A data model for collaborative manufacturing environments

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Abstract

This paper addresses the problem of information exchange required for collaborative manufacturing planning processes at supply network levels. For a few years now, the traditional manufacturing planning paradigm has shifted toward optimizing collaborative plans at the inter-enterprise level driven by cloud-enabled tools (manufacturing platforms), from which the need to share data between networked partners arises to solve intra-enterprise plans in real-time scenarios. Collaboration among enterprises has to increasingly deal with the sharing the information encoded in ontologies. Cloud repositories are seen as collaboration mechanisms whose main aim is to exchange data regardless of their origins and nature. In line with this, industrial planning research is encouraged by solving problems regarding information exchange, sharing and storage in cloud collaborative environments. The contribution of this research paper lies in identifying information used by manufacturing enterprises when they follow their planning processes in a cloud collaborative manufacturing context to propose common formalized data terminologies. This paper introduces a novel data model for collaborative manufacturing environments (CMData) by building a taxonomy of data concepts to represent information about the replenishment, production and delivery planning domains. Although there are standards aimed at exchanging product data that covers different parts of the history of a product from conceptual design to disposal, this proposal is defined as a detailed version of such current standard initiatives covering the specific area in the domain of production planning and supply chain collaboration. Moreover, this proposal complements and gives an answer to the new cloud collaborative business needs from industry. The CMData has the following objectives: (i) to solve problems related with data interpretation; (ii) to solve the sharing between enterprise legacy systems and cloud environments through the mapping procedure and (iii) to identify the required data coming from different enterprises to collaboratively compute the joint planning activities. The proposed CMData are validated through their application in the collaborative production scheduling plan of a second-tier supplier and a first-tier supplier in the automotive industry. Future work and open issues are also discussed.

Keywords: data model, cloud environment, collaborative manufacturing

1. Introduction

In recent years, companies are increasingly working on developing and implementing information-oriented management to support decision making. However, the main problem related to managerial decisions is to organize, structure and manage this information. Palmer and Caldwell (2011) define “pertinent information” as the right information at the right time in the right format. However, employing the right information requires handling, shaping and establishing appropriate tools and mechanisms for proper management.

In light of this, it is worth mentioning that knowledge is considered the key asset of modern organizations and industry (Costa et al. 2016). For these authors, knowledge representation gains a new impetus with the advent of computer age. With the growing adoption of cloud manufacturing environments, new forms of knowledge representation are needed in common data formats. Cloud manufacturing is considered a service-oriented, high-efficiency and low-consumption knowledge-based new mode of networked manufacturing that has been recognized as a transformative model for future manufacturing (Lu and Xu 2017).

In the pursuit of long-term strategic competitiveness, Europe promotes research priorities in the manufacturing scope. One of the megatrends defined by the European Commission leads to high-performance production, in which enterprises have to combine flexibility, productivity, precision and zero-defect. Accordingly, high-performance production has to deal with managing and processing vast volumes of data and information from the factory shop floor up to the supply chain level. One of the major challenges that manufacturing supply chains face today is the growing complexity of replenishment, manufacturing and delivery planning processes, and the vast quantities of information handled in these planning activities. In supply chains, connectivity is a key aspect to achieve the aforementioned high-performance production; thus Enterprise Information Systems (EIS) have to be opened -at the same time as they have to be secure- to facilitate collaboration among different supply chain partners. Enterprise resources, such as machinery, robots, lines, items and workers, form part of the EIS used in production planning processes, and they all need to be connected to one another and to back-end.

Distributed and collaborative applications are being increasingly implemented in cloud technologies. In order to offer reliable and secure services, the cloud-computing paradigm must offer information standards to ensure interoperability in terms of both data and applications. Collaborative and decentralized manufacturing environments are more often supported in cloud infrastructures to allow enterprises of the supply chain to subscribe and consume real-time data. Therefore, the consideration of interoperability concepts in cloud environments will ensure data consumption and processing to compute supply chain planning processes more efficiently and quickly. Along these lines, the Supply-Chain Operations Reference (SCOR), developed by the Supply Chain Council, provides a description of supply chain processes, performance metrics, and best practice and enabling technologies. This terminology supports the decision, arrangement and implementation of supply chain processes (Delipinar and Kocaoglu 2016). The SCOR model is described by the five supply chain processes: Plan, Source, Make, Deliver, Return (APICS 2020), as follows:

- **Plan:** processes that balance aggregate demand and supply to develop a course of action that best meets the established business rules
- **Source:** processes that procure goods and services to meet planned or actual demand
- **Make:** processes that transform goods to a finished state to meet planned or actual demand
- **Deliver:** processes that provide finished goods and services to meet planned or actual demand, typically including order, transportation and distribution management
- **Return:** processes associated with returning or receiving returned products for any reason. These processes extend to post-delivery customer support

All these processes require planning activities to achieve global supply chain goals. However, the joint and disseminated nature of supply chain manufacturing processes makes knowledge management more complex. In cloud manufacturing, planning activities usually comprise several entities of different natures with several information readiness levels, which means different input data with a different terminology from different entities. To face this difficulty, it is necessary to commonly represent the data required to perform planning optimization.

Zhou, Wang, and Xi (2005) state that the main task for a database design is to map real-world requirements into a formal data model. To do so, Chung and Jeng (2002) describe four main activities: requirement analysis, conceptual design, logical design, physical design. In the present research, the two first activities are analyzed. The requirement analysis focuses on identifying planning needs from two perspectives: literature review and users' real requirements. For this activity, the relevant information needed for planning optimization purposes is collected and analyzed, whereas the conceptual design translates such information needs into a conceptual model to structure the data model.

The CMData plays an important role to define the optimization models and heuristic algorithms created to plan the activities of a company or supply chain. The optimization models and heuristic algorithms are hosted in a cloud environment. With the objective that enterprises use the models and algorithms, a mapping process is applied. This mapping process translates company data into CMData in a way that it could be used to compute the models and algorithms in the cloud. The mapping is done bidirectionally, thus the results of models and algorithms are translated into the company data.

The main aim of our paper is, therefore, to propose a data model to support enterprises' planning processes by considering a collaborative environment. The proposed CMData have been validated in the H2020 European Project "Cloud Collaborative Manufacturing Networks" (C2NET GA:636909, 2017) after considering the intra- and inter-enterprise planning processes carried out by enterprises belonging to different industrial sectors; e.g., automotive, dermo-cosmetics, metalworking, original equipment manufacturer (OEM). Accordingly, the defined CMData enable the information-sharing processes for performing planning, traceability and execution in supply networks by assisting enterprises' decision making. This paper is structured as follows: Section 2 illustrates the scenario that motivated this research and the related works. Section 3 describes the methodology followed to build CMData from academic and industrial perspectives. Section 4 presents the resulting data model for CMData. Section 5 illustrates the validation scenario by implementing the proposed CMData in a collaborative manufacturing planning optimization algorithm. Finally, Section 6 concludes the paper and summarizes future research lines.

2. State of the art

In the last few years, the socio-economic environment has improved through the cloud computing paradigm, which is considered one of the most popular recent innovations to allow computing services to be offered over the Internet (Rodríguez-García et al. 2014). The fact that today's knowledge and service business have increased, along with a cloud-based economy, have led researchers to show concern about managing massive amounts of data, which come from a variety of sources (Beheshti, Benatallah, and Motahari-Nezhad 2016). The literature addresses this current scenario by proposing approaches that deal with topics like interoperability, data model management, ontologies and standardization. The state of the art performed in this paper attempts to identify the gaps in the literature as regards the proposal of data models, particularly in the collaborative manufacturing paradigm. Figure 1 shows the main related approaches found in this review.

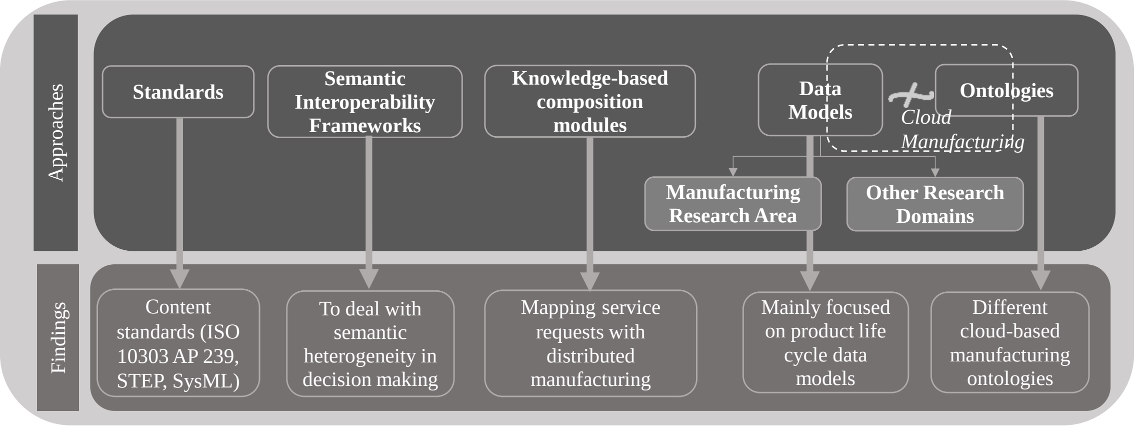

Figure 1. State of the Art Conceptual Model

Firstly, different standards have been identified. Semantic interoperability frameworks and knowledge-based composition modules have been also identified as approaches that present synergistic characteristics to data models. Continuing with the review, data models are analyzed from two perspectives (i) the manufacturing area and (ii) other research domains that provide valuable principles on data models. Moreover, the differences between data models and ontologies are analyzed to shed light on its distinctiveness. Finally, when analyzing data models and ontologies, we have also identified its application in a cloud manufacturing environment.

