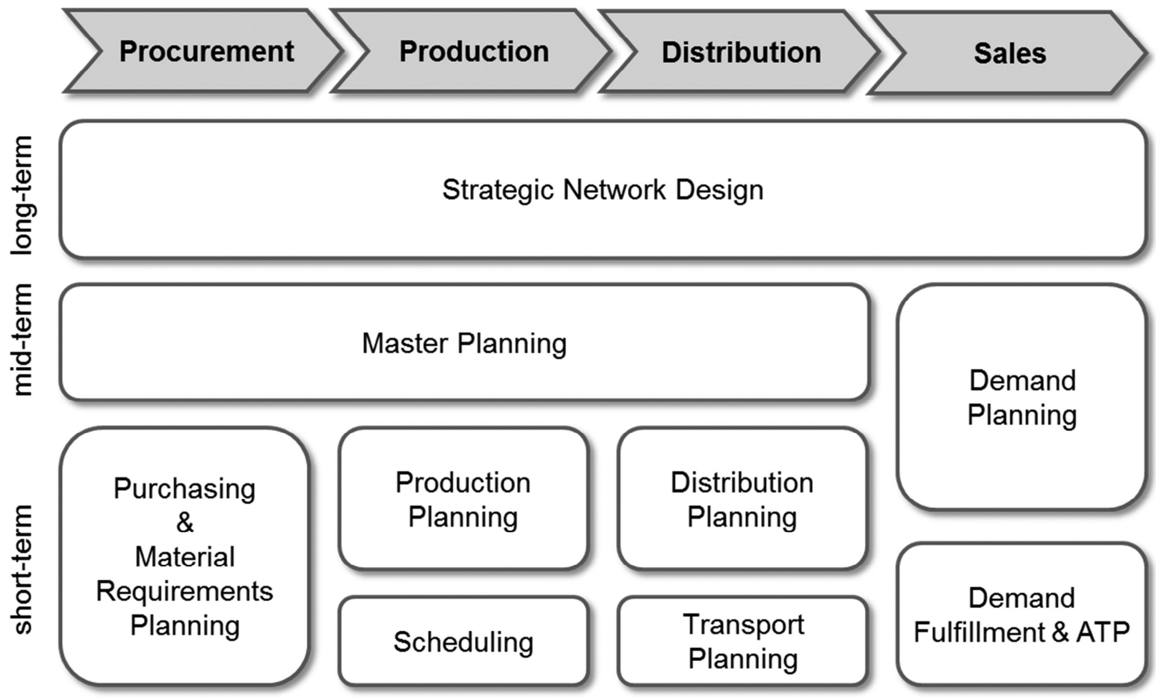

Figure 1. Software modules covering supply chain planning tasks (Meyr et al., 2008).

planning hierarchies, the concept of 'Sales and Operation Planning (SOP)' combining Demand Planning and Master Planning is used (cf., e.g. Thomas et al., 2008; a systemic approach to characterise APS can be found in Vidoni & Vecchietti, 2015). As Master Planning only considers final products and critical materials, the planning task of Purchasing & Material Requirements Planning is to calculate production and procurement order quantities for all materials not yet considered. This task is mostly left to ERP systems, but these hardly consider 'advanced' concepts like automated supplier selection, quantity discounts, or lower and upper bounds on supply quantities. The module Production Planning is in most cases responsible for lot-sizing (i.e. the balancing of changeover (setup) and inventory holding costs), whereas the module Scheduling is responsible for machine scheduling (i.e. the allocation and sequencing of production orders/lots with respect to the available production resources) and shop floor control. However, these planning tasks are often integrated in a single module to obtain better planning results or due to the interdependencies between them. Concerning these (short-term) planning tasks, it is important to stress that their particular dependency on the organisation of the production system has to be considered during planning. That's why, due to specific production environments of different industrial sectors (and production processes) and their explicit requirements, very heterogeneous planning problems arise. The modules Distribution Planning and Transport Planning cover the planning of inventory levels (mostly by warehouse replenishment strategies) and transportation quantities on an aggregated or detailed level, respectively.

2.3. *Related work*

To assess and analyse the current state of research related to cloud-based APS, we started with literature from other research projects to define the scope of the subsequent structured literature search by journals and keywords (cf. the methodology used in Gahm et al., 2016). The literature search bases on a keyword search in the most relevant, high quality journals and proceedings of renowned conferences (as recommended by Webster & Watson, 2002; Vom Brocke et al., 2009). The selection of journals is based on the 'SCIMAGO Journal & Country Rank' in combination with the SJR-Index and on the JOURQUAL3 ranking of the German Academic Association of Business Research (VHB). In detail, we defined all journals to be relevant if they have an SJR-Index not lower than 0.90 in 2019 and belong to one of the following SJR subject categories: Computer Science (miscellaneous), Computer Science Applications, Industrial and Manufacturing Engineering, Information Systems, Information Systems and Management, Management Information Systems, Management Science and Operations Management, Software, Theoretical Computer Science. Additional journals are selected based on the VHB ranks A+, A, and B in the sub-discipline rankings Logistics, Operations Research, Production Management, and Business Information Systems. In total, 381 journals have been considered. Conference proceedings are neglected despite the proceedings of the International Conference on Information Systems (ICIS) and the European Conference on Information Systems (ECIS). These have been considered due to their high reputation (Willcocks et al., 2008). For the keyword search in journals, we used all databases in the 'Web of Science' and for the search in the proceedings, we used the 'AIS Conferences Collections (AIS eLibrary)'. In a first keyword search, we looked for directly related articles by the CC keyword group and the APS keyword group listed in the second row of Table 4. As this first search among title, abstract, and keywords has not provided appropriate results, we performed a second search looking for less restrictive APS keywords amid titles (cf. the third row of Table 5).

In this way, we obtained a sample of 290 articles to be analysed for relevance (cf. Table 5). We are aware that the selection of journals and the approach of quality assessment by indices as well as the selected keywords only lead to a limited literature sample. However, this is the usual approach used in literature.

During the literature analysis based on title, abstract, and full text (if required), we observed that most of the initially found articles address the topics cloud resource planning (elasticity management) and scheduling (174; cf., e.g. Sebastio et al., 2017 or

Table 4. Pricing models.

Pay-per-use	"[. . .] consumers only pay for what they actually use." (Koehler et al., 2010) "Much like a utility, cloud resource charges are based on the quantity used."(Durkee, 2010)
Flat-rate	"[. . .] consumers pay a fixed amount e.g. a month and can use the service as often as they want." (Koehler et al., 2010)

Table 5. Keywords and results articles.

CC keyword group (combined by OR)		APS keyword group (combined by OR)	Number of initial hits in	Relevant
'cloud*', 'Software-as-a-Service', 'SaaS', 'Platform-as-a-Service', 'PaaS', 'Infrastructure-as-a-Service', 'IaaS'	AND	'advanced planning*', 'APS', 'scheduling*system'	12/1 (journals/ proceedings)	1/0
		'scheduling', 'planning', 'decision'	272/5	16/1

Liang et al., 2018), cloud manufacturing (23; cf. e.g. Chen et al., 2019 or Vahedi-Nouri et al., 2020), and cloud service selection (9; cf., e.g. Hu et al., 2020 or Liu & Prybutok, 2020). Finally, 18 relevant articles have been identified and are analysed in detail, whereby 17 of these articles address specific planning tasks and only one article addresses the topic in a general manner.

