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A systemic approach to define and characterize Advanced Planning Systems (APS)

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ABSTRACT

Advanced Planning Systems (APS) have become an important tool for manufacturing and production companies that require a specific system to optimize production, logistic, material and human resources, etc. with the goal of improving the economy of the companies and offer a good customer service. An APS must be integrated to the Enterprise's System (such as an ERP), but this task usually lacks of a specific methodology to be performed and is generally made ad-hoc. With the ultimate objective to provide an approach to facilitate this integration, this work presents a characterization of the APS from a systemic point of view, using standardized Software Engineering concepts. The idea is to provide a definition and characterization of Advanced Planning Systems, by establishing the main goals of this type of system, and considering Functional Requirements, Quality Attributes and a reference model for the architecture. The selected choices are established on the base of several international standards from the Software Engineering area, such as the SEBoK (System Engineering Body of Knowledge) and the SQuaRE (Software product Quality Requirements and Evaluation) model, among others, and aim to serve as a base line for the general concept of APS.

1. Introduction

Enterprise Resource Planning (ERP) has become a *de facto* standard to manage organizations' business in all sectors where information automation is possible (Shaojun, Gang, Min, & Guoan, 2008). However, many authors in the literature have mentioned that a gap exists between what an ERP can do for a production company in terms of planning and scheduling of its production processes, what the theory allows doing, and what the organizations truly need (Framinan & Ruiz, 2010; Henning, 2009; Hvolby & Steger-Jensen, 2010). In 1993, Burgeois, Artiba, and Tahon (1993) stated that the increased competition and the need of a higher productivity require new tools to improve the optimization and the control of the production scheduling. Years later in 2003, Fleischmann and Meyr (2003) said that ERP systems and their MRP (Material Requirements Planning) module did not provide the functional needs. Adding to this, Stadtler (2005) established that ERPs have a deficiency in the area of planning. Helo, Suorsa, Hao, and Anussornnitisarn (2014) have listed four weaknesses of ERP systems: lack of extended enterprise functionality, lack of flexibility in adapting to changes in the supply chain, lack of advanced decision support capabilities and lack of an open modular architecture. Finally, in 2014 Öztürk and Ornek (2014) said that those issues directly rely on the fact that the basic reasoning of MRP-II systems is flawed.

Owing to this, manufacturing and production companies require a more specific system in order to manage production planning and scheduling to optimize material and human resources, improve the company economy and offer a good customer service (Stadtler, 2005). That kind of system has already been mentioned in the literature under many names, being 'Advanced Planning and Scheduling systems' the most commonly found (Hvolby & Steger-Jensen, 2010). As a consequence, there are many proposals in the literature about what these systems are, and which modules and solutions they include (Fleischmann & Meyr, 2003). There are many definitions about them and several systems on the market do not fulfill a common description.

Some high-end ERPs offer extra modules of this type, like SAP does with APO (Advanced Planning and Optimization) (Mannah & Segatto), which offer planning and optimization functionalities in different business processes. However, the size of this type of proprietary systems, along with their implementation complexity – that includes the organizational changes derived from it – turns

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SME (Small and Medium Enterprise) to direct their own developments, generating *ad-hoc* applications tied to their enterprise systems which have similar functionalities to APS, but demanding lower budget and an impact scaled to their organizational size.

In general, APS have a better performance and more complete functionalities than ERP system in the production planning area, because it is their main goal. Nevertheless, implementing this type of system on a given organization is a process that involves several stakeholders, consultants and internal people. Therefore, there is a high interest in better understanding the success and failure factors in the implementation of this type of software (Zoryk-Schalla, Fransoo, & de Kok, 2004). The vast majority of the literature expresses that the discussion about APS implementations are rather theoretical without real accomplishments, and focuses on the models that solve the planning problem, instead of the system as a whole (Harjunkoski, Nyström, & Horch, 2009; K. Chen & Ji, 2007).

At this point, it is worth mentioning the concept of Industry 4.0 that has risen on the German-speaking area (Herrmann, Pentek, & Otto, 2015). While the horizontal integration of the supply chain through a seamless end-to-end digital information flow is an interesting idea that has the potential to change the industry, it is not an standard yet and its proposal can only be achieved on the mid to long term (Heng, 2014). In the meantime, there are many companies around the world that are far from becoming smart factories through the implementation of CPS (Cyber-Physical Systems) and require the application of an Advanced Planning System. Therefore, this article is directed for these companies.

Nevertheless, the goal of this article is the characterization of Advanced Planning Systems using a Software Engineering approach. In order to reach this objective, it is proposed a definition of APS, a set of Functional Requirements and Quality Attributes; and a basic reference model for the Software Architecture.

An important step for this purpose is to study current definitions of such systems and establish the relationships between concepts, to extract a clearer and more adequate meaning about what is involved in Advanced Planning Systems. To have solid foundations on the characterization, several standards of the Software Engineering area are used, such as the SEBoK (System Engineering Body of Knowledge) (BKCASE Editorial Board, 2014), the ISO/IEC 25010:2011 (Committee ISO/IEC JTC 1/SC 7) – the SQuaRE (Software product Quality Requirements and Evaluation) model – and the ISO/IEC/IEEE 42010:2011 (ISO/IEC/IEEE 42010:, 2011) for Software Architecture.

2. Scope of factory planning

A number of authors state that APS have different functionality groups, which are usually called 'modules' or 'planning levels' (Fleischmann & Meyr, 2003; Hadaya & Pellerin, 2008; Hvolby & Steger-Jensen, 2010; Kung & Chern, 2009; Meyr, Rohde, & Stadtler, 2002; Stadtler, 2005; Staeblein & Aoki, 2014; Zoryk-Schalla et al., 2004; Öztürk & Ornek, 2014). These levels are separated considering the segment of the organization or supply chain (SC) that optimizes (procurement, production, distribution and sales) and on their scope (short, mid or long-term).

The next list includes the planning levels defined by Fleischmann and Meyr (2003):

- *Strategic Network Planning (SNP):* covers the quantitative part of strategic planning, and questions of network design like plant location, dimension of stock or production capacities.
- *Demand Planning (DP):* focus on forecasting future demand in a make-to-stock environment, on both mid-term aggregate and short-term basis.
- *Master Planning (MP):* coordinates the material flow of the supply chain as a whole for a mid-term planning horizon.
- *Production Planning and Scheduling (PP&S):* modules deal with lot-sizing, machine assignment, scheduling and sequencing.
- *Distribution Planning (DtP):* concerns the tactical constrains within the distribution system, such as the regular transport links, delivery areas, and allocation of sources.
- *Transport Planning (TP):* deals with dispatching of shipments in the distribution and procurement side.
- *Demand Fulfillment and Available to Promise (ATP):* covers the arriving of customer orders, and comprises the tasks of order promising, availability of materials and due date setting.

Nevertheless, many of these levels have common features or time horizon, which allow them to be grouped in a generalized category. The level that works as a container is found on the definition of Factory Planner provided by Zoryk-Schalla et al. (2004):: *"[...] determines at which time each manufacturing operation of a given customer order [or forecast] should be performed on which particular resource by creating a factory-wide plan [...]"*. They also state that an organization may have several of these levels, one for each production site, or even for different time horizons.

Following that idea, such level includes the following planning levels: Production Planning and Scheduling, Distribution Planning, Transport Planning and Demand Fulfillment, and Available to Promise. As a consequence, this work defines factory planning (FP) as a wider concept that includes several types of planning, most of them at short-term, and that is part of what is called supply chain planning (SCP), which includes mid and long-term time horizon (Fleischmann & Koberstein, 2015, Chapter 6). It is worth noting that while the main goal of a supply chain is to be optimized as a whole, each organization that is part of it must optimize its own processes before attempting to reach a SCP. Owing to this, this work will focus on optimization problems related to factory planning.

3. Advanced planning system definition

However, besides the lack of common agreement on the APS literature, there are also gaps in the research, which have been cited numerous times.