In order to achieve manufacturing data integrity through a variety of different manufacturing processes, numbers of standards have been proposed by avoiding possible interoperability problems. In a way to classify them, a hierarchical typology of standards is proposed by (Rachuri et al. 2008)

- Type Zero: Standards for implementation languages (e.g., FORTRAN, C, C++, Java).
- Type One: Information modeling standards (e.g., EXPRESS and UML)
- Type Two: Content standards – domains of discourse (e.g., ISO 10303 AP 239, STEP, Systems Engineering Modeling Language (SysML))
- Type Three: Architectural frameworks standards (e.g., Zachman Framework)

Of this typology of standards we focus on the Type Two, highlighting the ISO 10303 standard, which fulfills seamless cooperation and integrates systems with different native languages/standards (Nassehi et al. 2008; Guo, Zhang, and Tao 2011; Valilai and Houshmand 2013). ISO 10303 is informally known as the STandard for Exchange of Product model data (STEP). STEP is an international standard for the representation and exchange of information on industrial products throughout product's lifecycle management (PLM), regardless of any particular information system (Allen, Harding, and Newman 2005).

Subrahmanian et al. (2006) and Rachuri et al. (2008) proposes a map of the major Type Two standards, using two dimensions, see figure 2.

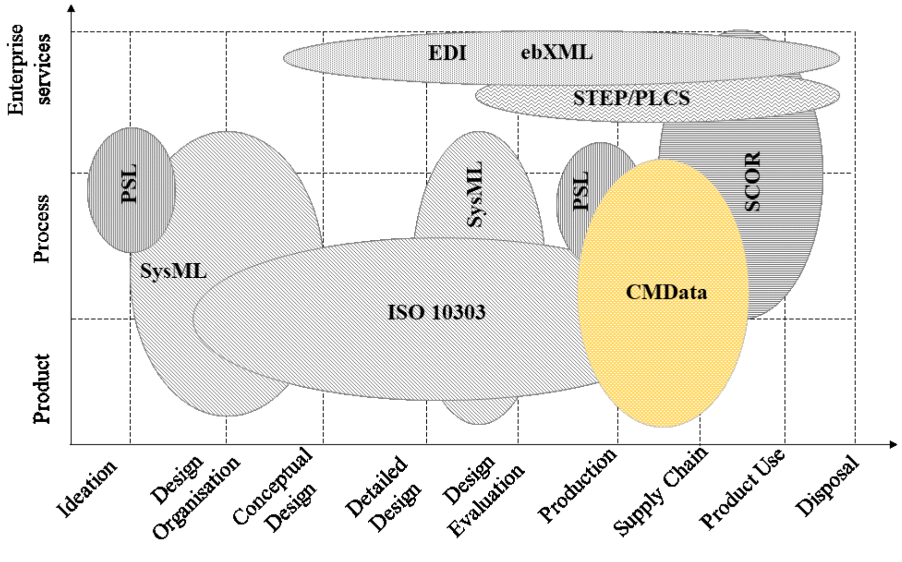

Figure 2. Standards and coverage on product's life cycle (based on Rachuri et al. 2008) and ISO 10303-239 (2012)).

The horizontal axis of the map corresponds to the PLM, and the vertical axis of the map represents three complementary aspects of the information. The figure shows that there is no standard that provides full coverage of the PLM. Using the same map, we consider the CMData to cover a specific area in the domain of production planning and supply chain collaboration, using the different stages of planning operations defined in the SCOR reference model. Accordingly the CMData focuses on the planning operations at enterprise and supply chain level, including source, make and deliver plans and all its variants to deal with collaborative planning, source-make, make-deliver, source-make-deliver (Andres, Sanchis, Poler, and Saari 2017)

Apart from the aforementioned languages and standards, semantic interoperability frameworks are also proposed to deal with semantic heterogeneity in decision making (Eck and Schaefer 2011). Knowledge-based service composition modules are also studied in the literature for their accuracy to map customized service requests with distributed manufacturing capabilities (Lu and Xu 2017).

In the manufacturing research area, the literature review identifies different data models such as the life cycle standard data model (Mandolini et al. 2019) or product data model and data operation developed by Wei et al. (2013) to support product data consistency control; just to mention a few. In addition, valuable knowledge on data models can also be obtained in other research domains. We refer the reader to the following authors analyzed in Table 1 (Arnold and Kunz, 2000; Faraj and Alshawi, 2004; Halfaway, Vanier, and Froese, 2006; Yang et al. 2006; Santodomingo et al. 2014).

The main contribution of this paper is to define and design a data model for CMData. In order to not generate any confusion between data models and ontologies we clarify this issue based on the definitions of Spyns, Meersman, and Jarrar (2002). On the one hand, these authors state that data models specify the structure and integrity of data sets, which refer to the specific needs and tasks that have to be performed in an enterprise. On the other hand, ontologies represent knowledge that formally specifies agreed logical theories for an application domain, which are generic, task-independent reusable, shareable, reliable, portable and interoperable. Although data models and ontologies have different meanings, the review of ontologies may support to outline the proposed CMData, some relevant papers in the literature are Yuqian Lu et al. (2014), El Kadiri and Kiritsis (2015) and Talhi et al. (2019) that propose ontologies for manufacturing resources in a cloud environment.

Our review also shows the emphasis that the European Commission places on interoperability and the creation of standard data models (Scapolo et al. 2014). Some examples of some research initiatives are the European research projects: Virtual Factory Framework (VFF GA: 228595, 2013) and Virtual Factory Open Operating System (vf-OS GA: 723710, 2017), to mention a few.

Collaboration and manufacturing data integrity play a major role in global manufacturing enterprises' success. With collaboration, new resources can be added to increase production capacity without raising concerns about compatibility. Cloud-based frameworks for manufacturing collaboration enable all manufacturers in a value chain to work together and to collaborate with their demanding customers (Lu, Liu, and Ju 2012). Existing manufacturing systems and cloud technologies enable all supply chain partners to connect and integrate legacy systems with partners using cloud technology. To this extent, Jin (2013) and Sheng et al. (2016) define a common intelligent semantics of a cloud manufacturing service, while Benotmane, Belalem, and Neki (2017) propose a cloud computing model for optimizing a transport logistics process.

Table 1 summarizes the analysis carried out in 33 reviewed papers. The solution type identifies if the analyzed paper proposes an ontology or a data model. Then, it is identified the application on a cloud manufacturing perspective. From the industrial manufacturing scope, different features are evaluated including the product features and PLM, the decision making, and the planning process addressed. Finally, the column of other scopes refers to the other industrial sectors, different from the manufacturing, in which the authors contextualize the paper.

Table 1. A review of data models for their application in the cloud paradigm

Author	Solution Type		Cloud Paradigm	Industria Manufacturing Scope					Other Scopes
	Ontology	Data Model		Product Feature and PLC	Decision Making	Planning Process			
						Replenish	Manufacture	Deliver	
Trappey and Trappey (1998)		x		x					
Arnold and Kunz (2000)		x		x					Engineering
Faraj and Alshawi (2004)		x							Construction
Allen, Harding, and Newman (2005)		x		x					
Zhou, Wang, and Xi (2005)		x					x		
Halfaway, Vanier, and Froese (2006)		x							Public Administration
Yang et al. (2006)		x							Electric Power
Firat, Madnick, and Grosof (2007)	x				x				Tourism
Nassehi et al. (2008)		x					x		
Lee (2009)		x		x					
Eck and Schaefer (2011)		x		x					
Guo, Zhang, and Tao (2011)		x	x				x		
Lu, Liu, and Ju (2012)		x	x				x		Electronic
Jin (2013)		x	x			x	x		
Li, Xie, and Sang (2013)		x	x	x			x		
Valilai and Houshmand (2013)		x	x				x		
VFF GA: 228595 (2013)		x							Factory Design
Wei et al. (2013)		x	x	x					
Yuqian Lu et al. (2014)	x		x				x		
Santodomingo et al. (2014)	x								Energy Smart Grids
El Kadiri and Kiritsis (2015)	x			x					
Costa et al. (2016)	x								Construction
Sheng *et al.*, (2016)	x		x		x				
Benotmane, Belalem and Neki, (2017)		x	x					x	
C2NET GA:636909 (2017)		x	x	x	x	x	x	x	
Y. Lu and Xu (2017)		x	x		x		x		
Bruno, Taurino, and Villa (2018)		x		x			x		
Izhar and Apduhan (2018)	x		x		x				
Yuqian Lu, Wang, and Xu (2019)	x		x	x					
Mandolini et al. (2019)		x		x					
Nazarenko et al. (2019)	x	x	x		x				
Šormaz and Sarkar (2019)	x		x				x		
Talhi et al. (2019)	x		x	x					

3. Motivating scenario

The proposal of CMData is reinforced by future trends and positive effects on developing collaborative manufacturing processes in the cloud. Accordingly, Adamson et al. (2017) outline a critical review of recent development and future trends in the cloud manufacturing paradigm, who conclude that: (i) information systems inflict high costs and problems concerning integration, maintenance and data sharing; (ii) from a collaborative perspective, the resource-matching problem between resource providers and resource consumers is a challenging issue to be dealt with; (iii) a company-wide sharing approach for full connectivity, remote access and interoperability for all resources is required (iv) web service technology supports the interoperability of soft resources, but the description of manufacturing tasks is more complex because they often comprise more diversity and semantic meanings; (v) interoperability among systems is necessary; and for this reason a model and/or an ontology is required to define an agreed reference model (Fraile et al. 2019) that encompasses resources, services, business processes and enterprise architectures.