Tarantilis et al. (2008) present a web-based ERP system that includes not only standard ERP functionalities but also explicit SCM and particular manufacturing process management functionalities. They state that 'the most powerful properties of the proposed Web-ERP tool is the ability to integrate through its workflow and resource planning processes, several supply chain problems' (Tarantilis et al., 2008). Unfortunately, the authors do not provide any further details about the planning capabilities of their approach. Hartmann and Laroque (2011) address the topic of web-based applications for planning in the context of SCM. The authors give a general overview about planning topics, data modelling, and the basic architecture of the developed rich internet application. Guo et al. (2014) propose 'A cloud-based intelligent decision-making system for order tracking and allocation in apparel manufacturing'. In their system, real-time production data is collected and the decision-relevant data is extracted to the intelligent order allocation module. This module performs the planning task using multi-objective memetic optimisation, Monte Carlo Simulation, and a heuristic pruning procedure. Somasundaram and Govindarajan (2014) present a CLOUD Resource Broker (CLOUDRB) for scheduling and managing high-performance computing (HPC) applications in science clouds. The implementation is based on a cloud architecture consisting of the layers 'Cloud Resources', 'Cloud Middleware', and the CLOUDRB that consist of the services 'Request handler service', 'Job scheduling and resource allocator service', 'Dispatcher service', 'Cloud resource information aggregator service', 'Cloud resource provisioner service', and 'Cloud monitoring and discovery service'. 'A cloud-based MODFLOW service for aquifer management decision support' is presented by Jones et al. (2015). Their developed web service provides a new scripting framework enabling the development of automated systems for modifying and executing MODFLOW models to support groundwater management. Pang et al. (2015) propose advanced planning and scheduling services for fleet management in industrial parks (FAPS). FAPS comprises several modules covering the planning tasks 'Fleet Selection Planning', 'Transportation Planning', and 'Resource Scheduling'. Their service-oriented architecture explicitly enables the integration of third-party services, such as planning and scheduling services, which are delivered by the SaaS model. In their study, Mishra et al. (2016) propose a cloud-based multi-agent architecture for the efficient integration of manufacturing scheduling and process planning of distributed manufacturing firms. In their architecture, clients interact with the system based on the SaaS model. Unfortunately, the authors focus on the multi-agent architecture and give no further information on the cloud aspect. Mourtzis et al. (2016) develop a cloud-based platform consisting of two main services that are responsible for monitoring machine availability and calculating process plans. A cloud manufacturing production planning and control system in the area of sheet metal processing is presented by Helo and Hao (2017). Data about manufacturing resources and manufacturing capabilities are used by a cloud computing-based optimisation system for production planning and control. Z. Li et al. (2017) propose a cloud-aided comfort-based route planning system. A road profile and anomaly database combined with a road infrastructure database provides the planning relevant data for the route planning with the objective to increase travel comforts. The task of product design in a cloud manufacturing environment is addressed by the framework for cloud-based design (CBD) proposed by Zheng et al. (2017). Their framework comprises three layers: resource layer, service layer, and application layer. The resource layer defines product planning resources and contains two sub-layers: the physical resource sub-layer and the virtual resource sub-layer. The service layer consists of four modules: the request processing module, product planning module, service encapsulation module, and service management module. The application layer provides interfaces between the users (manufacturing service providers and customers) and the CBD system. Dai et al. (2018) propose a cloud-based decision support system for self-healing ('automatic discovery and correction of faults') in distributed automation systems using fault tree analysis. A cloud-based approach is used as CC can provide sufficient computing power to ensure the real-time constraints for self-healing. A cloud-based cyber-physical system (CPS) for adaptive shop-floor scheduling and condition-based maintenance is proposed by Mourtzis and Vlachou (2018). The considered CPS comprises the physical shop-floor consisting of sensor boards, micro-controllers, and cloud gateway providing the link to the cyber shop-floor hosted on a cloud platform. The cyber shop-floor contains components for adaptive scheduling and condition-based maintenance decisions. Special attention has been paid to the consolidation of the information provided by the sensor network and the machine-tool operators. For the multi-level aggregate service planning in a cloud manufacturing environment, Yu et al. (2018) propose a cloud platform to efficiently offer product and service configurations for varying demands. A cloud architecture for production scheduling as a service for sheet metal manufacturing is developed by Helo et al. (2019). Their architecture comprises user role specific application interfaces, web server load balancing, data bases, and a server cluster to execute genetic algorithms in a distributed environment. For running power system simulations, Luo et al. (2019) developed a fully elastic, on demand cloud computing platform. The platform itself is hosted in a cloud and supports the power system planners to make tradeoffs between cost and completion time. This allows the engineers to focus on power system planning and operation. 'A cloud-based resource planning tool for the production and installation of industrial product service systems (IPSS)' is proposed by Mourtzis et al. (2020). Their system architecture is based on three modules: the module 'designer' aids the mechanical engineers in designing an IPSS according to customer's customisation options; the module 'planner' is responsible for creating resource and production plans; and the module 'procurement' stores all the required information about resources needed for the production of IPSS.

Table 6 summarises the planning task-related literature:

In contrast to the previous literature, the framework of service-oriented decision support systems (DSS in cloud) proposed by Demirkan and Delen (2013) is the only research, to the best of our knowledge, that addresses the topic at a general and conceptual level. The authors present a conceptual architecture and define 10 research directions. One of these directions (Research Direction 2 – The Definition of DSS Service) states that 'research should be undertaken to define type of services in DSS environment based on component-approach model […]'. In Addition, the authors formulate the concept of analytics-as-a-service (AaaS) for turning utility computing into a service model for analytics. This AaaS concept mainly focus on data science aspects (data mining, text

Table 6. Related articles and addressed planning tasks.

Planning task Article	Strategic Network Design	Master Plannig	Demand Planning	Purchasing & MRP	Production Planning	Scheduling	Distribution Planning	Transport Planning	Demand Fullfillment & ATP	Other
Tarantilis et al. (2008)						x				
Hartmann and Laroque (2011)	x					x				
Guo et al. (2014)									x	
Somasundaram and Govindarajan (2014)						x				
Jones et al. (2015)										x
Pang et al. (2015)							x	x		
Mishra et al. (2016)				x	x	x				
Mourtzis et al. (2016)						x				
Helo and Hao (2017)						x				x
Z. Li et al. (2017)								x		
Zheng et al. (2017)										x
Dai et al. (2018)										x
Mourtzis and Vlachou (2018)						x				x
Yu et al. (2018)		x								
Helo et al. (2019)						x				
Luo et al. (2019)	x									
Mourtzis et al. (2020)				x		x				

mining, etc.). Furthermore, the authors depict decision support concepts like optimisation, simulation, or automated decision systems in their conceptual architecture but do not provide any details.

Based on this analysis of the related literature and the introducing remarks on CC and APS, we conclude that there is an emerging need to merge both within a general conceptual framework, addressing structural and system architectural questions. Our framework particularly addresses the previously described research direction 2 and defines types of services and components supporting the application domain of supply chain planning.