Stadtler (2005) mentions that there are three areas for improvement: first, within the modules of today's planning systems; second, the issues that challenge current premises; and third, integration between functions. Henning (2009) states that there is a lack of research regarding Advanced Planning and Scheduling in the area of Information Systems (IS) and also a deficiency in industrial approaches. Aslan, Stevenson, and Hendry (2012) point out that some issues remain a problem: the literature is scarce, there are no details on the concept of planning systems and there is a need of insight in the inner-workings and applications of such systems. Framinan and Ruiz (2010) also state that planning research has often overlooked the architecture and the related literature is unusual and do not provide developers with a comprehensive view of the scheduling system. Moreover, Kallestrup, Lynge, Akkerman, and Oddsdottir (2014) reinforce the idea of requiring a research in the development of this type of system. Changing the topic, Zoryk-Schalla et al. (2004) brought up the fact that implementing a system like this might demand many organizational changes, and that the literature in that matter is uncommon.

In order to work on these areas that need improvement, the concept of *factory planning* that was previously introduced, is used as a base to build a systemic concept for Advanced Planning Systems, while eliciting knowledge and requirements from the current literature. Nevertheless, this is not an easy task, since there is not a consensus about what is involved in an APS and what is its scope (Fleischmann & Meyr, 2003). Hvolby and Steger-Jensen (2010) highlighted this issue: "[...] *no common accepted definition of APS systems exists, and several systems on the market do not fulfill a common description [...]*".

As a consequence, and in order to provide the needed frame for this work, there is a need to establish a definition to cover all the concepts found on the current literature.

3.1. Related acronyms

Several acronyms and names are used in the literature to define systems used to automatize *factory planning* problems. Table 1 shows those acronyms, the meaning used on each work, and the reference.

It can be seen that, on the current literature, the acronym APS has two different standings on the literature: 'Advanced Planning System' and 'Advanced Planning and Scheduling'. However, each of the meanings is studied and defined in the following subsections, comparing differences and similarities, while establishing relationships between them.

3.1.1. Advanced planning and scheduling

This name is one of the most used and also complex on the area.

Many authors use the acronym APS as both meanings ('Advanced Planning System' and 'Advanced Planning and Scheduling') interchangeably. However, among the current definitions, many of them bound the concept of Advanced Planning and Scheduling to either a specific solving approach, or to a given type of problem. This can be seen on the next examples:

Hvolby and Steger-Jensen (2010) define Advanced Planning and Scheduling as a computer program that uses simulation or an optimization method to solve the production planning process. This definition limits the scope of the software capabilities and also the *solving approaches* that can be used to only two methods: mathematical optimization and simulation. Also, they define Advanced Planning and Scheduling as a problem to be solved only through the use of operation research approaches.

Another definition states that Advanced Planning and Scheduling is any computer program that uses advanced mathematical algorithms or logic to perform optimization on finite scheduling (Hadaya & Pellerin, 2008). This definition not only considers mathematical optimization as the only possible solving approach, but also limits the problem to the finite scheduling, does not allowing more types of planning and also does not include other functionalities to the system.

An additional meaning is found at Chen and Ji (2007): they consider Advanced Planning and Scheduling as a schematic problem to satisfy customer request and reduce work-in-progress inventory, subject to multiple resource capacity constraints and complex precedence constraints among operations. While they do not prescribe a fixed type of solving approach, they limit the scope to the planning problem to be solved.

It can be seen that many authors support mathematical optimization as a primary solving approach for the planning problem. This situation is addressed in Table 2, which shows a comparison between definitions that only includes mathematical optimization, and those also considering genetic algorithms. This is highlighted by Kung and Chern (2009) who establish that *[...] "though MIP* [Mixed Integer Programming] *is a popular way to solve supply chain factory planning, the MIP model becomes unsolvable for complex problems, due to the time and computer resources required*", making explicit why other solving approaches are needed.

Gayialis and Tatsiopoulos (2004) give an interesting insight on the new trends which are available to solve the planning problem: current computer programming languages and the increasingly powerful hardware, which support the use of many algorithms and techniques in Advanced Planning and Scheduling systems. Beyond these definitions, a number of works often add the word 'systems' at the end of Advanced Planning and Scheduling, generating a different concept (Aslan et al., 2012; Badell, Romero, Huertas, & Puigjaner, 2004; Gayialis & Tatsiopoulos, 2004; Hadaya & Pellerin, 2008; Hvolby & Steger-Jensen, 2010; K. Chen & Ji, 2007; Zoryk-Schalla et al., 2004). Some of them state that Advanced Planning and Scheduling systems are equipped with a range of capabilities that includes finite planning at floor-level, constraint based planning, logic for supply chain management, among others, having the purpose of obtaining fast solutions for production scheduling, based on planning data (Estombelo Montesco, Pessoa, & Blos, 2015), with the intention to provide a global optimization of the enterprise (Öztürk & Ornek, 2014). Based on that idea, Welker, van der Vaart, and van Donk (2008) made the concept more explicit, by saying that APS systems are developed to support order processing decisions throughout the supply chains, thus starting with short-term planning and moving to mid and long-term time horizon.

Analyzing those definitions, it can be seen that there are two meanings for the same acronym: 'Advanced Planning and Scheduling' as a problem to be solved through a given advanced technique,

Table 1
Acronyms and their meaning found in literature.

Acronym	Meaning	Uses	Papers
APS	Advanced Planning System	7	Henning (2009), Fleischmann and Meyr (2003), Stadtler (2005), Zoryk-Schalla et al. (2004), Staeblein and Aoki (2014), Kallestrup et al. (2014), and Van Nieuwenhuyse et al. (2011)
APS	Advanced Planning and Scheduling	14	Hvolby and Steger-Jensen (2010), Öztürk and Ornek (2014), K. Chen and Ji (2007), Hadaya and Pellerin (2008), Kung and Chern (2009), Aslan et al. (2012), Badell et al. (2004), Lee, Jeong, and Moon (2002), Masuchun, Masuchun, and Thepmanee (2009), Kelle and Akbulut (2005), Gen, Lin, and Zhang (2009), Welker et al. (2008), Gayialis and Tatsiopoulos (2004), and Hahn and Packowski (2015)
MES	Manufacturing Execution Systems	2	Helo et al. (2014) and Harjunkoski et al. (2009)
SS	Scheduling Systems	2	Framinan and Ruiz (2010) and Burgeois et al. (1993)
DAPS	Dynamic Advanced Planning and Scheduling	1	K.J. Chen and Ji (2007)
APPS	Advanced Process Planning and Scheduling	1	Moon and Seo (2005)

Table 2
Solving approach comparison between mathematical optimization and genetic algorithms.

Type	Citations	Quotes
Mathematical Model	8	Hvolby and Steger-Jensen (2010), Burgeois et al. (1993), Öztürk and Ornek (2014), Zoryk-Schalla et al. (2004), K. Chen and Ji (2007), Van Nieuwenhuyse et al. (2011), Badell et al. (2004), and Masuchun et al. (2009)
Genetic Algorithm	5	Kung and Chern (2009), Lee et al. (2002), Gen et al. (2009), K.J. Chen and Ji (2007), Moon and Seo (2005), and Zhang, Ong, and Nee (2015)

and 'Advanced Planning and Scheduling systems' with a larger scope covering the automation of the problem mentioned before.

3.1.2. Advanced planning system

Zoryk-Schalla et al. (2004) define Advanced Planning System as software tools that enable companies to take decisions about supply chain structures, supply plans and detailed operational schedules. Fleischmann and Meyr (2003) define APS as a framework to put planning optimization into practice; they also emphasize the lack of consensus and variety of definitions that are currently being used in the literature.

The current definitions of APS as 'Advanced Planning System' distinguish this acronym as an information system that solves planning problems. In this line of thought, Henning (2009) mentioned that the main function of an APS is to complement existing ERP systems to overcome some of their weaknesses. It is also worth remarking that Advanced Planning Systems does not replace Enterprise Resource Planning systems (Fleischmann & Meyr, 2003) but complement it.