Moreover, driving the development of cloud collaborative manufacturing environments entails a number of foreseen positive effects: (i) vast increasing amounts of data involved in collaborative manufacturing activities, which come in different formats and information systems. Thus cloud manufacturing could facilitate the management and sharing of this information within and between systems of collaborative users in cloud manufacturing environments; (ii) research into interoperability in cloud manufacturing focuses on developing an integrated manufacturing resources' environment by solving incompatibility issues in the heterogeneous data environment of multi-providers; (iii) all the information, descriptions, algorithms, rules, strategies and data that support cloud collaborative manufacturing can be considered to be knowledge, and knowledge engineering and management are crucial for making cloud manufacturing capable of solving collaborative problems intelligently.

Based on the features of the current scenario, the aim of proposing CMData stems from the need for a common terminology in the C2NET project. The main aim of this project was to create cloud-enabled tools for supporting the small and medium-sized enterprises' (SMEs) supply network optimization of manufacturing and logistics assets based on collaborative demand, production and delivery plans. The C2NET Project provided a scalable real-time architecture, platform and software to allow supply network partners to: (i) master the supply network's complexity and data security; (ii) store and share product, process and logistic data; (iii) optimize manufacturing and logistics assets by the collaborative computation of production, replenishment and delivery plans; and (iv) render a complete supply chain management dataset in any decision makers' digital mobile device (PC, tablets, smartphones) to enable them to monitor, visualize, control, share and collaborate such data.

In order to increase the efficiency of using the supply network's manufacturing and logistics assets, optimization algorithms for collaborative manufacturing and logistics processes have been specified and developed withing the C2NET research. This set of algorithms is addressed to solve the different planning problems that are classified according to the SCOR model. Both the planning problems and developed algorithms have provided sets of input data, objectives and output data that require homogenization. This homogenization need has led data categories to be proposed to create a common terminology and to enhance the interoperability, congruity, and coherence of the algorithms' input data, objectives and output data. This has resulted in CMData being developed to provide the data needed for optimization purposes in a structured way; the information in many locations has to be searched, shared, and synthesized whenever necessary, and basically in the scope of collaborative scenarios.

The CMData herein proposed goes beyond the product characteristics and the isolated perspective of planning processes. Accordingly, this paper pays attention to the following statements:

- The proposal of a data model (CMData) is used for modeling and solving purposes at intra- and inter-enterprise levels, as well as replenishment, production and delivery planning problems, and all this from the cloud collaborative manufacturing paradigm scope.
- CMData responds to the characteristics defined for the open standards. Rachuri et al. (2008) define a typology of standards according to the origin, which include (i) open standards; (ii) industry standards; and (iii) de facto standards derived from the consensus and widely accepted and used. Indicating that open standards should ensure that the features incorporated are useful not just for an only enterprise, but also for all the different

enterprises of the supply chain that are affected, and which participate in the planning processes.

- In case different companies are willing to collaborate in the cloud, the CMData is ready since it has been tested in a cloud environment inside C2NET European project.
- It is applicable in the industry and has been created from the industry, involving experts in operations planning.
- It has the scientific and academic rigor, which has allowed to build CMData in collaboration between the industry and the academy.
- CMData has a naming structure that is logical enough so that the semantic search is easy to interpret. In the generation of CMTables and fields, a logical syntax is followed that is made up of a set of rules that govern the structure of the fields, including word order. The logic is built upon a nominal kernel with complements that are placed after it (adjectives, numerals, demonstratives).
- CMData is generated in order to normalize the exchange of information among companies of the supply chain to collaboratively compute replenishment, production and delivery plans. The common thread to compute such plans is the exchange of demand. Transactions between companies are based on the exchange of customer orders and demand plans to calculate the aforementioned collaborative plans.

4. Methodology to define the data model for Collaborative Manufacturing Environments (CMData)

The methodology carried out for building CMData considered two approaches as shown in Figure 3 (Andres, Sanchis, Poler, and Saari, 2017). First, the academic approach that focuses on the literature review of replenishment, manufacturing and delivery planning problems. The modeling and solution approaches proposed in the reviewed papers were analyzed. Second, the main aim of the industrial approach is to identify the plans followed by real-world enterprises, whose solutions are not addressed from an academic perspective given the high particularization and complexity in solving them. The industrial approach provides in-depth view of the planning problems that appear in companies and between collaborative partners of the supply chain from a real and tangible viewpoint. A set of six enterprises was analyzed in terms of planning, and corresponds to these sectors: automotive industry, dermo-cosmetics, metalworking SMEs and OEM equipment manufacturer. The consideration of these sectors is not random, but they belong to the validation of the industrial pilots participating in the H2020 European Project “Cloud Collaborative Manufacturing Networks” (C2NET) (C2NET GA:636909, 2017), the project on which the present work is based and developed.

4.1. Literature review strategy performed in the Academic Approach

Before presenting the strategy conducted in the state of the art, as part of the academic approach, the authors wish to emphasize that the analyzed papers were peer-reviewed to determine their appropriateness for the review scope. The three authors are experienced in the reviewed topic.

First, plans were classified in the SC OR framework (APICS 2020) that comprises make (M), source (S) and deliver (D) plans. The combinations of the previous typologies of plans were also examined to allow the analysis of integrated planning approaches and collaborative planning models, including source-make (SM), make-deliver (MD) and source-make-deliver (SMD).

The main purpose of this study was to select only the papers proposing the models and algorithms that address replenishment, production and delivery plans at two different levels: (i) intra-enterprise level, at which plans refer to a single enterprise; (ii) inter-enterprise level, which addresses plans involving two supply chain entities or more. Thus, we chose only the papers that focus on source, make and delivery plans, and their combinations, and these at both the modeling levels. The next steps were taken to search for papers.

Step 1. Research is limited to those papers published in electronic academic databases, including Science Direct, Web of Science, Scopus, and journal repositories such as IEEE Xplore, Springer and Emerald. The analysis of works covered the period from January 2000 to December 2019.

Step 2. The literature review used the keywords classified according to the plan type (see Table 2); moreover, common keywords were also used, including algorithm, heuristic, industry, mixed integer linear programming, planning and optimization.