Furthermore, the emerging concept of cloud manufacturing emphasises the need for cloud-based APS since integration and coordination needs are even higher in such environments (compared to traditional supply chain management and manufacturing environments; cf., e.g. Chen et al., 2019 or Y. Liu et al., 2019).

3. Methodology

The development of the conceptual framework of cloud-based APS is generally based on the design science research (DSR) paradigm (cf. Hevner et al., 2004; Peffers et al., 2007). This prescription-driven and problem-solving paradigm seeks to create viable (design) artefacts like constructs, models, methods, or instantiations which provide solutions for organisational problems (Hevner et al., 2004). In conjunction with the DSR knowledge contribution framework (Gregor & Hevner, 2013), we classify our paper in the 'Exaptation' quadrant as we extend CC to the problem domain of AP. During the research project, we followed the general guidelines (Hevner et al., 2004) and processes (Peffers et al., 2007) for DSR and structured our research based on the three-cycle view (as illustrated by Figure 2) consisting of the relevance cycle, the design cycle, and the rigour cycle (Hevner, 2007).

The relevance of the proposed conceptual framework (representing a model artefact) for the integration of CC and APS is derived – apart from the topicality of both concepts in

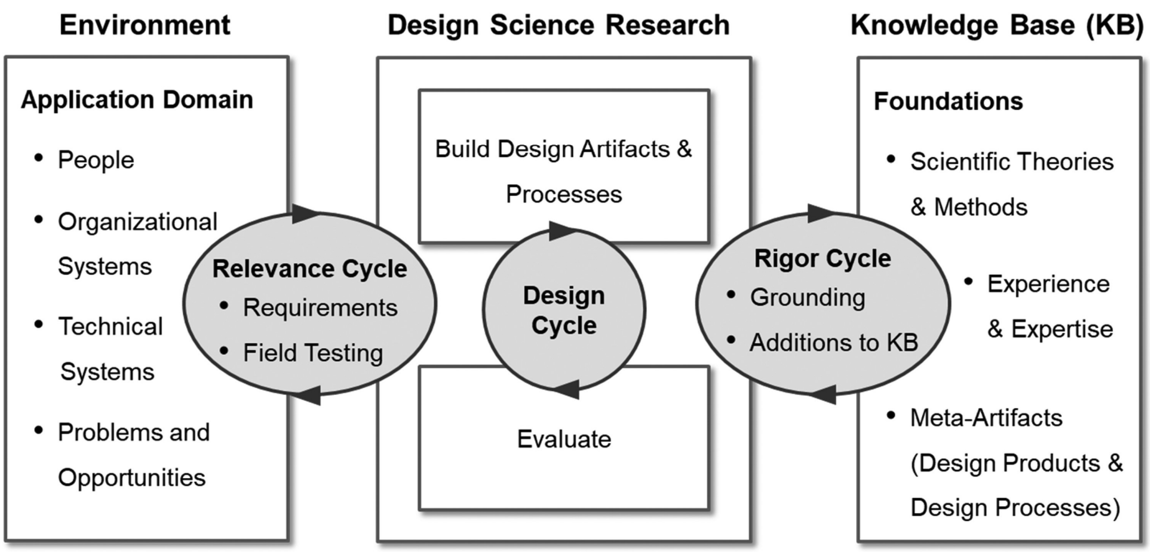

Figure 2. Design science research cycles according to Hevner (2007).

research and practice – from the conclusion of Bichler (2006) that many IS problems can be solved by an integration of methods and models from Operations Research/ Management Science (OR/MS; like optimisation programs, algorithms, heuristics, or simulation) and Computer Science (the superior research field of CC). The relevance of cloud-based APSs has also been confirmed by several experts from the industry which have been involved in the research project. These experts are either project partners that we supported in supply chain planning projects or former colleagues with PhD degrees that are now working in the private economy. Thus, the appropriate qualification of the experts is given. Altogether, 12 experts with different positions (e.g. plant manager, project manager, senior consultants) at seven different globally active German companies located in different business sectors (e.g. special purpose machinery, logistic service provider, base chemicals, or IT/IS and SCM consulting) have been involved.

To develop the theoretical foundation of the proposed conceptual framework and to ensure its innovation, we started the rigour cycle with a systematic literature review. The methodology and outcome of this review is presented in section 2.3. The limited number of articles addressing both CC and AP/APS (or at least related concepts) at all and the result that only a single article addresses the topic at a conceptual level further strengthens the relevance of the proposed framework for cloud-based APS.

Based on the results of the rigour cycle, we started a first design cycle and developed an initial version of the framework. To develop the initial version, we analysed the planning task-specific concepts, elaborated similarities, and synthesised the approaches to define major services and components. The initial version mainly included the basic concepts and aspects of the framework (like actors, general consumer requirements, and basic service components) with short descriptions. After the first design iteration, we sent the initial version of the framework along with brief descriptions of CC and APS (see sections 2.1 and 2.2) to the experts. To ensure that the experts fully understand the basic concepts, we discussed these concepts as well as the potential instantiation with them. Based on these discussions, we performed a first evaluation of the initial version of the framework and started the next design iteration. Within this iteration, we incorporated the expert knowledge, refined the basic concepts, and specified the conceptual framework in detail. Afterwards, the final structure describing services and components is analysed and discussed with the experts. Here, all experts agreed upon the opportunities of cloud-based APS, particularly to reduce costs and implementation efforts. However, the experts also stated the necessity to establish common standards and common domain 'languages' as well as service (component) reference models for the different supply chain planning tasks.

4. A conceptual framework for cloud-based APS

The following conceptual framework of cloud-based APS is the result of the previously described research process, particularly of the synthesis of existing (planning problem-specific) concepts and the experts' knowledge. As this is the first conceptual article addressing cloud-based APS and since the framework is intended to provide a comprehensive and holistic view on the major aspects, we are not going to cover all aspects in detail. However, we are going to discuss and analyse the most relevant topics and their interdependencies to provide a common understanding and a first theoretical base for cloud-based APS.

The layer-based structure of the conceptual framework of cloud-based APSs is depicted in Figure 3 and describes the basic software and service components as well as the information flows between the participating actors that are essential to achieve the motivated integration of CC and APS.

Before describing and analysing its elements in detail, participating actors (organisations) and their roles, namely consumers, service providers (SP) and infrastructure providers (IP), are briefly described from a business-oriented perspective (cf. Leimeister et al., 2010 for a detailed description of these concepts):

▪Consumers (or customers) demand services according to their planning tasks and IT infrastructure. Depending on the deployment model, consumers could, for instance, be a business unit or department of the service providing company (private cloud) or a 'real' customer if services are provided by an external company (public cloud). Moreover, consumers are not restricted to companies and consulting or research organisations (cf., e.g. J. Liu et al., 2016) are also conceivable.