With these definitions in mind it must be pointed out that 'Advanced Planning System' is indeed a different concept than 'Advanced Planning and Scheduling'; however, it is similar to definitions for 'Advanced Planning and Scheduling systems'. Several examples about this can be found in the literature. Aslan et al. (2012), propose a definition that helps to establish a link between both concepts. They provide a definition of a system (Advanced Planning System) while using the name of Advanced Planning and Scheduling: *"[...] APS is developed to address manufacturing planning and scheduling problems based on hierarchical planning principles. It is a company-wide software system making use of analytical approaches to address company-wide and supply chain problems"*.

A second example of this idea was found on Gayialis and Tatsiopoulos (2004), where they state the rapid advance of operation research in the form of advanced planning and scheduling system showing that those algorithms can be applied in practice if they are either embodied on information system or interfacing ERPs.

As a conclusion, while 'Advanced Planning and Scheduling' is a *factory planning* problem that can be solved using several types of methods, an 'Advanced Planning System' is a complex information software system that automatizes the solving process of such problems. Because of this, the latter is a wider concept that represents a type of system that automatizes the solving of a problem, and not only a problem to be solved.

3.1.3. Scheduling systems

This term is not as popular as the previous ones, and its acronym is SS. Framinan and Ruiz (2010) define it as a particular case of BIS (Business Intelligent Systems), and state that SS has two levels of scheduling: a higher one that uses the output of production planning to set up the dates for the beginning of each job on each machine, and a lower one involved with real-time displacement of the items.

However, Henning (2009) makes a more explicit relation between SS and the Advanced Planning System concept, establishing that the first ones are now an integrated module of the latter. This idea leads to a new relation between concepts: SS are a more specific part of an APS.

3.1.4. Decision support system

Decision Support Systems (DSS) are IS that support business and organization decision-making activities, by offering information in an organized and accessible way for the decision-maker; it is a tool to facilitate organizational processes (Keen, 1980).

The general idea of the relation between a DSS and APS seems to be diverse. There are some authors that state that, through the continued expansion of functionalities, APS has become a particular case of DSS (Öztürk & Ornek, 2014). In this topic, Hahn and Packowski (2015) establish that APS systems are model-driven DSS that support strategic and operational supply chain planning, following a prescriptive analytic approach, and backing up the idea of APS as a specification of DSS.

Conversely, there are others opinions. For example, some authors considered that a DSS is positioned within the hierarchical structure of the APS and the organization (Kallestrup et al., 2014), meaning that DSS are a specific part of an Advanced Planning System. However, Gayialis and Tatsiopoulos (2004) proposed the reverse idea: enhance an APS by incorporating it to a Decision Support System.

The last notion is that Scheduling Systems are built upon modules of a DSS (Framinan & Ruiz, 2010), and due to the relation between SS and APS that was derived before, it can be stated that the latter are also built upon the modules of a DSS, leading to a conclusion that contradicts the idea of DSS being a part of APS.

3.1.5. Manufacturing execution system

Acknowledged by the acronym MES is a concept often mentioned in the literature related to Advanced Planning Systems. Henning (2009) made it clear that both are different types of systems that need to be integrated.

However, from the work of Harjunkoski et al. (2009) it can be seen why these systems are related. They say that MES systems supply information to the APS to enable optimization of production processes from order generation to finished product. MES manages and initiates activities by the use of current and precise data.

Namely, these IS are related and must be integrated, but making clear that are two different types of systems.

3.1.6. Other particular cases

Dynamic Advanced Planning and Scheduling (DAPS) Chen and Ji (2007) is a specialization and more complex case of an "Advanced Planning and Scheduling problem". The DAPS is defined as a more real-life specification, because it takes under consideration the existence of some unexpected events may arise, such as the arrival of new orders, breakage of machines, among others, and disrupt the manufacturing system. These circumstances lead to the study of dynamic advanced planning and scheduling.

Similarly, Moon and Seo (2005) proposed the Advanced Process Planning and Scheduling problem (APP&S) as another specialization. They defined it as the problem solution of the assignment of factory machines to production tasks, considering all alternatives on machines and its operation sequences.

Therefore, both DAPS and APP&S are specializations of the basic Advanced Planning and Scheduling problem.

3.1.7. Enterprise resource planning

On the literature, the authors references two types of relationships between ERP and Advanced Planning Systems.

The first type reflects that the APS needs to extract different sorts of data from the ERP in order to process it and store the results back again on the ERP. Several works mention this link (Badell et al., 2004; Fleischmann & Meyr, 2003; Framinan & Ruiz, 2010; Hadaya & Pellerin, 2008; Stadtler, 2005; Van Nieuwenhuyse, De Boeck, Lambrecht, & Vandaele, 2011) while others also add the need to integrate the APS to financial-oriented systems (Badell et al., 2004; Hahn and Packowski, 2015) or real time control devices (Stadtler, 2005).

Another concept that can be seen on the literature: ERP-II or Extended ERP. Aslan et al. (2012) defines this new system as the following: "ERP's functionality has continued to grow and their

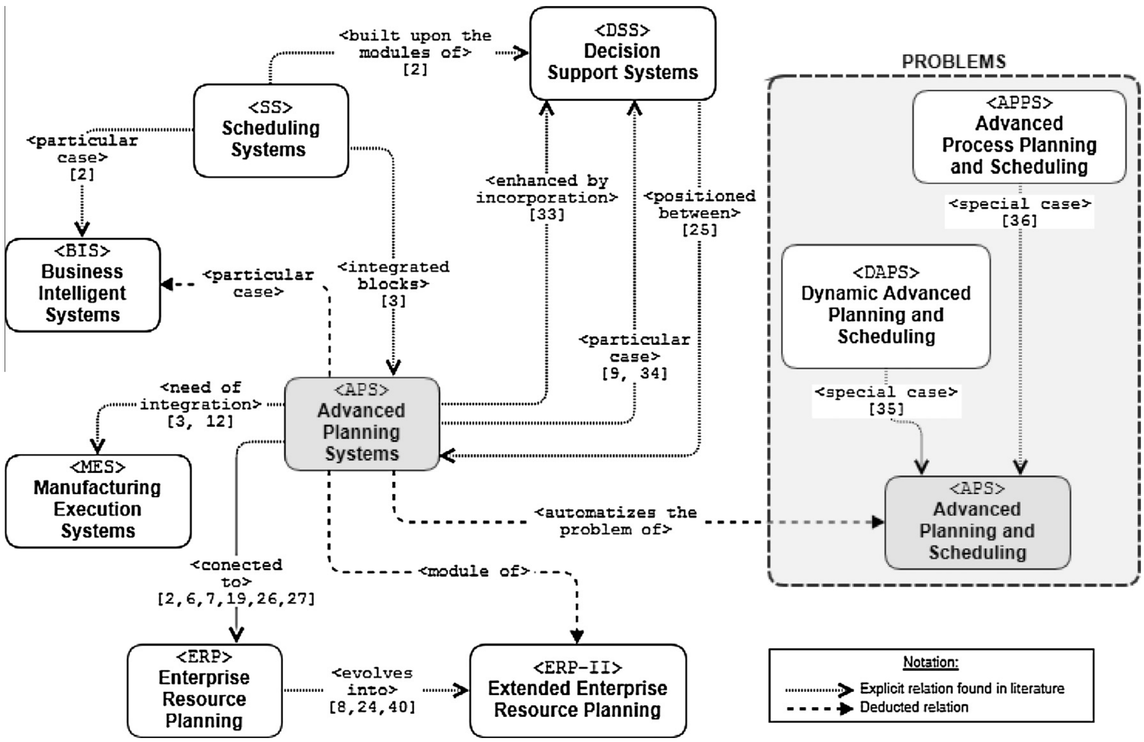

Fig. 1. Relations and meanings of acronyms found in literature and deducted from it.

scope has begun to extend from internal process to collective an external process. This trend has led to the term Extended ERP or ERP-II". Helo et al. (2014) used 'Extended Enterprise' as a synonym for the concept 'Extended ERP', trying to represent the idea that a company is made up not just of its employees and its managers, but also its business partners, its suppliers and its customers.