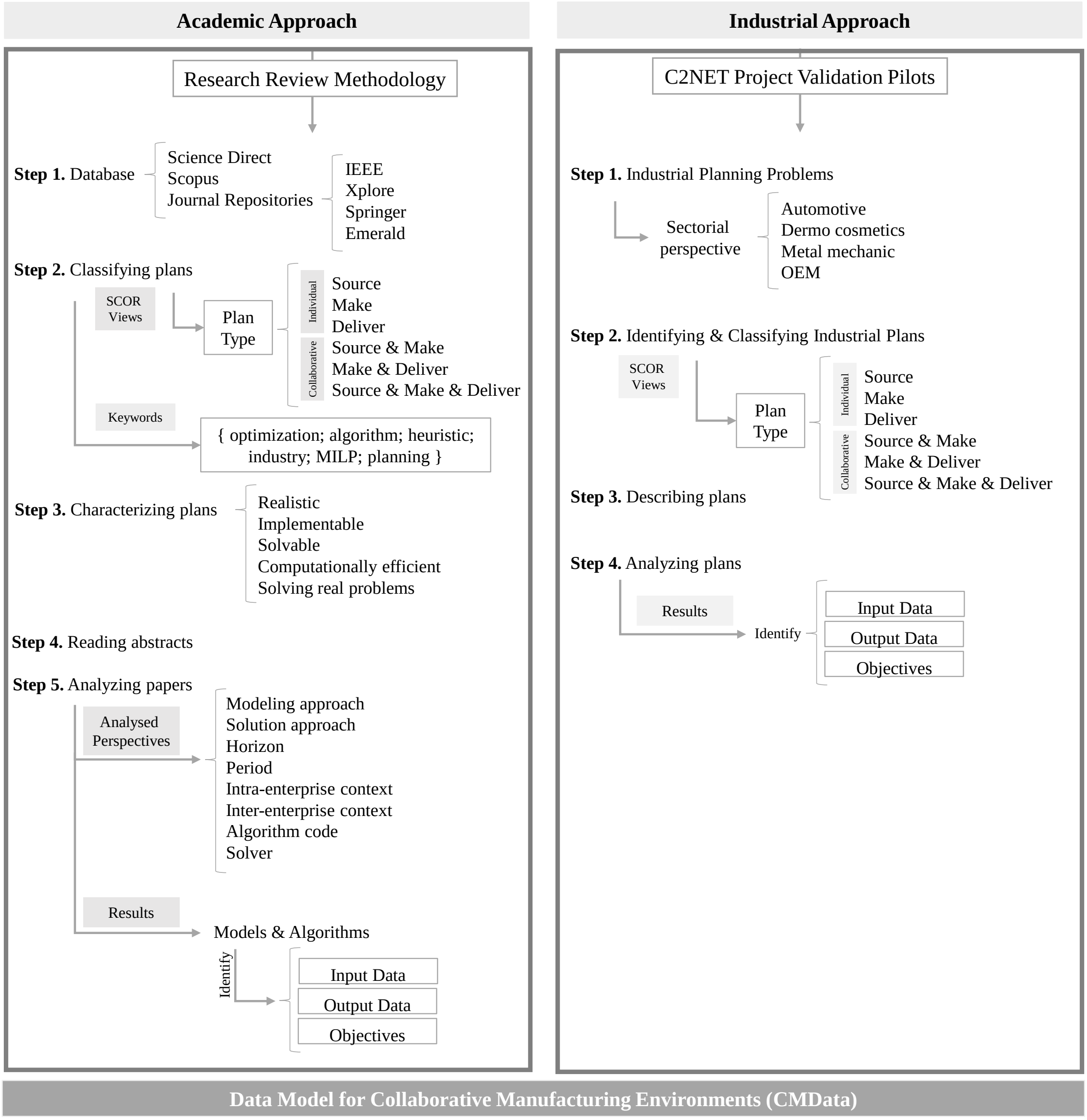

Figure 3. Approaches considered to build CMData

Table 2. Keywords combination. A classification using SCOR Plan Types

Plan type	**Keywords**
Source	*auction; inventory; logistics; procurement; purchasing; raw materials*
Make	*aggregate production planning; flow-shop; production planning, scheduling; sequencing*
Deliver	*available-to-promise; demand management; distribution network; distribution planning; logistic; order promising; route planning; transportation; vendor managed inventory*

Plan type	Keywords
Source & Make	*collaborative; material requirement planning; production manufacturing systems;* supply chain
Make & Deliver	*collaborative; logistics; multi-level multi-objective decision-making; production and distribution planning; third party logistics;* supply chain; *vehicle routing*
Source & Make & Deliver	*collaborative; multi-level multi-objective decision-making; production, replenishment, delivery, routing and inventory management; supply chain*

Step 3. The selected plans are characterized by being (i) realistic, considering real-world problems; (ii) implementable, by using mathematical models and algorithms; (iii) solvable, using large real amounts of data; (iv) computationally efficient, to solve real problems in reasonable times according to the planner's expectations (e.g., if the planner requires a solution of an optimized plan in 1 h, the measure of reasonable time is 1 h, but no longer; if there are algorithms that provide more accurate solutions, but involve a longer time, e.g. 8 h, which would not be a reasonable time for the planner). Additionally, the application of plans to real-world problems was considered a significant criterion to select papers from the academic approach.

Step 4. Reading abstracts and the final selection of papers. Table 3 summarizes the classification, per plan type and authors, obtained from the literature plan. In order to gain in-depth insight into the analyzed models, we refer readers to the corresponding papers by providing a literature source in Table 3.

Table 3. SCOR taxonomy to classify the models and algorithms that solve intra- and inter-enterprise plans

Plan type	Authors
Source (S)	Buffett and Scott (2004); Mula, Poler, and Garcia (2006); Goossens et al. (2007); Yadati, Oliveira, and Pardalos (2007); Sun and Liu (2008); Serna and Marín (2009); Narmadha, Selladurai, and Sathish (2010); Hernando et al. (2011); Liu et al. (2013); Ma and Zhao (2014); Deng et al. (2014); Deng et al. (2014) Nizam et al. (2015); Díaz-Madroñero et al. (2017); Esteso et al. (2019)
Make (M)	Sabri and Beamon (2000); Jang et al. (2002); A. Gupta and Maranas (2003); Hall and Potts (2003); Chen and Lee (2004); Grabowski and Wodecki (2004); Park (2005); Pascual and Doll (2005); Gupta and Magnusson (2005); Hosang Jung and Jeong (2005); Chern and Hsieh (2007); Bilgen and Ozkarahan (2007); Pibernik and Sucky (2007); Kreipl and Pinedo (2009); Leung and Chan (2009); Alemany et al. (2010); Aghezzaf, Sitompul, and Van Den Broecke (2011); Ramezanian, Rahmani, and Barzinpour (2012); Chakrabortty and Akhtar Hasin (2013); Golle, Rothlauf, and Boysen (2014); Franz, Hällgren, and Koberstein (2014); Gansterer (2015); Sun et al. (2015); Grillo et al. (2015); Reyes et al. (2017); Andres et al. (2019); Martín, Díaz-Madroñero and Mula (2019)
Deliver (D)	Disney and Towill (2002); Pibernik (2005); Venkatadri et al. (2006); Chan, Chung, and Choy (2006); Schulze and Li (2009); Wang, Lai, and Shi (2011); Yang, Chan, and Kumar (2012); Okongwu et al. (2012); Rim, Jiang, and Lee (2014); Diez, Mula, and Campuzano-Bolarin (2014); Wolfinger, Tricoire, and Doerner (2019); Chagas et al. (20(20); Gruler et al. (20(20); Maneengama and Udomsakdigoola (2020)
Source & Make (SM)	Giglio and Minciardi (2003); Dong and Leung (2009); Mula, Peidro, and Poler (2010); Mula, Peidro, and Poler (2014); Andres et al. (2016); Hein and Almeder (2016); Díaz-Madroñero, Mula, and Peidro (2017); Wang, Pang, and Ng (2019);
Make & Deliver (MD)	Lee and Kim (2000); Sakawa, Nishizaki, and Uemura (2001); Dhaenens-Flipo and Finke (2001); Lee and Kim (2002); Kallrath (2002); Bredström and Rönnqvist (2002); Perea-López, Ydstie, and Grossmann (2003); Chen and Lee (2004); Gen and Syarif (2005); Park (2005); Ekşioğlu, Edwin Romeijn, and Pardalos (2006); Nafee Rizk, Martel, and D'Amours (2006); Lim et al. (2006); Aliev et al. (2007); Roghanian, Sadjadi, and Aryanezhad (2007); Meijboom and Obel (2007); Rizk, Martel, and D'Amours (2008); Selim, Araz, and Ozkarahan (2008); Jung, Chen, and Jeong (2008); Liang and Cheng (2009); Karimi, Ghare Hassanlu, and Niknamfar (2019)

Plan type	Authors
Source & Make & Deliver (SMD)	Timpe and Kallrath (2000); Jayaraman and Pirkul (2001); Torabi and Hassini (2008); Coelho and Laporte (2014); Liotta, Stecca, and Kaihara (2015); Qiu, Qiao, and Pardalos (2019); Chitsaz, Cordeau, and Jans (2019); Gruson et al. (2019)

Step 5. The review of the papers under study focused on analyzing plans according to the modeling approach, the solution approach, the planning horizon and period, the scope of the application (at intra- and inter-enterprise levels), the mathematical formulation and the proposed algorithm code. In a first attempt to build CMData, an in-depth analysis of each paper was performed regarding the input data, objectives and output data formulated in the models and algorithms proposed by the authors to solve S, M, D, SM, MD and SMD plans. In order to combine forces to complete CMData, the industrial approach is next performed.

3.2. Pilot Plans analysis performed in the Industrial Approach

Some generic problems identified in the literature can solve the problems identified in the project's industrial pilots, while others do not. For this reason, the industrial approach was considered to complete the input data obtained in the academic approach, and to build more accurate and widespread CMData. The industrial approach allows an adequate number of elements to be obtained to build CMData, which are broad enough to serve companies and supply chains, regardless of the sector to which they belong, as a basis data model.

The main aim of the **industrial approach** is to identify the plans that appear in enterprises from different sectors; automotive, dermo-cosmetics, metalworking SMEs, OEM. The attention paid to these sectors was motivated by the work done in the C2NET project; sectors to which industrial pilots belong (Andres, Sanchis, Poler, and Saari 2017). Validation pilots are in charge of testing the innovative functionalities of the tools developed in the C2NET project for their future exploitation in the industrial world. In this vein, some generic problems identified in the literature can solve pilot planning problems, while others are not specifically designed to offer an appropriate response to industrial needs. For this reason, the industrial approach allowed us to identify the replenishment, manufacturing and delivery plans followed by pilot companies. The input received from pilots allowed us to identify those problems that include new restrictions to solve the problems that were not considered in the generic algorithms identified by the academic approach. Accordingly, the industrial approach allowed us to characterize the solutions that were not addressed and solved in the literature for their complexity and particularity, and dealt with the different specifications and constraints that apply to diverse industrial sectors. The input received from pilots allowed us to identify new restrictions to solve the problems that were not considered in the generic algorithms. Table 4 depicts a scheme of the set of plans taken from the C2NET industrial pilots. The industrial pilot plans were classified according to: (i) plan type, following the SCOR classification; (ii) plan subtype, which corresponds to a more precise classification in the type of plan, and overviews replenishment, production and transport plans; (iii) plan description, i.e., the detailed plan performed by industrial pilots is described in each plan subtype, and coincides with the plan followed by each industry. The plans collected in Table 4 were analyzed and grouped for the main aim of obtaining the:

1. Input data needed to compute the plan. Some examples are provided:
    - Needs: Customer Orders, Demand Forecast, Internal Orders
    - Resources: Machines, Labor, Tools, Vehicles, Space, Materials, Energy, Money
    - Methods: Bill of materials, Routes
2. Objectives pursued to meet the expectations of the planners, the company and/or the different entities of the supply chain, such as:
    - Source plans: minimize stockouts of raw materials, minimize backorders, minimize replenishment costs, maximize resourcing benefits, etc.
    - Make plans: minimize production costs, maximize production benefits, minimize setup costs, etc.