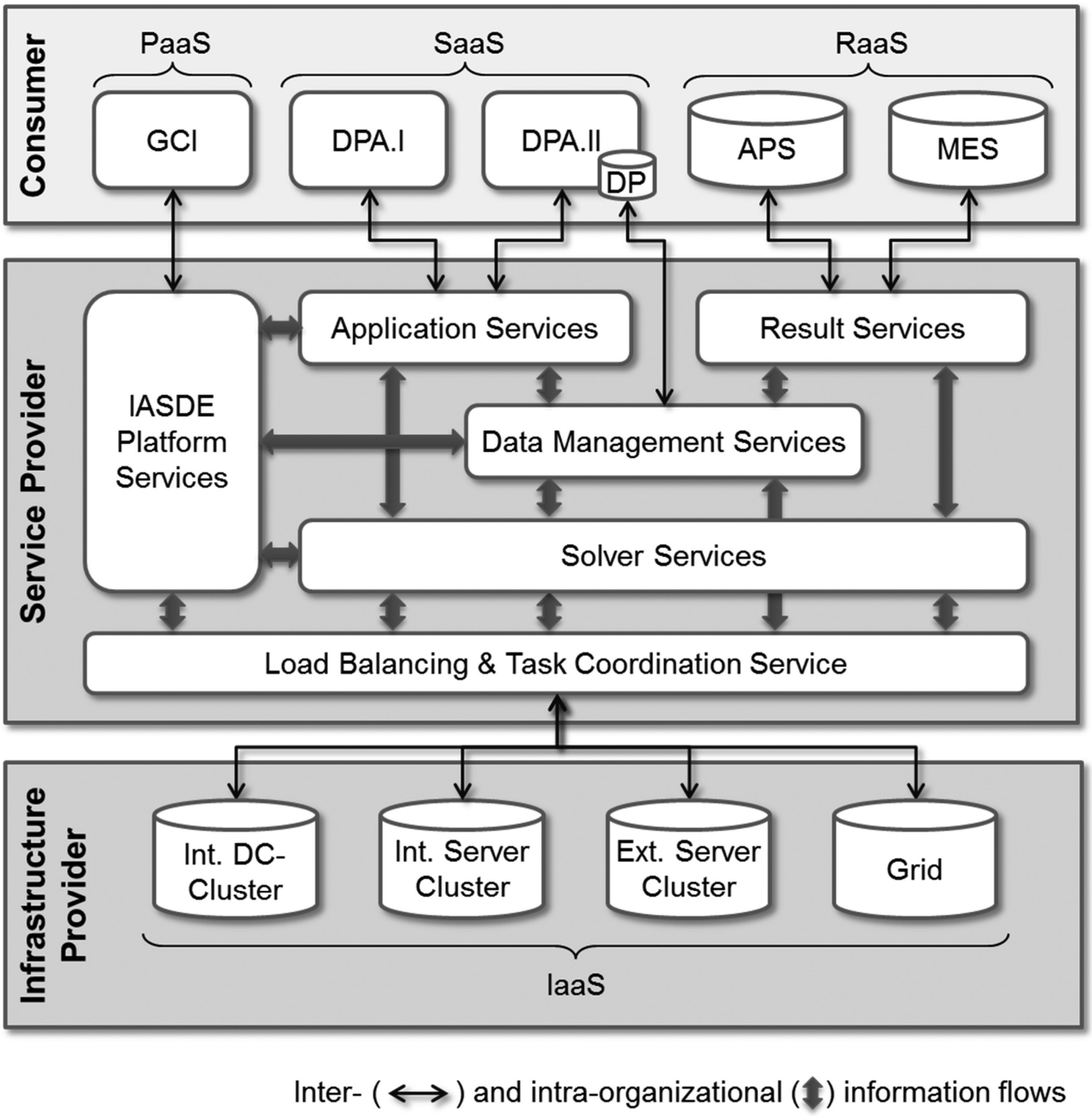

Figure 3. The conceptual framework of cloud-based APSs.

▪Service providers develop and operate services to fulfill the consumer demands. A service provider itself can also act as consumers, if existing services and applications from third party providers are aggregated to a new service (on the topic of cloud service composition cf., e.g. Ahmed & Majid, 2019).

▪Infrastructure providers offer hardware and infrastructure services that are used by service providers.

4.1. Consumer requirements and service models

The basic goal of consumers demanding for services of a cloud-based APS is the execution of a supply chain planning task and to get a solution (or a pool of solutions) for a certain supply chain planning problem, respectively. Here, different types of requirements, mainly depending on the planning problem (cf., e.g. the literature listed in Table 6) and the existing IT infrastructure (at consumer side), can be distinguished and these demand types determine the service model to be used to fulfill consumer needs. Accordingly, we discuss different consumer requirements and appropriate service models in the following sections.

Infrastructure-as-a-Service – IaaS

Because IaaS models are independent from the domain of supply chain planning, these are not considered as services for the 'planning' consumer but as fundamental services for the service provider. IaaS are fundamental because they are responsible for the essential characteristics resource pooling and rapid elasticity and thus for one of the main benefits of cloud-based APS compared to on-premise APS. The benefit provided by the computing power of CC is concluded from the fact that supply chain planning problems are mostly very complex and thus their solution is often very time (e.g. CPU time) and resource (e.g. RAM) consuming. To reduce computation times or solve larger and more complex planning problems, scientists from OR/MS and Computer Science are developing distributed and/or parallel solution methods to solve supply chain planning problems. The application of such solution methods in cloud-based APS enables the exploitation of the computing power of CC. As distributed and/or parallel solution methods are not subject of this article, we want to refer the reader to the book by Kaminsky (2010) for a comprehensive introduction to parallel and distributed computing and to Crainic and Toulouse (2003) for an introduction to the topic of parallel strategies for meta-heuristics. The influence of such solution methods are, for instance, analysed by Lu et al. (2011).

Platform-as-a-Service – PaaS

The first type of service models directly related to the domain of supply chain planning is PaaS. The corresponding requirements are expressed by experts like application and planning/solution method developers, scientists, and consultants. They demand for an integrated environment to efficiently develop, adapt, enhance or test (existing) planning applications, services, methods, software components, or frameworks (e.g. for the development of solution methods; e.g. HeuristicLab or the MOEA Framework) provided by the service provider or others (cf. Giessmann & Stanoevska, 2012 for a comprehensive study on consumers' preferences). The range of functionalities of such a PaaS model can be varied due to the requirements of the consumer. A main benefit is that no special IT infrastructure on consumer side is required – just a desktop computer with internet access and a generic client interface (GCI) like a web browser or a remote desktop client. Furthermore, the generic structure of platforms enables the consumer to solve 'any' supply chain planning problem (e.g. by the IBM ILOG CPLEX Optimisation Studio or the General Algebraic Modelling System GAMS). However, regarding supply chain planning, this generic structure is also the main drawback as the planning effort is quite high and moreover, scarce and extensive expert knowledge is required to fulfill the planning task. As a result, concerning the concrete solving of a planning problem, PaaS models are preferable to solve long-term planning problems in the domain of Strategic Network Design since the frequency of planning is low.