Nevertheless, a proper definition for each term can be found in Gupta, Sharma, and Rashid (2009):

- *Extended ERP:* Extends the basic ERP system functionalities such as finances, distribution, manufacturing, human resources, and payroll to customer relationship management, supply chain management, sales-force automation, and Internet-enabled integrated e-commerce and e-business.
- *ERP-II:* open ERP systems beyond the enterprise level to exchange information with supply chain partners and customers. ERP II extends beyond the four-walls of the business to trading partners. Typically, ERP II includes customer relationship management (CRM), supply chain management (SCM) and e-business packages.

According to the previous definitions, APS are external modules that connect to an existing ERP, however, with extra modules and improvements, and ERP evolves into an ERP-II. It is important to mention that an organization may use a transactional system of in-house development, a combination of several market-made systems, or even standard packaged software, and the relation between such system and the APS will be the same as stated on this sub-section. As a consequence, this work will use the term *Enterprise System* (ES) as an umbrella term that includes ERPs, transactional systems, and other IS that manages the enterprise's data.

3.2. Proposed definition

In order to have a more visual approach about the concepts and its relationships presented in the previous subsections, Fig. 1 shows the discussed acronyms, their meaning, and the relationships between them. In Fig. 1 the dotted line represent the links found in literature, while the dashed lines the associations inferred in this work. Also, the links have names derived from the definitions on the literature, the concepts inferred and also the quotations that support them.

The first concept corresponds to a transitive deduction, based on the fact that if Scheduling Systems are particular cases of BIS and are integrated blocks to an APS, then likewise, those are particular cases of Business Intelligent Systems.

The second relationship is between Advanced Planning Systems and ERP-II, in order to make explicit the concept that an APS is a module of this ERP evolution.

The third inferred concept is the most important one, which is adding a missing link on the literature, and relating the concepts of Advanced Planning System and Advanced Planning and Scheduling. When discussing each acronym and their meanings, Advanced Planning and Scheduling is identified as problems to be solved than a system itself. This can be included in the proposed definition of *factory planning*, since this is broader concept and more inclusive. However, Advanced Planning System is an extensive concept referred to an IS as a whole, that automatizes the solving of an advanced planning and scheduling problem.

This third relation is also the base for the proposed definition, which uses the concept of factory planning previously introduced:

> *"Advanced Planning Systems (APS) are information software systems conceived to solve one or several factory planning problems by means of an advanced solving approach such as operation research, genetic algorithms, and simulation, among others. An APS must interoperate with the Enterprise System (ES), to achieve a coordinated workflow. Also, an APS do not replace the human planners but complements them, allowing them to be always in control to accept, modify or reject the results offered by the Advanced Planning System".*

It is noteworthy that even when APS is a type of system, it is intrinsically related to the factory planning problem that aims to solve. As previously stated on the proposed definition, such problem may be solved through several methods, which – from now on – will be referred to by using the umbrella term of *solving approach* (SA).

4. Software Engineering approach

Software Engineering (SE) is an engineering discipline concerned with all aspects of software production from the early stages of system specification until maintaining the system after its implementation (Sommerville, 2006). The sub-discipline in charge of generating the software specification is *Requirements Engineering* (RE), which focuses on the elicitation, modeling, and analysis of requirements and environment of a system, in order to generate its specification (Burnay, Jureta, & Faulkner, 2014). Elicitation is a non-trivial process that gathers requirements from stakeholders; there are several practices to extract and validate the correctness of the requirements.

The purpose of this article is to provide a generic characterization of APS, compliant to the SEBoK (BKCASE Editorial Board, 2014), the SQuaRE model (ISO/IEC 25010:, 2011) and Software Architecture standards (ISO/IEC/IEEE 42010:2011, 2011); this is based on a set of Functional Requirements (FR), a set of Quality Attributes (QA) and a reference model to use as starting point for the Software Architecture (APS-RM), consistently modeled and interrelated. The aim is to provide a baseline of concepts that are generic enough to define a type of system, but that can be extended and specialized to fit each particular implementation of Advanced Planning Systems.

Since this is a high abstraction level characterization, there are no explicit stakeholders and the hardware to be used in the architecture is not defined. Owing to this, the situation is similar to the development of a massive marketed system, where is common to gather the requirements by means of marketing policies, technical support, user groups and publication reviews. It is common in this cases that requirements are conceived by project developers based on strategic business objectives, domain knowledge and product vision (Potts, 1995). Therefore, the main source to propose FR and QA are the current topics in academic literature, and the experience in the research group in consulting works by which a factory planning solution was linked to the company system. After the discussion of Functional Requirements and Quality Attributes, a Software Architecture is introduced.

It is worth noting that the FR and QA proposed on this work are not related to the 'functional attributes' or 'structural attributes' that can be found on the literature (Meyr & Stadtler, 2015), because they do not state characteristic of the system *per se*, but instead study the information managed through an APS. However, this attributes could be employed to perform an analysis of the quality of data, by applying the ISO/IEC 25012:2008 "SQuaRE Data Quality Model" (Committee ISO/IEC JTC 1/SC 7, 2008) and related standards.

4.1. Functional requirements

Based on the SEBoK (Software Engineer Body of Knowledge) (BKCASE Editorial Board, 2014), System Requirements *"[...] are all of the requirements at the system level that describe the functions which the system as a whole should fulfill to satisfy the stakeholder needs and requirements, and are expressed in an appropriate combination of textual statements, views, and non-functional requirements [...]"*. It also makes clear that a requirement is a statement that identifies a product or processes operational, functional, or design characteristic or constraint of the system, and is unambiguous, testable, or measurable and necessary for product or process acceptability.

As more specific, SEBoK (BKCASE Editorial Board, 2014) states that Functional Requirements (FR) *"[...] describe qualitatively the system functions or tasks to be performed in operation; FR defines what the system must be able to do or perform"*.

From a SE point of view, the consulted literature regarding the features of Advanced Planning Systems contains contradictions and vague definitions; the following are the most commonly found issues in this matter:

- Some works propose a list of requirements for an APS which are more appropriate for a mathematical model than for a system.
- In other cases, many of the features listed belong to a system, but present Quality Attributes as Functional Requirements.
- Lastly, there are some system-related features that do not have a direct impact on the solving approach – but do affect the system – that are not mentioned at all. For example: log-in, data administration, control of data redundancy, and more.

As a result, the articles used to extract the requirements introduce ideas, concepts and suggestions about an APS which are usually presented as general statements. Those notions are elicited, organized and translated into FR and QA, by using the international standards as a frame. Furthermore, as an APS is intrinsically linked to the *solving approach* used to solve a *factory planning* problem, a Functional Requirement can be related to the APS in three ways: affecting both the system-side and the solving approach or affecting only one side (system or SA).

Table 3 lists the proposed FR for an APS. Each row on the table is a new requirement which has three columns: a name, a column for the FR related to the solving approach and a third one to specify the FR related to the system.

As mentioned, these requirements are generic and not all of them must be met by an APS, due to a particular implementation that may need additional features that are not listed, or may not want to implement some. Each requirement will be discussed, in order to trace its origin and establish the impact into the system.

4.1.1. Optimization points management

This requirement is the core aspect of the functioning of an APS (ISO/IEC/IEEE 42010:2011, 2011). An *optimization point* (OP) is a planning problem that needs to be solved through an Advanced Planning System. There must be at least one point to optimize, but there is no maximum limit of how many points that an APS may solve. Since it can be multiple points, the system should give the capability to manage them and select one to optimize on each run.

This requirement is extracted from the proposed definition of APS where the system must able to manage one or several factory planning problems, and also is elicited from literature concepts which stated that the APS aim to solve optimization problems (Framinan & Ruiz, 2010; Zoryk-Schalla et al., 2004).

4.1.2. Model and objective management

Each optimization point must have at least one model (a specific solution to a factory planning problem, using a particular approach) to solve each problem, with no restriction on the maximum amount of available models per point. Also, each model must have at least one objective (what the model seeks to optimize, e.g. minimize cost, minimize time-span, maximize revenues, etc.) but can also have multiple objectives, with one defined as default.