   - Delivery plans: minimize delivery times, achieve just in time (JIT) transportation, maximize the service level, minimize the routing time and costs, minimize the transport time and costs, etc.
3. Output data correspond to the plans' solutions; they indicate the amount to be produced, ordered or supplied during each planning horizon period.

Table 4. Plans collected from the C2NET industrial pilots

Industrial Pilot	**Plan Type**	**Plan Subtype**	**Plan Description**
Automotive industry	Source (S)	S/Material Requirements Planning	Replenishment Master Plan Replenishment Plan (2 weeks, fixed; 6-month forecast)
		S/Replenishment Planning	Urgent Replenishment Plan (planning change or stock break)
		S/Capacity Requirements Planning	Components Urgent Replenishment Plan
	Make (M)	M/Production Planning	Master Production Plan (Injection Plan)
		M/Injection Plan	JIT Injection Scheduling
		M/Paint Plan	Painting Scheduling
		M/Spare Parts Plan	Spare Parts Production Plan
	Deliver (D)	D/Delivery Planning	Delivery Plan
Dermo-cosmetics	Deliver (D)	D/Demand Planning	Dynamic Forecast and Replenishment
		D/Order Promising	Continuous Replenishment
		D/Transport Planning	Agile Fulfillment
Metalworking SMEs	Source (S)	S/Replenishment Planning	Collaborative Purchase Plan
	Make (M)	M/Production Scheduling	Production Plan
	Deliver (D)	D/Income Transport Planning	Collaborative Transportation Plan
OEM equipment manufacturer	Source (S)	S/Material Requirements Planning	Purchasing Plan
	Make (M)	M/Production Planning	Production Plan Special Product Testing Plan
	Deliver (D)	D/Demand Planning	Deliver Plan
		D/Transport Planning	Transportation plan

Accordingly, from the pilot plans, a set of input data, objectives and output data was identified by considering a widespread number of scenarios for building CMData. With this approach, the data that pilots provided were checked as enterprises sometimes do not have the available data required by the algorithms and models that they use when solving their plans. The industrial approach enabled us to more precisely build CMData by allowing companies to interoperate with any data framework in the cloud, regardless of the language, nature and sector of the companies willing to connect to cloud services.

As a result of analyzing different optimization and heuristic approaches that can be found in the literature to solve plans, a profound examination was carried out of the plans performed by piloting industries, and a large amount of input data was collected to create CMData. Therefore, by considering the input data, output data and objectives obtained by both academic and industrial approaches, the next section focuses on the description of how CMData were generated.

4. CMData structure

The CMData basis is defined according to a generic terminology that focuses on manufacturing and supply chain needs. Accordingly, collaborative manufacturing tables (CMTables) are created to develop a common terminology in the C2NET project. A structured terminology and the corresponding relational structure were created to gain a shared understanding of all the different needs in terms of collaboration and optimisation of replenishment, production and delivery plans. Although CMData were applied in the C2NET context, the CMTables utilization is applicable regardless of the industry or supply chain involved in the calculation of replenishment, production and delivery plans. Thus, the CMTables terminology contributes to a more application-oriented context among supply chain entities. The hierarchical structure of CMData creation is presented in Figure 4.

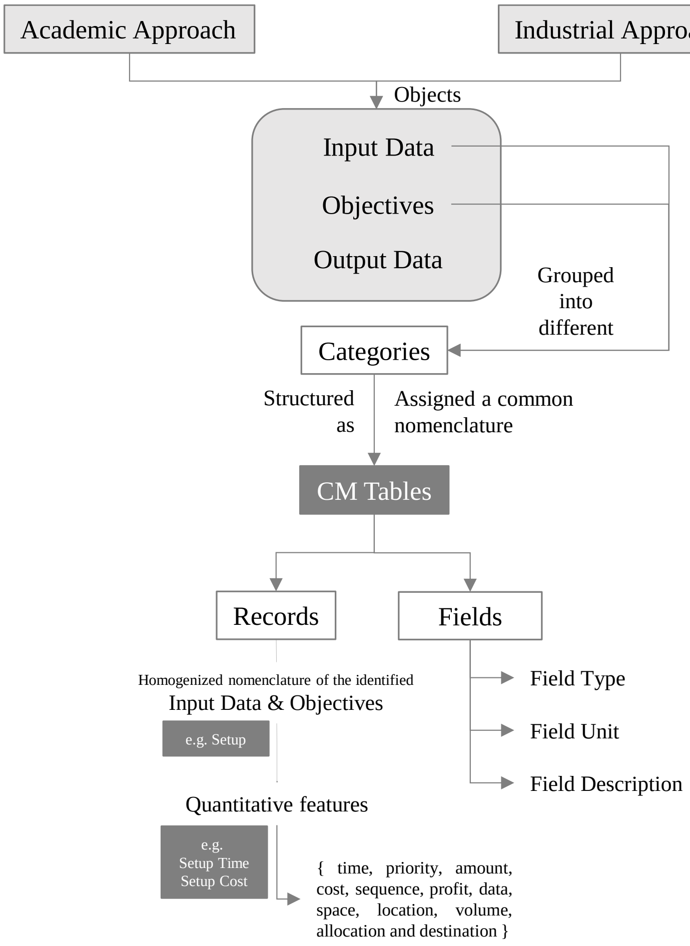

Figure 4. Hierarchical structure of CMData

The academic and the industrial approaches allowed us to identify a set of **objects,** classified into three groups: (i) input data, referring to the data required to compute planning problems; (ii) objectives, regarding the desired results that the planning problems are committed to achieve; (iii) output data, concerning the results of planning problems. Such planning problems refer to replenishment, production and delivery plans, followed at both enterprise and supply chain levels. A set of 223 input data, 69 objectives and 110 output data was identified from analyzing the Pilot Plans and Plans reviewed in the literature. In order to classify these input data, a collection of categories was created, which allows to unify all the terms consistently. The list of categories is taken from grouping the input data and objectives identified in the literature plans analysis (academic approach) and the industrial pilot plans (industrial approach).

Accordingly, all the **input** identified **data** were grouped into **categories**. Grouping was based on the different C2NET project consortium parties reaching a consensus. Consortium parties include pilot industries, users, developers, and researchers, all of who have plenty of expertise in the replenishment, production and delivery planning areas.

The CMData here proposed are structured into tables, each corresponding to each identified category. The terminology by which these tables were designated was also agreed, based on the previously defined categories. CMTables were created to devise a common nomenclature of the categories defined and employed in the planning context. The process allowed searches for compatibilities to avoid any repeatability of previously identified categories. CMTables purpose hosting the format of input data (input datasets structured according to CMTables).

The proposed CMData enclose a set of CMTables, currently composed of 63 CMTables. CMTables are classified into three types

- One-dimension simple CMTables (see Table 5). This type of CMTables refers to one-dimension tables, e.g. “Machine”. This means that the CMTable “Machine” only contains fields related to the object machine. For example, the field “Amount” refers to the number of machines; the field “PurchaseCost” refers to the cost of purchasing a machine
- Two-dimension combined CMTables (see Table 6). This type of CMTables combines two dimensions, e.g. “Machine” and “Tool”, which contain data related to both terms machine and tool. For example, the field “SetupTime” refers to the time required to set up the tool (e.g. a mold) in the machine
- Three-dimension combined CMTables (see Table 7). This type of CMTables combines three dimensions, e.g. “Machine”, “Tool” and “Labor”. This type of CMTables refers to the data of these three terms, machine, tool and labor. For example, the field “SetupTime” refers to the time needed by labor to set up the tool in the machine.

Tables 5, 6 and 7 list the CMTables, which are sorted alphabetically, and come with a brief description. There are 16 main CMTables that represent the main objects (Container, Customer, Labor, Machine, Operation, Order, Part, PartGroup, Period, Route, Site, Supplier, TimeFrame, Tool, Vehicle, Warehouse), 36 two-dimension combined CMTables and 11 three-dimension combined CMTables which associate different objects. The current CMTables and fields allowed us to build CMData, used to represent a complex, and a structured tree of concepts with appropriate relations.