Software-as-a-Service – SaaS

Responsible decision makers and planners articulate the demand for the second type of services, SaaS. Their goal is to solve specific planning problems and thus designated planning applications (DPAs) are required. Consequently, different software applications, depending on the planning tasks, have to be provided for using the SaaS model. For instance, the domain Demand Planning requires other functionalities and user interfaces for planning inputs or result visualisations than Scheduling. For the implementation of such DPAs (e.g. for a scheduling tasks), the i-DESME framework proposed by Dimopoulos et al. (2015) assures a structured software development lifecycle. In addition, the IT infrastructure requirements on consumer side strongly depend on the planning task, particularly on the frequency of planning. If the frequency of planning and also the quantity of planning relevant information are low so that a manual data transfer is efficiently manageable, no additional, specialised IT infrastructure is necessary (like in the case of PaaS). In contrast, if frequency is high and/or much (changing) information is required, like in the domain of Scheduling, it is necessary to instantiate a data provider (DP) or a DaaS infrastructure (cf. Demirkan & Delen, 2013) to be able to provide the data efficiently.

Result-as-a-Service – RaaS

The third type of demand originates from unsatisfactory planning results caused by insufficient planning methods implemented in existing ERP systems or APS on consumer side (as reported by several experts). Unsatisfactory or even unusable planning results are mostly caused by standardised planning software that is either not able to consider all consumer specific requirements (planning constraints and objectives) or the provided solution methods are not able to calculate results with a sufficient solution quality within reasonable computation time. Therefore, we introduce the service model 'Result-as-a-Service – RaaS'. The RaaS service model provides the capability to efficiently calculate feasible and suitable solutions for a specific planning problem (e.g. a scheduling problem or a transport planning problem). Using this service model, the consumer operates his own planning system (e.g. an APS or a Manufacturing Executions System; MES) that is directly coupled (by interoperable system-to-system interfaces) to the systems of the RaaS provider. Whenever a new solution/plan is required, the consumer's planning system requests it from the RaaS provider. It has to be remarked here, that this service model is very similar to the conceptual aspects of web services (cf. the web service definition of the W3C). Due to the system-to-system integration, RaaS are particularly suitable for short-term planning tasks with a high planning frequency (like scheduling or transportation planning). The main drawback of this service model is the required IT infrastructure on consumer side, which contradicts some fundamental benefits of CC. However, if the IT infrastructure already exists and planning results are not satisfying, this model might be very useful.

Summary

Figure 4 summarises planning task characteristics and the most suitable service models: with decreasing planning horizon and increasing planning frequency, the most suitable service model shifts from PaaS to SaaS and RaaS.

The required on-site IT infrastructure and the scope of services and functionalities to be provided by the service provider to fulfill the consumers' demands are depicted in Figure 5: while the required infrastructure increases and the service scope decreases, the most suitable service model shifts from PaaS to SaaS and RaaS.

4.2. Service provider and basic service components

In this section, we are not going to describe all service (components) and functionalities in greatest detail nor do we raise the claim to give a complete overview about all thinkable services. Instead, we describe the main services and functionalities that are of central importance for offering cloud-based APS.

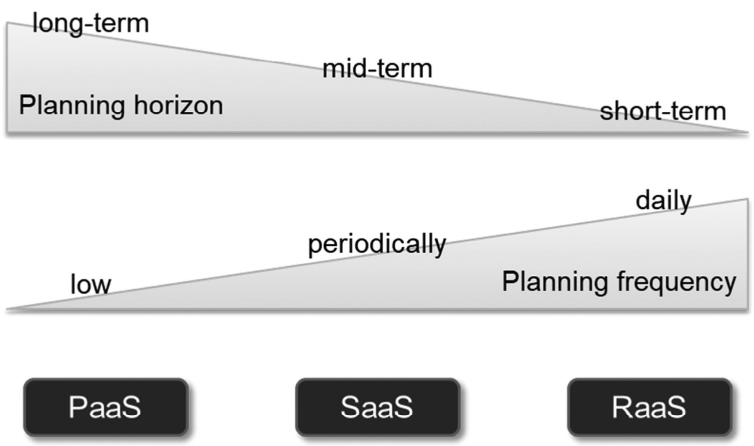

Figure 4. Planning task characteristics and appropriate Service Models.

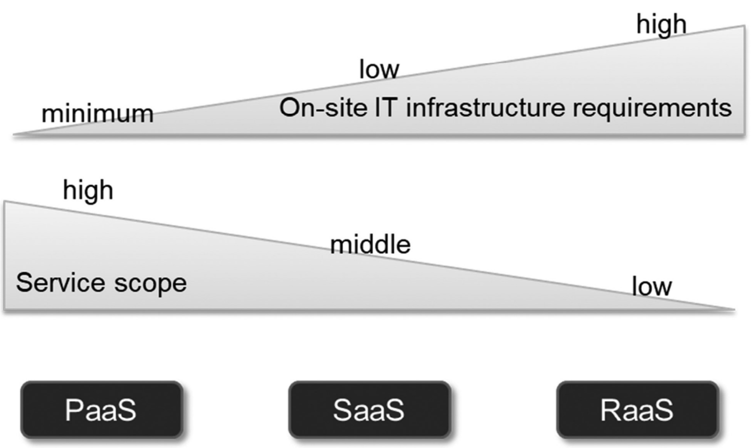

Figure 5. Scope of services and required on-site IT infrastructure.

Solver services

The fundamental service for all service models (PaaS, SaaS, and RaaS) is named Solver Services. It provides solution methods to calculate solutions (plans) for the corresponding supply chain planning problem. Hereby, an unambiguous specification of the planning problem is necessary in order to select or adapt existing or to develop new solution methods. As can be seen in Figure 1, the range of supply chain planning is wide and therefore, we suppose that for each module a specific problem classification scheme should be used to describe the problems of the planning domain. To be able to solve a specific problem of a planning domain with its often very individual requirements (concerning planning constraints and objectives) in an efficient manner, Solver Services should base on a generic structure of components, frameworks, and data models. This approach is also proposed by Klöpper et al. (2009) by their definition of a generic, customisable data model for the domain of Production Planning and Scheduling and also by Fink and Voß (2002), where a heuristic optimisation framework based on the generic programming paradigm is presented. Furthermore, the possibility to use standard solver engines like CPLEX from IBM, Gurobi or OptQuest should be provided. In this context, a service provider could also act as a service aggregator by using the RaaS service model.

Data management services

The second basic type of components to be provided is summarised under Data Management Services. Their main functions are the persistent storage of planning relevant data (including problem instance and scenario management), provisioning of input and output interfaces as well as data preparation and aggregation procedures. Strongly related to Data Management Services is the concept of Data-as-a-service (DaaS) discussed in Demirkan and Delen (2013). The authors claim for DaaS that data can be stored in a local computer or in a server inside a cloud computing environment and therefore, any business process can access data wherever it resides. In such an environment, the service provider can use DaaS to substitute the Data Management Services. Regarding RaaS, it is also possible to use Solver Services without Data Management Services (e.g. without data preparation and a persistent storage of data) if the data is available in a proper manner and thus can be directly transferred to the Solver Services.

Result services

Result Services provide the necessary interfaces for receiving planning relevant data and for sending calculated results from and to the consumers planning systems. They interact with the Solver Services to get the planning results and if necessary, they can interact with the Data Management Service to prepare and store planning data persistently.