At any rate, the system should allow the user to select the point, the model and the objective. The APS should also offer a 'default' combination of model/objective for each point. This is elicited from the idea that an APS must suggest a model, the possibility of multi-algorithm scheduling, and other features (Framinan & Ruiz, 2010).

Table 3
Proposed generic Functional Requirements of an APS, with their association to either the solving approach (SA) or the system.

Name	Related to SA	Related to System
Optimization Points Management	An Optimization Point (OP) is a planning problem that needs to be solved through a solving approach. At least one OP should be available, with no maximum limit	The system must offer the user a way to easily select which Optimization Point would be used for each run. In any case, it must also have a point marked as the 'default' (used when no other OP is selected)
Models Management	Each OP must have at least one model, with no maximum limit for the model/points relation. Each model can use a different solving approach	The system allows the user to easily select the model to be used. However, it should suggest a default model for each point, and use it in case no other model was selected
Objectives Management	Each model must have at least one available objective without the need of being multi-objective. The objectives must change from model to model, and from point to point A model can also be multi-objective	The system allows the user to select the objective to use with each model. However, each model must have a default objective that will be used in case no other one was manually selected
Parameters Settings	Each model must have parameters that allow the generation of scenarios. Those can be customized with either a fixed value or a range of value with a given increment. Each parameter must also have a default value	The system must offer a graphical way for the user to customize the parameters (changing values, ranges and increments). In case no value was changed, it must use the default values
Scenario Generation		After the used input of the parameters, the APS must automatically generate each scenario, showing the progress to the user and allowing them to continue with other tasks
Scenario Storage		The scenarios results must be automatically stored (in either success or failure/infeasibility situations) no the APS database, to be later revised and studied by the human planner. Results are only impacted on the ES once the user approves them
Scenario Comparison		The system must offer a graphical way to compare scenarios results, and allow the human planner to modify them. For successful cases, the comparison should show charts, graphics, statics of resolution times, and so one. For unfeasible results, the showcased information must help the planner to understand why the model turned unfeasible
Input Data	Each model should run with real data from the organization. Each point can be MTS, ETO or MTO, and it can vary from point to point	The APS must automatically extract the input data for each model, from the ES, as required by each model/point
Consistency Check		There must be a consistency check on the data entered on the system, and before running each model This should check the existence of all needed resources, e.g. including availability of raw materials (comparing BoM against current stock), machines states, and so on. If the check fails, it must be clearly informed to the user
Output Data	The models will produce optimized plans as results. There would be a result per generated scenario	The system translates the results of the selected scenario to a format understood by the ES, and stores it on the Enterprise System. This is only done when approved by the user
Log-In Function		This function restricts the access to the system to authorized-only personnel. Credentials may be the same of the ES', or new ones
Information Exchange		The exchange of information between the APS and any other system should be based on a standard (such as S95 or S88)
Open/Saving Results		The system should be able to open and show previous results with the same charts, graphics and displays used before, during the Scenario Comparison. This also applies for unfeasible cases
Algorithm Integration		An authorized user must be able to modify, add or remove models or objectives for each optimization point; they could also change the default combination for each OP (model, objectives and parameter values), and modify the default value, range or increment for each parameter All changes must be stored on security logs, and related to the user that made the change/s
Bottleneck Detection	Models must be able to detect bottlenecks and consider them on their restrictions	The system should check bottlenecks and under-loaded resources before running each model; if any issue is detected, it must be clearly informed to the user, and await their input before optimizing
Post-Execution Evaluation		The system should monitor the execution of the scheduled plans in order to measure the deviation between plans and the actual situation This can be set on automated mode (it will trigger alone, and save a report) or manually (triggered by the user, showing real-time reports). This function can be only applied to some optimization points, and may work differently for each of them
Reschedule Checking	Models should allow rescheduling, while keeping some of the jobs as they were already scheduled on the first run. This may only apply to some models	In view of the deviation from the plans, the system should show whether the current jobs have to be rescheduled. The decision should be taken by the human planner, or allow an automatized option
Model & Procedures	Separation of model and solution procedures, so different procedures can be applied to a given problem instance	
Database Use		The APS should have its own database (regardless of where and how it is implemented), to store data exclusive from the APS (such as data related to models, objectives, parameters, and not-committed scenarios)

4.1.3. Standard integration with ES

There are several proposed requirements that are affected by this concept, because they imply interrelation between the APS and the ES.

Several articles support this concept. A first reference affirms that an APS should be integrated with the current transactional systems through an automated interface that ensured consistency (Burgeois et al., 1993). Another one states that all the information should come from the ES and be automatically read by the APS (Keen, 1980), which needs to gather the information automatically (Helo et al., 2014).

APS needs to handle large amounts of input data and generate output data (Gayialis & Tatsiopoulos, 2004), which consumes resources and needs a standard base to communicate it. Harjunkoski et al. (2009) write about this matter, in an APS-centered perspective: "*[...] According to the ISA-95 standard, scheduling functions interface with the manufacturing control system functions through: a production schedule, actual production information and production capability information. [...] The information generated or modified by the production scheduling functions thus include: production schedule, actual production versus planned production, production capacity and resource availability, and current order status*".

It is noteworthy that the authors mentioned the ISA-95 standard, which is also known as ANSI/ISA-95 or S95 (Gupta et al., 2009). It is an international standard made of four parts, for developing an automated interface between enterprise and control systems. It was written for global manufacturing and clarifies application functionalities and how the information must be used. S95 aims to provide consistent terminology for the communication between suppliers and manufacturers and also gives consistent information and operation models.

The use of standards to integrate systems is highly recommended in the APS literature (Fleischmann & Meyr, 2003; Hadaya & Pellerin, 2008; Hvolby & Steger-Jensen, 2010; Van Nieuwenhuyse et al., 2011), and was extracted from those sources. A standardized interface to exchange information helps to achieve a seamless integration between systems, whether they are from the same organization, same interorganizational network, or from an external source.

This also enable a straightforward definition of tasks, allowing an easier collaboration between systems and procedures (regardless if they are manually done, or through systems).

4.1.4. Information consistency

Related with 'Standard Integration', this subset includes 'Consistency Check' and 'Bottleneck Detection' requirements of Table 3, both of them require a standard information exchange between the ES and the APS, to improve the data extraction and make it more effective.

The idea behind this group of FR is allow the APS to work on real capacity of resources, and to provide an automatized interface to check availability (of raw material, equipment, personnel, and more). The data should be checked and evaluated before executing an optimization point, in order to reduce execution times for cases that are unfeasible due to resources constraints that can be previously known; all of these results must be easily accessed in order to facilitate the decision-making.

More particularly, in 'Bottleneck Detection' the system should check for bottlenecks and under-loaded resources.

4.1.5. Scenario management

Requirements such as 'Parameters Setting', 'Scenario Generation', 'Scenario Storage' and 'Scenario Comparison' (all from Table 3), are related because they allow the user to automatically set the APS to run several optimizations of the same point with different parameters, to enable a subsequent comparison between results.

These requirements are very useful, because its results can be used to make decisions and help to keep consistency among them (Shobrys & White, 2000), while keeping the human planners on control. This can be done by allowing manual modification of the model's parameters, despite the fact that the APS should be able to estimate them, and provide default values. An APS should allow a *what-if* analysis. The analysis can be done by modifying the parameters of the model, in order to evaluate many situations and complex settings. This type of FR has a high impact on the proposed QA.

4.1.6. Human expertise

This is a feature that is present on several FR and that will heavily impact in the QA. It is elicited from a broad range of works of the APS literature (Framinan & Ruiz, 2010; Henning, 2009; Hvolby & Steger-Jensen, 2010; Zoryk-Schalla et al., 2004). This is also part of the proposed definition for Advanced Planning Systems.

It is important to mention that an APS is a DSS for its main users, the human planners, and does not replace them. As several specific FR mention it, the planners must always be able to perform manual adjustments, as they have an important role in many problem-solving stages, such as problem definition, solution process and results analysis, and among others.

Therefore, planners should be able to model and setup decisions rules for the planning and optimization: manual adjustments are always needed, either due to missing functionalities or low accuracy of the data. The importance of this requirement is demonstrated by the literature, and derives on how the planners/schedulers are not only users of the APS, but also stakeholders on its development, and need to be adequately involved.