Table 5. One-dimension simple CMTables

CMTable	Definition
Customer	Customers order and purchasing parts from the Company
Labour	The company’s Type of Labor
Machine	The company’s machines
Operation	Generic phase for changing an item from one state to another
Order	Generic Order (from a Customer to the Company, or from the Company to a Supplier)
Part	Generic Part (raw material, component, final product; purchased or sold by the company)
PartGroup	Group of Parts
Period	Periods of time (hours, days, week, months, etc.)
Route	Itinerary of a tour
Site	Site (a location, for a factory, distribution center, customer, supplier, etc.)
Supplier	Suppliers deliver parts to the company
TimeFrame	Generic timeframe
Tool	The company’s tools
Vehicle	The company’s vehicles
Warehouse	The company’s warehouses

Table 6. Two-dimension combined CMTables

CMTable	**Definition**
Customer_Order	Associates an Order with a Customer
Customer_Part	Associates a Part with a Customer (parts purchased by the customer from the company)

Customer_Site	Associates a Customer with a Site
Customer_TimeFrame	Associates a TimeFrame with a Customer (available timeslots for supplying parts to the customer)
Labour_Period	Associates a type of Labor with a Period (the type of Labor can be available, or not, during this period, or another status)
Machine_Container	Associates a Container with a Machine (the machine needs a number of empty containers to work)
Machine_Labour	Associates a type of Labour with a Machine (the machine needs labor to work)
Machine_Period	Associates a Period with a Machine (the machine can be available, or not, during this period, or another status)
Machine_Site	Indicates the Site where the Machine is
Machine_Tool	Associates a Tool with a Machine (the machine needs the tool to work)
Operation_Labour	Associates a type of Labor with an Operation (the operation needs labor to be performed)
Operation_Machine	Associates an Operation with a Machine (the operation needs the machine to be performed)
Operation_Operation	Relate 2 Operations (for establishing sequences)
Operation_Part	Associates a Part with an Operation (the operation needs the part to be performed or generates the part)
Operation_Tool	Associates an Operation with a Tool (the operation needs the tool to be performed)
Order_Part	Associates an Order with a Part (the part should be delivered in such order)
Order_Site	Associates an Order with a Site (the order should be delivered at this site)
Part_Container	Associates a Part with a Container (the part needs the container to be stored or transported)
Part_Machine	Associates a Part with a Machine (the machine produces the part)
Part_Part	Associates a Part with a Part in BOM terms (amount of a part to obtain one unit of another part)
Part_PartGroup	Associates a Part with a PartGroup (group to which the part belongs)
Part_Period	Associates a Period with a Part (information of the part during this period)
Part_Site	Associates a Part with a Site (the site where the part is)
Part_Tool	Associates a Part with a Tool (the part needs the tool to be produced)
Part_Vehicle	Associates a Part with a Vehicle (the part needs the vehicle to be transported)
Part_Warehouse	Associates a Part with a Warehouse (the part needs the warehouse to be stored in)
Route_Vehicle	Associates a Vehicle with a Route (itinerary of a tour)
Site_Site	Associates a Site with another Site (information between both Sites)
Supplier_Order	Associates an Order with a Supplier
Supplier_Part	Associates a Part with a Supplier (parts purchased by the company from the supplier)
Supplier_Site	Associates a Supplier with a Site (a supplier's location)
Supplier_TimeFrame	Associates a TimeFrame with a Supplier (available timeslots for receiving parts from the supplier)
Tool_Labour	Associates a type of Labor with a Tool (the tool needs labor to be set up)
Tool_Period	Associates a Period with a Tool (the tool can be available, or not, during this period, or another status)
Vehicle_Period	Associates a Vehicle with the period (the vehicle can be available, or not, during this period, or another status)
Warehouse_Site	Associates a Warehouse with a Site (the warehouse' location)

Table 7. Three-dimension combined CMTables

CMTable	**Definition**
Machine_Tool_Labour	Associates a Tool and a type of Labor with a Machine (the machine needs the tool to work, the tool needs labor to be setp)
Machine_Tool_Period	Associates a Tool with a Machine during a Period (the machine needs the tool to work during this period)
Machine_Tool_Tool	Associates two Tools with a Machine (indicates sequencing when a tool is set up in the machine with a previous tool)
Order_Part_Site	Associates an Order of the Part with a Site (the part of the order is delivered at this site)
Part_Container_Customer	Associates a Part with a Container and a Customer (the part needs the container to be stored or transported to a customer)
Part_Container_Machine	Associates a Part with a Container and a Machine. Modeling the picking activity whose load and cost depend on the container (unit, pack, factory box, distribution box, pallet) and the machine used to perform the picking activity of the part in the container
Part_Container_Supplier	Associates a Part with a Container and a Supplier (the part supplied by a supplier needs the container to be stored or transported)
Part_Customer_Period	Associates a Part with a Customer during a Period (information on such a part with the customer during that period)
Part_Supplier_Period	Associates a Part with a Supplier during a Period (information on such a part with the supplier during that period)
Route_Site_Site	Associates a pair of Sites with a Route (to create a complete route from the initial site to the end site)
Site_Site_Vehicle	Associates a Site with another Site and a Vehicle (information between both Sites using the Vehicle)

Each CMTable contains different fields “CMTables.fieldName”, including field type, field unit and field description.

- CMTables (Tables 5, 6 and 7) set homogeneous fields with the same structure. Each CMTable contains as many fields needed to store any kind of data from any enterprise. Similar concepts may appear in different CMTables due to specific characteristics from different enterprises. This means that enterprises have to select the fields that better fit their particularities before importing data
- Each record groups the information associated with an element of the CMTable, made up of different fields. By focusing on quantitative peculiarities, a set of terms is used to better characterize fields, including time, priority, amount, cost, sequence, profit, data, space, location, volume, allocation, destination
- Fields are each part in which the information of records is broken down. The record is the basic concept of CMTables, in which CMData are structured. Fields are described using three blocks:
  - field type, which refers to the type of data, which are encoded to ensure the common sharing of data types (Table 8);
  - field unit, regarding the magnitude of data, in which different units are defined and encoded with different values (Table 9). Accordingly, when the user inputs data into CMData, it must be done in the proper units. Thus, the enterprise can manage its information with different units; e.g. weights in grams should be included in CMData as kg to normalize data in CMTables;
  - field description, used to characterize the record representing its meaning

Table 8. Field Type description and codification

Field Type ID	Description
1	String
2	Integer
3	Floating-point real number (e.g. 12.345)
4	Boolean ("true" or "false")
5	Date in UTC as "YYYY-MM-DD" (e.g "2016-01-15")
6	Date and time in UTC as "YYYY-MM-DD hh:mm[:ss[.fff]]" (e.g. "2016-01-15 01:23", "2016-01-15 01:23:45", "2016-01-15 01:23:45.678")
7	Relative date and time as "years-months-days hours:minutes:seconds[.milliseconds]" (e.g. "0-0-1 2:34:5", "0-0-1 2:34:5.67")
8	Relative time as "hours:minutes:seconds[.milliseconds]" (e.g. "1:2:34.56" for 1 h, 2 min, 34 seconds and 56 milliseconds)
9	GPS location

Table 9. Field Unit codification, and description

Field Unit ID	Symbol	Description
1	_	Used for dimensionless values (or unit values)
2	m	Length in meters
3	kg	Mass in kilograms
4	s	Time in seconds
5	A	Electric current in amperes
6	K	Thermodynamic temperature in kelvins
7	mol	Amount of substance in moles
8	cd	Luminous intensity in candelas
9	N	Force or weight in newtons
10	Pa	Pressure in pascals
11	J	Energy, work or heat in joules
12	W	Power in watts
13	C	Electric charge in coulombs
14	V	Voltage, electrical potential difference or electromotive force in volts
15	F	Electrical capacitance in farads
16	ohm	Electrical resistance, impedance or reactance in ohms
17	ºC	Temperature in degrees Celsius
18	EUR	Currency: EUR
19	EURh	Cost per hour (EUR/h)
20	USD	Currency: USD
21	USDh	Cost per hour (USD/h)
22	Tn	Metric Tons
23	Km	Kilometers
24	m2	Area (m*m)
25	m3	Volume (m*m*m)
26	%	Percentage
27	h	Hours (3600s)

Table 10 provides an example with some attributes of CMTable “Part”, as the generic terminology of a product, including raw material, component, final product, purchased or sold by the company. From the example of CMTable “Part”, it is noted that all the CMTables are built to contain at least three main fields: (i) the identifier (ID), shown in the example as “PartID”, which is an integer number to associate the CMData unique identifier; (ii) the code that corresponds to a string data that contains the company's unique identifier to allow mapping between the company data and CMData; (iii) the description, including the company's definition for the record. These three main fields are positioned in the first three places in the table, and the others are listed in alphabetic order.

Table 10. Example with some Part CMTable attributes

fieldName	**fieldType**	**fieldUnit**	**fieldDescription**
PartID	2	1	C2NET unique identifier (auto numeric)
Code	1	1	Company unique identifier
Description	1	1	Company description
AreaConsumptionAmount	3	24	The amount of area (m^2) one part will require
AvailabilityAmount	3	1	Current amount of the parts available in the inventory
AvailabilityCost	3	18	Inventory cost per unit of the part
AvailabilityInTransitAmount	1	1	In the transit inventory for the customer (or from the supplier)
AvailabilityMaximumAmount	1	1	Maximum inventory of parts allowed
AvailabilityMinimumAmountTime	2	27	Minimum inventory allowed (in coverage time), e.g. safety stock
AvailabilityMinimumCost	3	18	Cost per part of having inventory below the AvailabilityMinimunAmount
AvailabilityMinimunAmount	3	1	Minimum inventory of parts, e.g. safety stock
BatchAmount	2	1	Lot size amount of parts taken together
DelayAmount	3	1	Amount of the part delayed
DelayCost	3	18	Cost of delaying the demand of the part (per unit per period)
Dimensions	1	1	Part dimensions
HandlingUnitLength	3	2	Length of the handling unit (part). It is important because it implies a truck requirement: platform meters
HandlingUnitRequirement	1	1	Handling Unit (part) Load/Unload Requirements (Bridge Crane, Stacker, Pallet Truck, etc.)
HandlingUnitType	1	1	Handling Unit (part) type (Pallet, bundle, etc.)
HandlingUnitWeight	3	3	Maximum weight per Handling unit (part)
LeadTime	2	27	Lead time: supply time of the component/raw material from the supplier to the manufacturer // Delivery time of the part from the manufacturer to its customer
NonAvailabilityAmount	2	1	Amount of unavailable parts (i.e. with negative units of the part available)
NonAvailabilityCost	3	18	Cost of part unavailability (i.e. with negative units of the part available)
PurchaseCost	3	18	Pruchase cost of the part
RequirementAmountFinal	1	1	Demand during the period corresponding to that after the last period
SalePrice	3	18	Sales price of the part
Sequence	4	1	1 if the part forms part of the sequence; 0 otherwise
Type	1	1	"Product", "Component", "Material", etc.
VolumeConsumptionAmount	3	25	The amount of volume (m^3) one part will require
WasteAmount	2	1	Amount of the faulty part classified as waste (in the past)
Weight	3	3	Weight of the part

The complete CMData (16 one-dimension CMTables, 36 two-dimension CMTables and 11 three-dimension CMTables, with a total of 183 fields) can be downloaded from https://cutt.ly/wtHOEfh.