Application services

The Application Services offer comprehensive planning applications including presentation, business logic, and data storage functionalities depending on the planning problem to solve. Concerning for example, the presentation of planning results, an optimised supply chain network could be presented by a map containing locations and material flows, whereas a machine schedule is best presented by a Gantt chart. This problem specificity leads to a general diversification of service components: planning domain specific components (e.g. for result visualisation) and general components that are independent from the planning domain (e.g. user/role management). Apart from that, as discussed in the previous section, data integration efforts also depend on the planning problem. Therefore, Application Services are deeply integrated with Data Management Services and the applications themselves are either developed as rich internet applications or as specific client applications. These types of applications make also the strong relationship between Application Services (SaaS) and Application Service Provision (ASP) obvious (cf. Weinhardt et al., 2009; Benlian & Hess, 2011).

IASDE platform services

A fourth type of services that are directly used by the consumer provide 'Integrated Application and Solver Development Environment (IASDE)' Platform Services. These services integrate Application Services and Data Management Services (or some components) as well as Solver Services within a platform that also comprises an integrated development environment (IDE). Hereby, the integration to Application Services has to enable the deployment of upgrades and updates for offered applications. Beside existing service components that can be used for integration as they are or as base for adaptations, further components should be provided, especially for the development of problem specific solution methods. A first group of additional components could cover the topic of capturing planning requirements, constraints, and objectives. This could for example, be supported by graphical interfaces for creating project network flow charts or state-task-networks diagrams to visualise planning problems. As IASDE Platform Services will be primarily used by experts of a certain planning domain, services or systems providing domain specific knowledge and data should also be available. For instance, Geographic Information Systems could be integrated to support Distribution Planning and Transport Planning. To support the development of problem specific solution methods, a third group of components should, on one hand, provide optimisation or general software frameworks (like the one proposed by Fink & Voß, 2002, the 'Java Genetic Algorithms Package – JGAP' or the 'Parallel Java Library' described in Kaminsky, 2010) to reduce development efforts and, on the other hand, functionalities to efficiently develop, evaluate, and compare solution methods, variants, and parameter settings with regard to solution quality and computation time. For this purpose, libraries containing instances for standard planning problems as well as a knowledge base that collects problems and solution methods used to solve them should be provided.

Load balancing & task coordination service

As the benefit of parallel and distributed solution methods has been shown by several authors (e.g. by Cahon et al., 2004) and resource pooling as well as rapid elasticity are two of the essential characteristics of CC, solution methods of cloud-based APS should be developed to take advantage of the available computing power in cloud environments. The computing power provided by multiple processors can be used for HPC to solve a fixed size problem in less time (called speedup, capability computing, or strong scaling), to solve larger problems in the same/in reasonable time (called size-up, cooperative computing, or weak scaling) or both (cf. e.g. Kaminsky, 2010 or Sterling & Stark, 2009). To achieve this in reasonable manner, a first level of (work-) load balancing should be operated by the service provider. Furthermore, load balancing could be further improved by task coordination mechanisms (also called capacity computing or throughput processing; cf., e.g. Sterling & Stark, 2009). As most planning tasks or evaluation processes of solution methods do not have to be executed immediately but within a certain time interval to meet a deadline, the Load Balancing and Task Coordination Service is responsible to schedule planning and optimisation tasks efficiently on the available resources (maybe offered by an external infrastructure provider). These tasks of load balancing and task allocation in CC represent classic OR/MS problems (or are at least very similar) and therefore are solved by methods from the field of OR/MS (cf. e.g. Finkbeiner et al., 2010; Page et al., 2010; Taneja & Taneja, 2011; Liang et al., 2018, or Keller et al., 2020). In contrast to this application of OR methods to improve CC, all the more surprising is the scarce research efforts to provide OR methods within cloud-based APS.

4.3. Infrastructure provider, deployment models and security issues

Generally, service providers can either operate their own computation, storage, network, and communication infrastructure and thus act as infrastructure provider simultaneously or use IaaSs provided by third party providers. It has to be stated that regarding cloud-based APS, the simultaneous provisioning of services and operation of the cloud infrastructure by a single organisation seem to be favourable due to reduced efforts for service governance and service level agreement management due to the reduced number of relationships (cf. e.g. Goo et al., 2009 or Janiesch et al., 2009 for an introduction into both topics). Additionally, this service integration reduces security issues (for an extended discussion of security issues in CC see for instance, Benlian & Hess, 2011 or Azogu & Ryan, 2012) and also supports the exploitation of benefits of integrated parallel/distributed solution methods. Nevertheless, a service provider could operate its services completely on an external infrastructure. Figure 6 illustrates the dependencies between participating organisations (infrastructure provider, service provider, and consumer), deployment model, and the criticality of security issues.

As defined by Mell and Grance (2011), private clouds are hosted by a single organisation, either the consuming or a third party enterprise. In this case, different business units of the same company act as consumer, service provider, and infrastructure provider. In this case, the cloud infrastructure can be based on an internal server cluster (located in the data centre of the hosting organisation), a desktop computer cluster, or a hybrid cluster (or grid) combining both (cf. Figure 3). In this context, the use of desktop computers connected by a specific middleware (cf. e.g. Goldchleger et al., 2004) to a 'desktop grid' (cf. e.g. Kacsuk et al., 2007 or Kondo et al., 2007) further reduces (up front) costs and therefore strengthens one of the main advantages of CC. A further benefit of the private cloud deployment model is an increase of security of data and legal and privacy issues compared to other deployment models. Because of these aspects, especially large enterprises, where several business unit (consumer) demands have to be fulfilled, will benefit from this deployment model and from an internal cloud infrastructure. For instance, in the domain of Production Planning or Scheduling, several production departments (like part manufacturing, component pre-assembly, or final assembly) can use the provided services for their planning tasks.

Public cloud

In contrast, public cloud services are offered to the general public and thus, consumers and providers are strictly separated. Hereby, the openness for public access leads to drawbacks and benefits for the consumer. Main drawbacks are data security and privacy

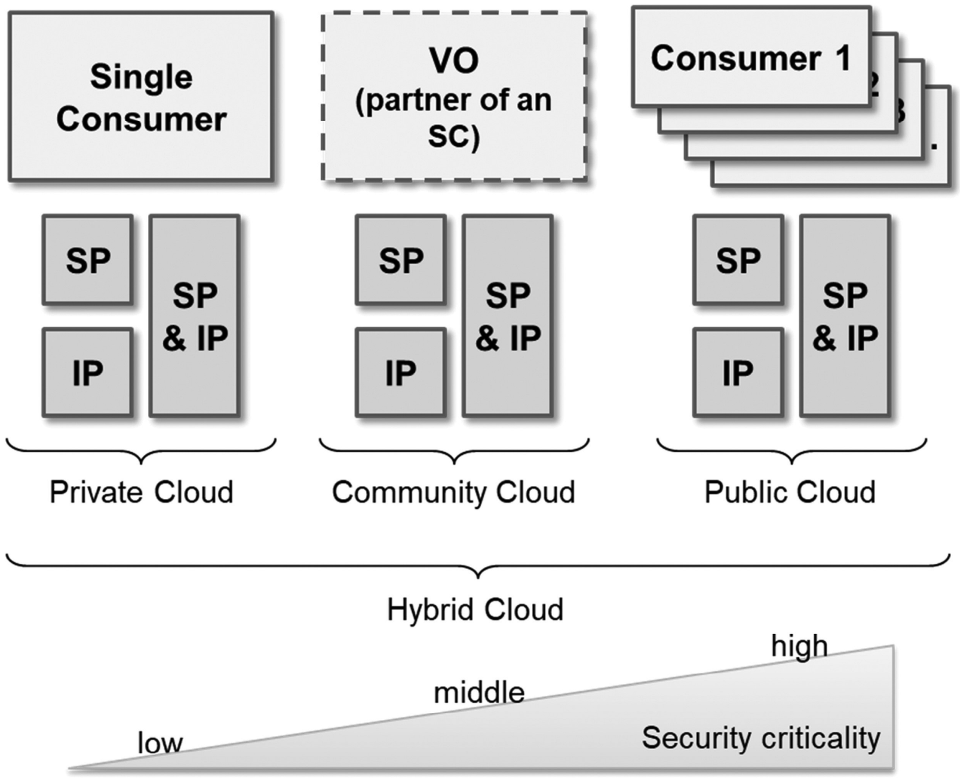

Figure 6. Deployment models, participating organisations, and security criticalityPrivate cloud.