4.1.7. APS database

The FR 'Database Use' of Table 3 is highly important because it has implications over the previous requirements and also on the resulting SwA-RM.

This requirement is elicited from the fact that an APS should carry its own database (DB) Fleischmann and Meyr (2003), regardless of where and how is implemented. This DB should not be an addition on the ES's database, but must be autonomous and managed exclusively by the APS; this logical implementation does not depend on any physical distribution they may have.

In this database, the APS should be able to store data regarding the models, objectives and parameters listed on Table 3. This DB should also allow the APS store the results of the executed scenarios but not yet approved by the planners, or those not selected to be saved on the ES.

4.1.8. Algorithm update and integration

The FR 'Algorithm Integration' of Table 3, mentions that optimization points should be able to be administrated through system interface; this include adding new models and objectives, or the modification and removing of the existing ones; this also includes modifying default combinations of model/objective/parameters values for each available point.

However, this feature needs to be restricted to a certain security measure, in order to avoid malicious use, and reduce the risk of incorrect modification/deletion of the models or other components, by users that do not have the required security level. This reinforces the idea of the 'Log-In Function' also listed on Table 3, to restrict the access to the APS tool to control the modifications that can be made on the system. This FR has a deep impact on the proposed Quality Attributes.

4.2. Quality Attributes

Quality Attributes (QA) are also known as non-functional requirements. The SEBoK glossary (BKCASE Editorial Board, 2014) defines them as *"[...] an inherent property or characteristic of an entity that can be distinguished quantitatively or qualitatively by human or automated means*".

The current standard for managing QA is the ISO/IEC 2500n: "Quality Management Division" series, also known as the SQuaRE (System and Software Quality Requirements and Evaluation) model. In particular, the ISO/IEC 25010:2011 (ISO/IEC 25010:2011, 2011) contain the model and definitions that are used on this article.

The Quality Attributes must be quantitatively studied in order to know how they are enforced in the system. In order to do this, QA must be assessed through specific metrics contained in indicators (a group of measures that provide knowledge about a process, comparing it to an 'expected' result). The ISO/IEC 2502n "Quality Measurement Division" of the SQuaRE series of standards provides a set of metrics and recommendation to quantitatively study the quality of software. However, this topic will be discussed in future works, because a first step is to select the QA to be applied on the system, and understand how they affect it. Therefore, the proposed QA list follows the concept of a generic characterization that will serve as a baseline that can be extended and specialized for each particular case. These are defined using the concepts established on both SEBoK (Herrmann et al., 2015) and SQuaRE standards (Heng, 2014).

These attributes are derived from the FR of Table 3, because many need specific non-functional features in order to properly fulfill its definition. They are also elicited from the literature, from ideas, notions or concepts that indicated a non-functional need. Nevertheless, the current APS literature has less than a few references to QA which they are not presented from a SE point-of-view; often, they are confused as functional features of a system and/or have outdated definitions.

It is worth mentioning that the proposed QA help to frame an APS development and not all of them need to be implemented. It is a decision of the APS development team how they are fulfilled. Consequently, the aim is to specialize the list for each particular case, adapting it to the needs of each organization.

4.2.1. Compatibility

It is the degree to which two or more systems or components can exchange information and/or perform their required functions while sharing the same hardware or software environment (ISO/IEC 25010:2011, 2011).

This QA complements many FRs of Table 3 – such as 'Input Data', 'Output Data' and 'Information Exchange', among others –, that establishes an interaction between the APS and the ES. It is a concept mentioned on the literature (Badell et al., 2004; Fleischmann & Meyr, 2003; Framinan & Ruiz, 2010; Hadaya & Pellerin, 2008; Stadtler, 2005; Van Nieuwenhuyse et al., 2011) because having good interoperability between systems requires compatibility. For this Attribute, two sub-characteristics are selected:

- *Interoperability:* degree to which two or more systems, products or components can exchange information and use it (Committee ISO/IEC JTC 1/SC 7).
- *Co-Existence:* degree to which a product can perform its required functions efficiently while sharing a common environment and resources with others without detrimental impact (Committee ISO/IEC JTC 1/SC 7).

4.2.2. Portability

It is the degree to which a system or component can be effectively and efficiently transferred from one hardware, software or other operational environment to another one (ISO/IEC 25010:2011, 2011). This is highly important because the functioning of the APS must always be the same regardless of the environment (software, hardware, or a combination of both) where is executed. The selected sub-characteristic is:

- *Adaptability:* the degree to which a product or system can effectively and efficiently be adapted for different or evolving environments (Committee ISO/IEC JTC 1/SC 7). This includes the scalability of internal capacity, and since the APS must be able to expand through requirements such as 'Algorithm Integration' and adding optimization points to adapt to changes while the organization grows and improve.

4.2.3. Reliability

It is defined as the degree to which a system or component performs definite functions under specified conditions for a given period of time (ISO/IEC 25010:2011, 2011). The selected sub-characteristic for these, is Fault Tolerance (the degree to which a system, product or component operates as intended despite the presence of hardware/software faults (Committee ISO/IEC JTC 1/SC 7).

The APS should be able to evolve seamlessly, being 'robust' not only to possible faults (from the software and the model side), but also to the conditions of its environment (both hardware and software). It should manage exceptions and clarify the situation to the users, so it can be addressed. The correct implementation of this attribute improves users' confidence in the APS and its results.

4.2.4. Maintainability

This Quality Attribute is defined as the degree of effectiveness and efficiency with which the product can be modified (ISO/IEC 25010:2011, 2011). It has several sub-characteristics that are consequences of the FR of Table 3, and each of them affects the APS in a specific manner.

- *Modularity:* degree to which a system or computer program is composed of discrete components such that a change to one of them has minimal impact on the others (Committee ISO/IEC JTC 1/SC 7). An APS should be developed in self-contained modules, that follow the idea of modules on the ES, and increases the robustness of a system, making it easier to add new functionalities on-demand. This also allows using an iterative an incremental developing life-cycle that will produce an earlier return of the development investment.
- *Modifiability:* composed by Changeability and Modification Stability, it is the degree to which a product or system can be effectively and efficiently modified without introducing defects or degrading the existing product quality (Committee ISO/IEC JTC 1/SC 7). Reinforcing the Modularity sub-characteristic, a system that is easy to change is more flexible to adapt itself. A FR that directly impacts on this is 'Algorithm Integration' and the possibility to allow the human planner to add, modify or remove existing *optimization points*, and their components This will also help on adapting the system to changes in the organization.
- *Testability:* it is the degree of effectiveness and efficiency by which test criteria can be established for a system, product or component. Tests can be performed to determine whether those criteria have been met (Committee ISO/IEC JTC 1/SC 7). This characteristic is mentioned because there is a tendency to reinforce the use of unit-test and automatize the testing of

the system while using iterative and incremental development; and also, because a system should be successfully verified and validated in order to be approved by the customer.

This attribute, and its sub-characteristics, are important on cases where the firm is bought by another one, and their systems must be integrated, also requiring Compatibility, Portability and Reliability.

4.2.5. Usability

This is an important Quality Attribute, it is the degree to which the product is easy to be understood, learned, used and attractive to the user, when used under specified conditions (ISO/IEC 25010:2011, 2011).

On an APS, the human planners' role is not only a group of main users but also important stakeholders; thus, the system must have a well-specified and user-friendly Graphic User Interface (GUI). This Quality Attribute is also reinforced by several of the proposed FR of Table 3, such as 'Optimization Points Management', 'Model Management', 'Objective Management', 'Scenario Comparison', 'Parameter Settings', and 'Algorithm Integration'.