5. Application example of CMData in C2NET

In the C2NET project, three main results were developed, namely the C2NET Data Collection Framework (DCF), C2NET Optimiser (OPT) and C2NET Collaborative Tools (COT). These three modules are hosted by the C2NET Cloud-based Platform (CPL), which provides a scalable real-time architecture, platform and software to confer SMEs access to previous modules for optimizing processes.

The C2NET Data Collection Framework (DCF), whose main goal is to collect and process data from IoT real-world resources and legacy systems, is capable of real-time data collection and provides modular architecture envisioning scalability, adaptation and plug-and-play functionality for the interoperability between intra-plant and extra-plant resources. The main DCF components are: (i) the C2NET Company middleware (CM) deployed at the enterprise and responsible for handling the IoT and legacy systems' data communication; (ii) C2NET DCF, which designs to process, transform and infer knowledge from the data provided by C2NET CM (Ghimire et al. 2015; Agostinho et al. 2016; Govindarajan et al. 2016; Mohammed et al.; 2018; Iftikhar et al. 2018).

C2NET Optimiser (OPT) provides advanced optimization algorithms for single and collaborative computations of production, replenishment and delivery plans in order to optimize using the supply network's manufacturing and logistics assets from a holistic point of view. It provides decision makers with a set of tools to easily manage decision rules collaboratively and to recalculate alternative plans in real time by increasing the efficiency of using the supply network's manufacturing and logistics assets from a holistic point of view by the global optimization of operations plans and schedules (Andres et al. 2018; Andres, Poler, and Sanchis 2017; Cunha et al. 2018; Katasonov et al. 2018; Andres, Sanchis, Poler, Mula, et al. 2017; Diaz-Madronero et al. 2018; Sanchis et al. 2018; Andres et al. 2019).

C2NET Collaborative Tools (COT) collect a set of high-level tools in charge of managing the agility of the collaborative operations among supply chain enterprises. These tools are specifically in charge of exploiting the collect data to support enterprises establishing collaborative relationships: from negotiation processes to the collaborative calculation of replenishment, production and delivery plans (Lauras et al. 2015; Benaben et al. 2016; Jiang, Lamothe, and Bénaben 2016; Hauser et al. 2018; Jiang et al. 2017).

Finally, the C2NET Cloud-based Platform (CPL) integrates the data module, the optimizers and the collaborative tools into the cloud. CPL provides all the necessary features to be used by the different manufacturing solutions modules to ensure good availability, scalability and fault tolerance. Through its different modules, CPL optimizes the manufacturing and logistics assets by the collaborative computation of production and delivery plans, while it masters the supply network's complexity and data security (Ferrer et al. 2017; Qureshi et al. 2017; Bendas et al. 2018; Chen et al. 2017). From the initial development phases of C2NET cloud platform modules, the need for making interoperable the data collected from enterprises' legacy systems was identified to achieve the interoperability of all the modules composing the C2NET cloud platform. DCF is the module that contains CMData, in which all the CMTables are included. CMData, and more specifically CMTables, would then be used by the other main C2NET platform modules, such as C2NET OPT, for optimization purposes.

The need for achieving interoperable communication among the main C2NET modules, especially between DCF and OPT, was the reason for defining CMData. Consequently, interoperability is also achieved between enterprises' legacy and C2NET modules. So, this means that the DCF framework is responsible for collecting data from enterprise legacy systems and OPT. The data from enterprises is thus used to optimize the planning processes desired by companies. By paying attention to the C2NET OPT module, a set of algorithms was developed to optimize replenishment, production and delivery plans at both the enterprise and collaborative network levels. In parallel to developing algorithms, and based on the defined homogenized categories, CMData were created and successively updated. The input data, objectives and output data that derived from developing the algorithms allowed the completion and refinement of the data contained in CMData according to OPT module needs.

The following algorithm, developed as part of the C2NET project to respond to a real company's optimization collaborative planning need, was selected as an illustrative example of using CMData in a real case of a production plan, or a Make (M) plan according to the SCOR model. This mixed integer linear programming (MILP) explained in Andres, Sanchis, Poler, Mula, et al. (2017) is related to a multi-machine injection molding sequencing plan, and has four indices for modeling: products (*i*), molds (*j*), machines (*k*), periods (*t*). The objective function of this MILP minimizes the sum of the cost of setting up the mold in a machine, and the product's inventory and backorder costs. The parameters and decision variables are described in Table 11.

Table 11. Nomenclature of the multimachine MILP

Index	
I	Set of products (p)
J	Set of molds (o)
K	Set of machines (m)
T	Set of periods (t)
Parameters	
c_{ij}	Production rate of product i using mold j
ca_t	Capacity of production in hours for period t
d_{it}	Demand of product i during period t
$INVMAX_i$	Maximum available inventory capacity for product i
$INVMIN_i$	Minimum inventory for product i
INV_{i0}	Initial inventory of product i
ci_i	Inventory cost of product i
cst_i	Stockout cost of product i
cd_i	Delay cost of one unit of product i
cs_j	Setup cost of the mold *j*
n_j	Amount of mold *j* available
ns_t	Maximum amount of setups allowed during period *t*
Decision variables	
Y_{jkt}	1 if mold j produces products in machine k during period t, 0 otherwise
S_{jkt}	1 if mold *j* starts producing products in machine *k* during period *t* and during period *t*-1 if it was another mold *j* setup in machine *k*, 0 otherwise
P_{it}	Amount produced of product i during period t
INV_{it}	Inventory level of product i at the end of period t
D_{it}	Delay amount of product i at the end of period t

The objective function (eq. 1) minimizes the sum of the cost of setting up mold *j* in a machine *k*, the inventory and backorder costs of product *i*.

$$Min z = \sum_j \sum_k \sum_t cs_j \cdot S_{jkt} + \sum_i \sum_t ci_i \cdot INV_{it} + \sum_i \sum_t cd_i \cdot D_{it} \tag{1}$$

Constraints are presented in Eq. 2 – 10:

During each period *t*, one or any mold *j* can be produced

$$\sum_j Y_{jkt} \leq 1 \qquad \forall\, t,k \tag{2}$$

In each machine *k*, the available amount of molds *j* can only be set up

$$\sum_k Y_{jkt} \leq n_j \qquad \forall\, j,t \tag{3}$$

Production of product *i* during period *t*, constrained by capacity

$$P_{it} = \sum_k \sum_j c_{ij} \cdot ca_t \cdot Y_{jkt} \qquad \forall i,t \tag{4}$$

The first activation of mold *j* in machine *k* during the first period *t=1*

$$S_{jkt} = Y_{jkt} \qquad \forall\, j,k,t = 1 \tag{5}$$

Setup restriction: 1 when mold *j* in machine *k* is active during period *t*, and was not active during period *(t-1)*, 0 if mold *j* in machine *k*

$$S_{jkt} \geq Y_{jkt} - Y_{jkt-1} \qquad \forall\, j,k,t > 1 \tag{6}$$

Mold *j* setups in machine *k* are limited by the maximum amount of setups allowed during the period

$$\sum_{k}\sum_{j} S_{jkt} \leq ns_t \qquad \forall\, t \tag{7}$$

Inventory balance and bounds

$$INV_{it} = INV_{i0} + P_{it} - d_{it} + D_{it} \qquad \forall\, i, t = 1 \tag{8}$$

$$INV_{it} = INV_{it-1} + P_{it} - d_{it} + D_{it} - D_{it-1} \qquad \forall\, i, t \neq 1 \tag{9}$$

$$INVMIN_i \leq INV_{it} \leq INVMAX_i \qquad \forall\, i, t \tag{10}$$

The main index of the model is mold *j*, which allows molds to be sequenced in a multimachine environment. The number of mold setups during each period is limited by the capacity constraints related to the availability of molds (3).

The application of CMData is shown in Table 11. The first column is the name of the field used by the company, followed by its description in the second column (using the enterprise language). The third column corresponds to the table in CMData where this field is defined following the name of that item in CMData. Moreover for each field, the type and units are defined following the nomenclature of the mixed integer linear programming model for multimachine injection molding sequencing (Andres, Sanchis, Poler, Mula, et al. 2017). The last column is the field description.