issues, while the main benefit is the available cloud infrastructure based on a (external) server cluster. Due to the multitenant model serving multiple consumers, the infrastructure provides greater elasticity and more potential for resource pooling. A great challenge in the context of APS is to provide appropriate services for the different kinds of supply chains and their specific planning problems, respectively, because these services are neither dedicated to a single organisation, nor to organisations with shared concerns like in the case of community clouds.

Community cloud

Community cloud-based planning services and infrastructures are shared by several (consumer) organisations that have common or coupled service requirements and benefit from scaling and integration effects. This concept of pooling independent organisations to dynamic, multi-institutional virtual organisations (VO; cf. Foster et al., 2001) can be seen as a predecessor of the cloud manufacturing concept. It is also a fundamental aspect of Grid Computing, which can be seen as a starting point of IaaS or even CC (cf. Rings et al., 2009). In this context, it has to be stated that Grid Computing is mostly applied by scientific grid communities (and research projects like SETI@home or Folding@home) and are lacking in sustainable business models (cf. Weinhardt et al., 2009). To overcome this, community clouds can be seen as the basic model not only to use PaaS, SaaS, or RaaS service models but to strengthen the possibility to combine several independent computing resources (like desktop computers or server) to a grid with less data security and privacy requirements (compared to public clouds) due to the common interests of the members of the virtual organisation (e.g. the involved enterprises of a SC or their business units).

Hybrid cloud

A hybrid cloud combines at least two of the deployment models with their inherent drawbacks and benefits. For instance, the elasticity of a private cloud can be improved by resources provided by public clouds. However, security implications have to be considered. Also, a dynamic combination of cloud deployment models by cloud bursting (offloading of workload from private onto public clouds) is possible (cf. Lilienthal, 2013).

4.4. Pricing models and accounting

Pricing and accounting of services are essential for consumers and providers (cf. Sekar & Maniatis, 2011). Consumers want to know about expected costs, for instance, to substantiate outsourcing decisions or to compare different providers, whereas providers have to adequately bill their service offers in order to operate in a profitable way. Generally, two pricing models are used for service accounting in the field of CC: pay-per-use and flat-rates. Additionally, the model one-time purchase as a special case of pay-per-use can be considered in this context. Concerning cloud-based APS, we propose pricing models depending on the frequency of planning, which itself correlates with the planning horizon and the planning level, and the service model (cf. heat map in Figure 7).

For planning problems with a low planning frequency (like in the planning domain of Strategic Network Design) one-time purchase or pay-per-use models are proposed to keep planning costs low. As in this case mostly PaaS and rarely SaaS services will be offered to the consumer, this proposal is in line with the observations of Koehler et al. (2010). Regarding these planning problems with a low planning frequency, consumers want to be flexible and therefore prefer flexible tariffs. A further aspect that reduces planning costs is software licencing (cf. Armbrust et al., 2010). Service provider, for instance, can buy an annual licence for a proprietary solver engine (like CPLEX from

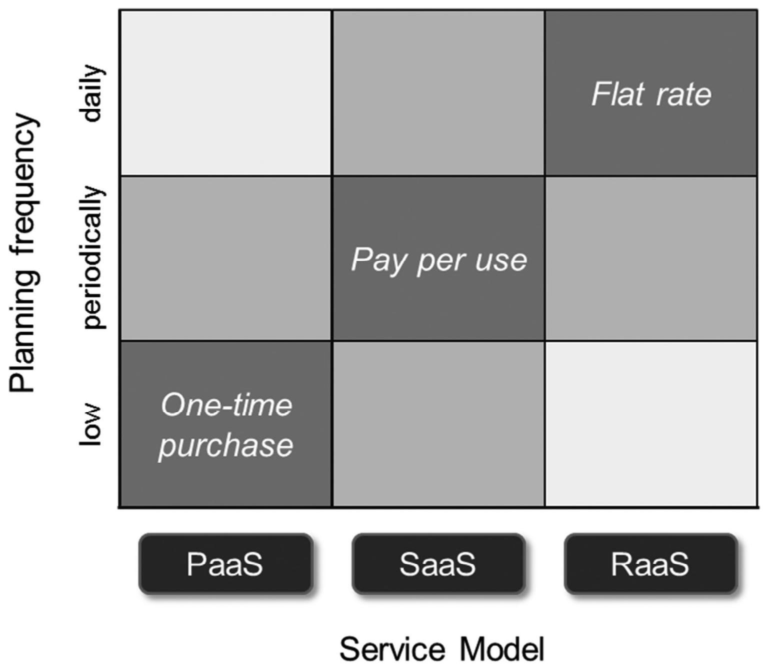

Figure 7. Pricing models depending on service model and planning frequency.

IBM) and offer 'optimization hours' to its customers. In contrast, for planning problems with a higher planning frequency, like from the domains of Scheduling or Transport Planning, flat rates are favourable as most consumers do not appreciate (high) variations in their costs (cf. Koehler et al., 2010).

Essential base for both pricing models, for the estimation of flat rates and the calculation of bills, respectively, is a comprehensive accounting model that includes infrastructure resources and services. Hereby, we forego giving a detailed description of general cloud accounting issues (cf., e.g. Richter et al., 2002), data storage service accounting (cf., e.g. Donovan & James, 2000), or general resource accounting (cf., e.g. Mihoob et al., 2010 or Sekar & Maniatis, 2011) and focus on accounting aspects especially referred to services provided within cloud-based APS.

A first aspect is, as discussed in the previous sections, that the used infrastructure (e.g. the number of CPUs) can significantly improve the solution quality and/or reduce the computation time of planning solutions. Therefore, not only the specification of infrastructure resources by the consumer is important, but also their accounting. For accounting, concepts and methods that are used by IaaS service models (cf. Elmroth et al., 2009) or Grid Computing (cf. Sandholm et al., 2004) can be adapted. Furthermore, as the benefits of multiple computing resources can only be exploited by appropriate solution methods, Solver Services could be categorised and accounted by their capabilities to use these resources. Here, a categorisation could be based on the applicable computer architecture (shared memory multiprocessors, clusters with distributed memory, hybrid parallel computers or grids; cf. Kaminsky, 2010, pp. 22–29) and the pattern of parallelism (result parallelism, agenda parallelism, or specialist parallelism; cf. Kaminsky, 2010, pp. 36–46). Concerning Result Services (and also Data Management Services if data preparation and aggregation procedures are used), accounting will be based on the number of planning task executions, the number of results (if different solutions with different parameters are calculated, e.g. for sensitivity analysis) and the urgency the results have to be computed (e.g. immediately, in the next hour, or overnight). The latter aspect helps to take the advantage of the Load Balancing & Task Coordination Service. The accounting for Application Services and IASDE Platform Services strongly depends on the available functionalities and (service) components. Hereby, basic functionalities and services can be offered for free (to easily enable developing and testing) and highly specialised (for certain supply chain planning domains) or third-party components are charged, either per flat-rate (e.g. for research organisations or consulting firms) or per-use (e.g. for single projects).