For this attribute, a number of sub-characteristics are selected:

- *Learnability:* it is the degree to which a product or system can be used by specified users to achieve goals of learning the product, in a specified context, with effectiveness, efficiency, satisfaction and freedom from risk (Committee ISO/IEC JTC 1/SC 7). This means that the user must be able to adapt swiftly and easily to the new system, and it must help to simplify his daily operations.
- *Operability:* defined as the degree to which a product or system has attributes that make it easy to operate and control. It corresponds to controllability, error tolerance and conformity with user expectations (Committee ISO/IEC JTC 1/SC 7). As a complement to Learnability, the user should not need an IT (Information Technology) assistant to perform their work, and more specifically, modify the system through FR such as 'Algorithm Integration', by easily adding models and objectives.
- *Accessibility:* it is the degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a particular goal in a specified context of use (Committee ISO/IEC JTC 1/SC 7). This means that the users should be able to easily access the system and use its functions.
- *User interface aesthetics:* degree to which a user interface enables pleasing and satisfying interaction for the user. This refers to properties of the product or system that increase the pleasure and satisfaction of the user, such as the use of color and the nature of the graphical design (Committee ISO/IEC JTC 1/SC 7). It is important because the results of solving an optimization point should be clearly and friendly displayed, with colors that will make easy to understand them.

4.2.6. Functional suitability

It is defined as the degree to which the product provides functions that meet the needs stated on the requirements, when the product is used under specified conditions (ISO/IEC 25010:2011, 2011). This Quality Attribute is more focused on developing a system that verifies and validates its Functional Requirements, meaning that it also satisfies the true needs of the users.

This is not only a consequence of a successful software development project, but was also elicited from the literature (Henning, 2009; Zoryk-Schalla et al., 2004). For this attribute, two sub-characteristics are selected:

- *Correctness:* it is the degree to which a product or system provides the correct results with the needed degree of precision (Committee ISO/IEC JTC 1/SC 7). This is a very important quality for some of the FR of Table 3, such as 'Scenario Comparison', 'Reschedule Checking' and others, because the APS must show correct results for the cases when the SA is capable of solving the problem under study, but also for those cases where the solution is unfeasible, and the human planner must be able to study the messages shown in order to deduce what led to SA to be impractical. The results are used to make decisions that directly affect the organization, so they must be well-defined, extensive and explicit.
- *Appropriateness:* it is the degree to which the functions facilitate the accomplishment of specified tasks and objectives (Committee ISO/IEC JTC 1/SC 7). As the APS is a tool to help the human planners, it should assist them to take decisions regarding the factory planning, facilitating his job and increasing their performance. The results the system must show must be appropriate and adequate to also achieve the benefits of Usability.

4.2.7. Security

This Quality Attribute represents the degree of information and data protection so that unauthorized persons or systems cannot read or modify them and authorized persons or systems are not denied access to them (ISO/IEC 25010:2011, 2011). Three sub-characteristics have been selected:

- *Confidentiality:* the degree to which a product or system ensures that data are accessible only to those authorized users (Committee ISO/IEC JTC 1/SC 7).
- *Integrity:* degree to which a system, product or component prevents unauthorized access to, or modification of, computer programs or data (Committee ISO/IEC JTC 1/SC 7).
- *Authenticity:* degree to which the identity of a subject or resource can be proved to be the one claimed (Committee ISO/IEC JTC 1/SC 7).

Several of the Functional Requirements proposed on Table 3 require a level of security on the system in order to decrease the chances of malicious or unauthorized use: this implies that the system must be able also to track the users that make changes on the system (for example through the 'Algorithm Integration or 'Scenario Storage'), ensuring consistency and traceability. The requirement 'Log-In' gives the privileges to each authorized account, by means of this it is possible to track who made each change, and restrict access to given features. This generates types of users with different levels of access and available functionalities, which must be taken into account when performing a detailed design.

4.2.8. Performance efficiency

This final attribute is defined as the performance relative to the amount of resources used under specified conditions (ISO/IEC 25010:2011, 2011). Two sub-characteristics were selected:

- *Time behavior:* degree to which the response and processing time and throughput rate of a product or system, when performing its functions, satisfy the requirements (Keen, 1980).
- *Resource utilization:* degree to which the amount and type of resources used by a product or system, when performing its functions, satisfy the requirements. This also considers human resources (Committee ISO/IEC JTC 1/SC 7).

The use of computing resources and waiting time that can arise during processes like 'Scenario Generation', 'Consistency Check' and 'Bottleneck Detection', among others, creates a need to measure the performance and provide the user a way to estimate how much time the system has been working, and how much will take to finish its tasks. This also affects what the user should see while the APS is running an optimization of a given point, and how they system should respond to actions during that period of time.

4.3. Software Architecture

Software Architecture (SwA) is an intrinsic part of software design, and must be properly detailed. It is defined as follows: "*Software architecture encompasses the set of significant decisions about the organization of a software system including the selection of the structural elements and their interfaces by which the system is composed; behavior as specified in collaboration among those elements; composition of these structural and behavioral elements into larger subsystems; and an architectural style that guides this organization [...]*" (Microsoft Patterns, 2009).

The current international standard for Software Architecture is the ISO/IEC/IEEE 42010:2011 (ISO/IEC/IEEE 42010:2011, 2011), and addresses the creation, analysis and sustainment of software system architectures, through the use of architecture descriptions. It also helps to establish a conceptual model founded with specifications, and indicating the required contents.

Designing the architecture of a system is not an easy task, and is intrinsically affected by the FR and QA that the system needs to achieve (Microsoft Patterns & Practices Team, 2009): architectural significant use cases, selecting the application type, and available technologies, are some of the aspects that must be identified before proceeding.

Regarding APS, there is a lack of information about this topic on the literature (Framinan & Ruiz, 2010), even when SwA is an intrinsic part of any software system, influencing its design and implementation. Also, current works often overlook system-related aspects of APS, and do not provide a comprehensive view of such systems (Framinan & Ruiz, 2010; Henning, 2009; Stadtler, 2005).

Owing to this, and following the concept of a generic characterization that could be specified for each particular case, this work propose a reference model for Advanced Planning Systems (APS-RM), which is a division of functionality together with data flow between the pieces, and is a decomposition into parts of a known problem that cooperatively solve the problem (Burnay et al., 2014); it does not impose specific design decisions, but provides practical software development guidance (ISO/IEC 25010:2011, 2011).

Therefore, the proposed APS-RM is presented using a n-layered organization of the main components. It is noteworthy that the architectural concepts of layers and tiers are different. *Logical layers* are a way to theoretically organize the code, without any ties to a possible physical distribution, while *physical tiers* only specify the physical location of the deployment of the local layers (Lothka, 2005). Therefore, this paper does not discuss physical tiers, due to their heavy link on the infrastructure of the organization that wants to implement an APS. A concept related to this issue is that the size of a firm is closely related to the adoption of an Advanced Planning System (Hadaya & Pellerin, 2008).

It is noteworthy that this *reference model* is the initial step to later construct a reference architecture based on the "4 + 1" View Model (Kruchten, 1995), which framed the APS architecture. This also allows the specification of a Software Architecture for particular cases. However, this RM is intrinsically linked to the current list of QA and FR.

The APS-RM is presented in Fig. 2 where the different layers are shown. In the implementation, they can be converted into a 2-tiers (client–server architecture), 3-tiers (web-based systems) or *n*-tiers. As said before, the choice depends on the organization's current infrastructure, the number of users that use the APS, the geographic distribution of those users, the required performance of the system, and the bandwidth availability, among others (Microsoft Patterns & Practices Team, 2009).

The following sub-sections discuss each of the proposed layers of the SwA for an Advanced Planning System.

4.3.1. Data storage layer

This layer persists the raw data that is managed by the system. It is composed by the database of the ES that must be linked (as it is mentioned on the proposed definition), an interface from the ES to connect to it, and the own database of the APS (discussed as a FR). This interaction is mandatory and is not influenced by the type of DBMS (Database Management System) that implements them. These databases and their connections are mentioned in several Functional Requirements proposed of Table 3.

Firstly regarding the database of the ES (simplified as ESDB), since it belongs to the transactional system, the APS can only read/write data on it, and must not execute structural changes on it. The ESDB can also have an Information Exchange Interface, allowing external systems to only access its DB through it; however, this may vary from ES to ES. Fig. 2 indicates this concept by framing the ESDB and the Exchange Interface in a dashed-lined-box, titled ES (for Enterprise System). In reference to the type of data, the ESDB persists the following: bill of materials, bill of resources, production orders, sales orders, forecast, equipment, inventory, stock control, and more.