Table 11. Application of CMData to the MILP proposed by (Andres, Sanchis, Poler, Mula, et al. 2017).

Enterprise		**CMData**				
Enterprise.Field	Enterprise.Description	CMData.Table	CMData.Field	fieldType	fieldUnit	Descripton
Set of products (p)	Set of products (p) using the to the enterprise codification	Part	Part	2	1	Generic part / product / good, including raw material, component, work in process, final product; purchased or sold by the company)
Set of molds (o)	Set of molds (o) using the to the enterprise codification	Tool	Tool	2	1	The company's tools
Set of machines (m)	Set of machines (m) using the to the enterprise codification	Machine	Machine	2	1	The company's machines / devices used to produce goods
Set of periods (t)	Set of periods (t) in weeks	Period	Period	2	1	Specifies periods of time (hours, days, week, months, etc.)
Production rate	Production rate of products using a specific mold	Part_Tool	NormalOperationAmount	3	1	Amount of the part produced by the tool
Production capacity	Capacity of production (in hours)	Period	NormalOperationTime	3	27	Time available during the period
Demand	Product demand during each period (defined as weeks)	Part_Period	RequirementAmount	3	1	Demand of the part during the period
Maximum inventory	Maximum inventory capacity per product	Part	AvailabilityMaximumAmount	3	1	Maximum inventory of parts allowed
Minimum inventory	Minimum inventory for each product	Part	AvailabilityMinimumAmount	3	1	Minimum inventory of parts, e.g. safety stock
Initial inventory	Initial inventory of each product	Part	AvailabilityAmount	2	1	Current amount of parts available in the inventory
Inventory cost	Inventory cost of products	Part	AvailabilityCost	3	18	Inventory cost per unit of the part
Stockout cost	Stockout cost of products	Part	NonAvailabilityCost	3	18	Cost of non availability of the part (i.e. having negative units of the part available)
Delay cost	Delay cost per unit of product	Part	DelayCost	3	18	Cost of delaying the demand of the part (per unit per period)
Setup cost	Setup cost of the mold	Tool	SetupCost	3	18	Cost of setting up the tool
Molds available	Amount of molds available	Tool	Amount	2	1	Number of tools
Maximum setups	Maximum amount of setups allowed during a period	Period	SetupAmountSum	2	1	Number of setups allowed, at the most, during the period

The process required to upload data about *Enterprise.Field* "*Demand*" on the C2NET cloud platform is depicted in the following diagram (see Figure 5). First of all, from its legacy systems the enterprise selects the legacy dataset to be uploaded and mapped. In this particular case, the *weekly demand* dataset is an Excel file that contains the information required to solve the scheduling planning problem, posed as an example of the validation of CMData. The Excel file collect the *weekly demand* information for the enterprise named *Pilot 1*. The *Weekly demand* file consists of a set of rows with all the *products of Pilot 1*, and columns depict periods as *weeks*. The crossing value corresponds to the *demand* of each product during each period, in this case weeks. Second, the *weekly demand* file is taken and uploaded to the C2NET cloud environment from the *ERP Resource* of *Pilot 1*. Third, a new window for mapping emerges in C2NET DCF. In order to map the field of the *"Demand"* used in the enterprise language, the field *RequirementAmount* of CMTable "Part_Period" is selected. Finally, the Field Mapping window appears and the company field "*Demand*", located in the company data source named *weekly demand*, is mapped to C2NET field *RequirementAmount*, which is contained in C2NET CMTable *Part_Period*.

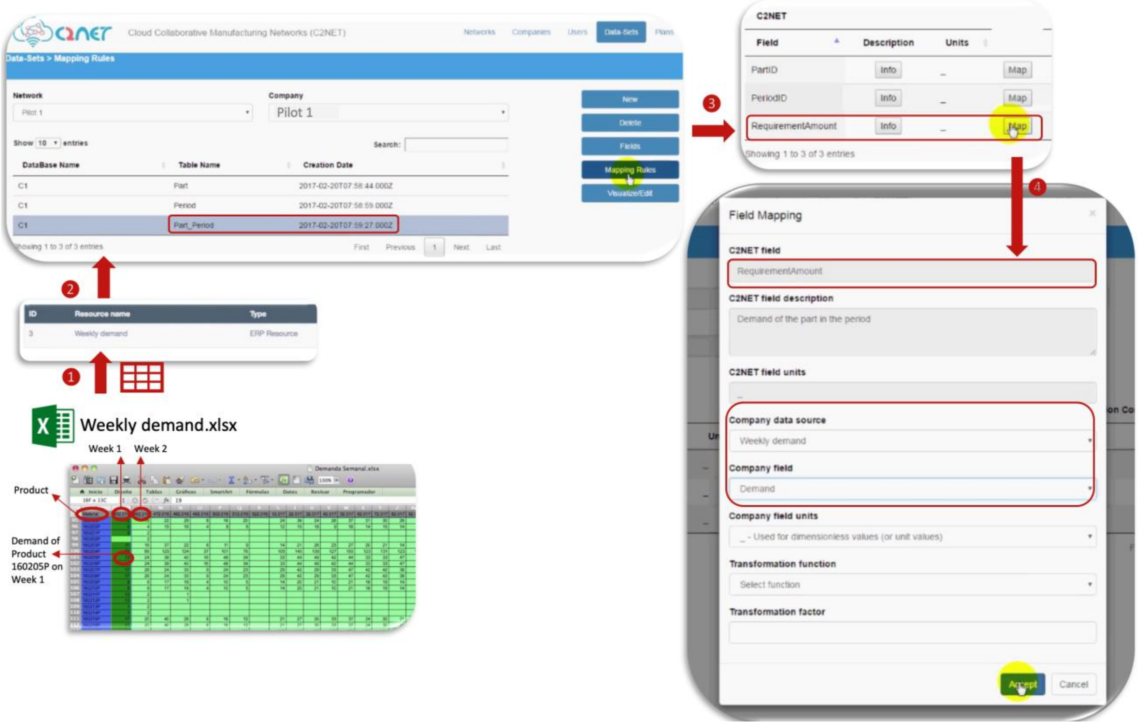

Figure 5. Mapping process to upload the enterprise data in the cloud platform environment using CMData

6. Conclusions

In this paper, a data model for CMData is proposed, whose main aim is to identify the data used by manufacturing enterprises when computing their plans in a collaborative environment. CMData propose common formalized terminologies and fields, which are grouped as tables (CMTables). CMTables allow enterprises to interpret data for the main purpose of making them interoperable for sharing them between enterprise legacy systems and cloud domains. CMTables enabled us to build a taxonomy of data concepts to represent the data about replenishment, production and delivery planning collaborative domains.

A literature review on data models showed that current data models focus only on product characteristics and limit data to isolated planning contexts, but do not consider data on spatial and temporal collaboration; that is, the calculation collaborative plans among networked partners and the computation collaborative plans at different enterprise decision levels. Accordingly, the proposed CMData bridge literature gaps and propose a data model that structures the data required to model and solve intra- and inter-enterprise plans including replenishment, production and delivery planning problems, and all this in the cloud collaborative manufacturing paradigm scope.

The methodology followed for building CMData considered two perspectives, namely the academic approach and the industrial approach. The academic approach enabled us to extract the commonest and the most characteristic data handling from the literature when performing replenishment, manufacturing and delivery planning problems. The industrial approach allowed us to characterize the replenishment, production and delivery plans performed by real-world enterprises, whose solutions are not addressed from an academic perspective given the marked peculiarity and complexity to solve them. The industrial approach was developed in the C2NET project context and in the participating pilot enterprises. Thus the industrial approach provided in-depth insight into the planning problems that appear in companies and between collaborative partners of supply chains from a real and tangible viewpoint (C2NET GA:636909 2017).

From both approaches, CMData were developed to provide, in a structured manner, the data needed for optimization purposes; as information in multiple locations have to be searched, shared and synthesized whenever necessary. CMData consist of a set of 63 CMTables (see Tables 5, 6, 7), where each CMTable contains several field names and their characteristics, including *fieldName*, *fieldType*, *fieldUnit* and *fieldDescription*.

Although the provided version of CMData is a consolidated one, the process of defining CMTables of CMData is not considered to be completely finished; on the contrary, it is being continuous extended and in such a way that new fields may be required to solve replenishment, production and delivery planning problems at both the enterprise and network levels when CMData are implemented into other industrial sectors and contexts beyond the C2NET project's scope.

CMData will enable the following future related research work to be carried out: (i) extend the current CMTables and fields to new contexts; (ii) develop new algorithms to solve planning problems in the scope of the CMData developed in the C2NET project, which are currently not solved in the literature, but are extremely interesting for enterprises in specific sectors; (iii) provide an extendable platform to support enterprises with a high interoperability level to cope with the connected factories concept in order to reach the zero defects goal; (iv) take it as a basic data model to collect data from the physical world in order to create a digital record of operations and networks, apply algorithms and automation to translate decisions into actions in the physical world (iv) apply current CMData to other cloud platforms, such as the "Zero Defects Manufacturing Platform" developed in the ZDMP H2020 project (ZDMP GA 825631, 2020) to allow companies to collaborate to achieve zero-defects manufacturing.

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