Beside the running (recurring) costs of using the services of a cloud-based APS operatively, also one-off (non-recurring) costs for the adaption, enhancement or problem specific development of solution methods for certain supply chain planning problems have to be considered (beside the usual customising and development costs of software products).

5. Implications and future research

Because the evaluation and assessment of the proposed framework was an integrated part of the whole development process (as described in the section 3), we are not going to repeat the experts' statements as these statements directly influenced the framework. Instead, we emphasise some topics of special interest and their implications for the realisation of cloud-based APS in this section.

All experts consent to the general potential of cloud-based APS but also have caveats, especially concerning security issues. This can be derived, in addition to corresponding statements, from the fact that almost all experts prefer private clouds. In this context, service governance and service level agreements are also seen critically for the implementation and adaption of cloud-based APS. Another highlighted critical aspect is the applicability of the more or less generic planning services of a planning domain on a company's specific planning problems. As particularly the experts from consulting firms have reported a relatively great dissatisfaction of their customers regarding planning results and planning efforts, cloud-based APS and its services have to be designed to be able to manage as many problems from a planning domain as possible and with low planning efforts. Based on this observation that is also substantiated by the experts from consuming organisations, we conclude that the provisioning of flexible and easy adaptable services would be the most important challenge – beside the general security issues of CC – for establishing cloud-based APS. Another result is that operational planning tasks like Transport Planning, Production Planning, and Scheduling are of special interest and that here the service model SaaS is mostly preferred, particularly by SMEs. This is not surprising as SMEs are hardly operating APS, in contrast to large companies that would also use RaaS to enhance the planning results of their (existing) APS. Regarding supply chain planning tasks in general, it has to be remarked that the experts consider PaaS less important than the other service models.

Concerning pricing models, the experts confirm the described dependency between planning frequency (problem), service model, and pricing model. The experts agree that planning tasks with a higher planning frequency provided by SaaS or RaaS should be accounted by flat-rate tariffs (and also the underlying IaaS) and tasks with a lower planning frequency by pay-per-use tariffs.

Condensing the experts' opinions, we can state that cloud-based APS could be a promising alternative to on-premise APS if security issues can be solved and appropriate planning capabilities for the different supply chain planning domains can be provided. As the first critical point, security issues and related technical issues are already known to be of special interest in the research community, we want to highlight some research topics regarding the second point, appropriate supply chain planning capabilities.

T1: Ontologies for planning domains

The development of ontologies for the different supply chain planning domains to describe specific problem characteristics unambiguously (e.g. by 'problem specification schemes'). This supports the comparison of services offered by different providers as well as the selection, adaption, or enhancement of problem adequate solution methods.

T2: Process and object reference models

Adaption, enhancement, or development of process reference models (cf. e.g. Zoryk-Schalla et al., 2004) and data/object reference models to improve the integration and aggregation of services and components (for an efficient development of APS Application Services).

T3: ERP service integration

Analysis of integration possibilities of supply chain planning services into 'ERP On Demand Platforms' like it is proposed for sustainability benchmarking services (cf. Koslowski & Strüker, 2011).

T4: Collaborative planning

Analysing the potentials of cloud-based APS to improve the inter-organisational collaborative planning (cf. e.g. Kilger et al., 2008).

T5: Currently available services

Based on the developed framework, a comparative study to evaluate the current state of existing industry solutions from providers such as SAP and Oracle is of interest.

6. Conclusion and limitations

To summarise and emphasise the contribution of this paper and the proposed conceptual framework for cloud-based APS, we answer the five central questions formulated by Whetten (1989):

What's new?

– The framework for cloud-based APS is the first approach combining the emerging paradigm of CC and APS on a general, conceptual level. As the review of related work has shown that no articles addressing both topics in such a manner exists, we started to close this research gap. Furthermore, we introduce the 'Result-as-a-Service – RaaS' service model. Further new concepts are the pricing models depending on the frequency of planning and the accounting aspects related to the basic service components (especially to Solver Services).

So what?

– Because cloud-based APS have particularly the potential to change the way SMEs are making decisions and enables them to take advantages of the latest innovations of planning concepts and methods from OR/MS. In addition, practitioners and scientists in the areas Information Systems and Computer Science are required to develop appropriate services and technologies (for instance, to solve security issues by using blockchain technology).

Why so?

– To develop the conceptual framework for cloud-based APS, we followed the DSR principles and went through the three inherent research cycles: relevance, design (in an iterative manner), and rigour. First, we analyse concerned and participating organisations, their roles and, in the case of the consumers, their requirements and expectations, and derive appropriate services for cloud-based APS. Second, we introduce and describe basic service components (cf. Figure 3) that are required to fulfill the requirements. The development and particularly the evaluation of the framework is based on the cooperation with several experts from different industries and ensures the practical relevance of cloud-based APS and the framework.

Why now?

– The emerging topic of Industry 4.0, also called the Fourth Industrial Revolution, fosters the willingness of managers to rethink and transform their business towards a comprehensive digitisation. Along with the resulting availability of data (e.g. due to the Internet-of-Things) comes the aspiration to use this data in a value adding way. Using cloud-based APS to provide and use planning services based on this data is just the logical consequence of this development. Accordingly, a general theoretical foundation like the proposed framework is required.

Who cares?

– The framework is aimed to support scientists in several research areas: in Information Systems and Business Management (particularly Supply Chain Management, Operations Management, and Production Management) to develop business and value adding models; in Computer Science to develop relevant services and technical infrastructure; and in OR/MS to develop concepts and solution methods that are useful for real-world applications. Concerning practice, the framework can be used by APS providers to develop and/or classify their service portfolio, whereas APS consumers can use the framework to evaluate offered service portfolios.

Finally, we would like to make some concluding remarks on the limitations of our research. First, we focused our literature sample on high quality journals and conference proceedings despite the fact that also other publications mediums, white papers, and also grey literature could provide meaningful insights. However, we followed common standards for the literature search. Second, the description of the research process is very brief and further information might be interesting. Nevertheless, we concentrated on the results of the research, the conceptual framework for cloud-based APS. Third, depending on the reader, some aspects of CC, APS, or cloud-based APS might be discussed too extensively, too briefly, or not all. Within this paper, we tried to focus on these aspects that are directly related to cloud-based APS and not to CC or APS in general. Beside the research topics described in section 5, these limitations also provide research potentials for the future. For instance, focusing on special aspects or the analysis of other not yet considered aspects.

Disclosure statement

No potential conflict of interest was reported by the author.

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