The goal of the APS database, simplified as APSDB, is enhance the functioning of the system and store data particular to its role, without needing the modification of the ESDB. There are no rules on how this database should be implemented, it can be relational or not, it can share the same database of the ESDB or not. None the less, it is a main part of any Advanced Planning System.

4.3.2. Data access layer

This layer is intrinsically related to Data Storage, and contains the mandatory blocks to enclose the logic to read/write data on each database that the APS connects to. Following the principles of the Modularity attribute, there is a block containing the logic to connect to the ESDB (using the Exchange Interface that could exists), and another one for the APSDB. Also, the proposed architecture adds a Database Translator block.

The two control blocks may share the same structure to allow reusing previously developed components to facilitate their modifications in case of adding/removing functionalities. If these blocks are built on an object-oriented programming language, a good recommendation is to use the same package hierarchy to extend from the same generic structure. This strategy also improves several QA, such as maintainability, modularity, and among others.

The third block, Database Translator, is in charge of inter-layer communication to the Schedule Generator layer, and managing the requests to each of the Control blocks, as needed.

4.3.3. Schedule Generator Layer

The Schedule Generator layer is in charge of the main business logic. A key block of this layer is the Factory Planning (FP), which implements the logic for each factory planning to be automatized by the APS. The number of instances of this block in the layer is variable depending on how many optimization points the APS implements. This is represented on Fig. 2 as cardinality next to the Factory Planning block.

In order to cover the extension of the system to include more than one Factory Planning, a good development practice is to employ a technique allowing a seamless and easy integration of the new block by reusing the components having the same average internal structure; then the suggestion is to use component-based design together with object-oriented interfaces.

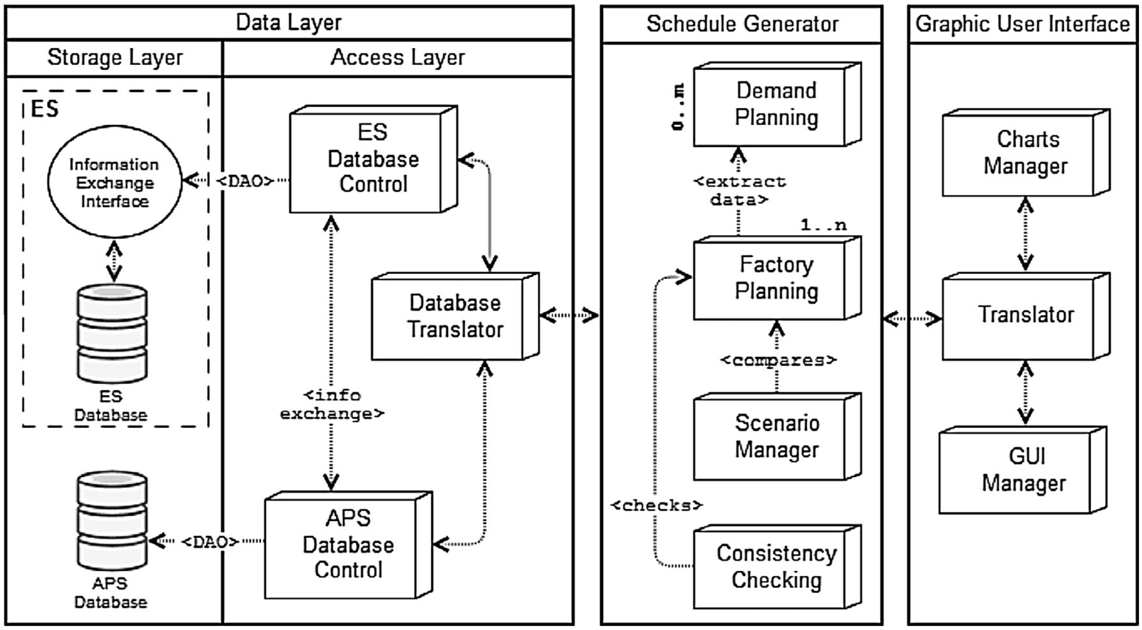

Fig. 2. Proposed generic *n*-layered reference model for a Software Architecture of an APS.

The Demand Planning (DP) block is needed only for the cases where a FP instance works with demand forecasts (meaning a Make-to-Stock process); therefore, an FP that optimizes a point that works as MTO (Make-to-Order) or ETO (Engineer-to-Order) does not need the corresponding DP (Kilger & Wagner, 2015). As a consequence, it is not necessary to have a correlation between the number of FP and DP blocks, hence the difference on the cardinalities of both blocks.

The third block is also related to FP, and is named Consistency Checking (CC); it is a consequence of several Functional Requirements from Table 3, such as 'Consistency Check' and 'Bottleneck Detection', because it contains the logic to implement those requirements.

The final block on this layer is Scenario Management (SM), and is associated with several Functional Requirements of Table 3, such as: "Scenario Generation", "Scenario Storage" and "Scenario Comparison". This block is in charge of the logic for the management of scenarios, as stated on the mentioned requirements.

4.3.4. Graphic User Interface

This layer encloses the logic for the Graphic User Interface, and should be compliant with the Quality Attributes of Usability and Performance, among others. Its goal is to provide an effective, complete and easy-to-use GUI giving equally varied and complex solution representations (Framinan & Ruiz, 2010).

Three blocks are proposed for this layer which are: Charts Manager, Translator and GUI Manager. While Charts Manager has the logic for managing different charts that are available to show the results, it needs the Translator block to convert data into a graphical representation in the format needed for the GUI. Finally, the block GUI Manager contains the logic for the rest of the graphic interface not directly related with charts.

Also, the Translator block should take care of the interaction with the Schedule Generator Layer.

More specific qualities of the GUI should be made such as programming language to be used, available infrastructure, amount of clients, and so on.

5. Conclusions

The present work presents a characterization of the Advanced Planning System from a System Engineering point of view. It provides a set of Functional Requirements (FR), Quality Attributes (QA) and a reference model of the Software Architecture (SwA-RM) for an APS in order to integrate it to an Enterprise System (ES) and, with that, to increase the capabilities of the ES in factory planning processes.

The paper studies the current acronyms and definitions of a scheduling system that exists on the literature, and clarifies its link with several other types of systems, such as MES, BIS and ERP, and among others. It provides a clear definition of Advanced Planning System as an information software system, and not as a mere model to solve a given problem. The proposed definition is also not bounded by the solving approach used to solve the planning and scheduling problem, those can include model and methods of several approaches like mathematical optimization, genetic algorithms, simulation, artificial intelligence and others.

The APS characterization is done analyzing the literature in the area, the expertise of the research group, and using a systemic view and widely-spread international standards of the System Engineering area, such as the SEBoK (System Engineering Body of Knowledge, managed and maintained by the IEEE, among others), the SQuaRE (Systems and software Quality Requirements and Evaluation, ISO/IEC 25010:2011), and the ISO/IEC/IEEE 42010:2011. Such characterization is generic and it is not restricted to any particular case, with the aim of providing a base to bridge the gap on the development of Advanced Planning Systems.

The proposal reinforces the link between Functional Requirements, Quality Attributes and Software Architecture. A given FR is complemented by QA, and has an explicit impact on the architecture. The interrelation between those concepts gives the ability to be adapted – in the future – to specific study cases.

Several future works derive from this research. First, complete the QA specification offering metrics and indicators – based on the ISO/IEC 2502n "Quality Measurement Division" standards – to be able to evaluate them on real systems. Also, a data quality model can be produced based on the same series of standard, to provide a baseline of information quality. Second, advance forward a Reference Architecture, using the 4 + 1 View Model documentation; this is an important and necessary topic to provide frame that could later be specified and detailed for the implementation of each particular case. Finally, the proposed characterization should be evaluated with more detail through study cases, comparing them to current proprietary systems such as SAP APO or Oracle e-Business ASCP, and also using the elicitation of stakeholder's requirements and comparing them to the characterization.

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