

# An Approach to Production Scheduling Optimization

## A Case of an Oil Lubrication and Hydraulic Systems Manufacturer

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**Abstract**—Cloud-enabled tools developed in the Cloud Collaborative Manufacturing Networks (C2NET) project address the needs of small and medium enterprises with respect to information exchange and visibility across the collaboration partners in the supply network, coupled with automated and collaborative production planning and supply management. This paper analyses a case of an oil lubrication and hydraulic systems manufacturer and describes a pilot application of C2NET where the production schedule is optimized according to the priorities of the pilot company. In this case the goal is a highly adaptive just-in-time manufacturing schedule with guaranteed on time delivery.

**Keywords**—supply network; production scheduling; optimization; enterprise collaboration; cloud-supported manufacturing; just-in-time manufacturing; on time delivery; information exchange; Small and Medium size Enterprise; Mixed-Integer Linear Programming

### I. INTRODUCTION

Driven by the globalization and changing market conditions, and enabled by the pervasiveness of the Internet, different supply chains are increasingly integrated with each other and transforming into supply networks [1]. In order to differentiate and compete, enterprises are seeking new collaborative structures to enable them to flexibly respond to market changes, to deliver better products, and to improve their productivity and cost efficiency. Just-in-time manufacturing with fast response times from suppliers, collaborative purchase of raw materials and components are a few examples of the cost-saving goals that may be involved. While traditional supply chains are based on centralized decision making, a larger supply network needs decentralized and collaborative decision processes, as the traditional approach often results in large inefficiencies in the performance of the entire network [2].

In such an environment, a smooth and efficient information exchange among the collaborating enterprises is of crucial importance [3]. The information systems of network participants need to work together, and this issue is increasingly significant not only for large scale enterprises but for companies of all sizes [1]. On the other hand, many small and medium enterprises (SMEs) are still relying on emails and

spreadsheet documents for interaction with their customers and suppliers. This typically makes the communications slow and, as a result, the planning processes rigid. When developing new infrastructure for SMEs the interaction of new tools and current legacy systems has to be enabled. Also the transition needs to be lean with minimal effect on business continuity, downtime and cost [4].

This paper describes a pilot application enabled by cloud-enabled tools created in the Cloud Collaborative Manufacturing Networks (C2NET) project [5]. The case is an oil lubrication and hydraulic automation manufacturing SME in Finland. The use case in this paper includes production planning with an optimization algorithm. In this paper optimization algorithm refers to a mathematical formulation of one or more problems with supporting calculations. Resource/process optimization is one of the value drivers for the digital transformation in the manufacturing industry. This digitalization of the industry is also known as Industry 4.0 based on the definition presented in [6]. Finland is one of the countries with highest readiness level for Industry 4.0 [7].

This paper argues that the C2NET platform is capable of addressing the needs of SMEs with respect to information exchange and visibility across a supply network, coupled with automated and collaborative production planning and supply management.

### II. THE CASE

#### A. The Company

Fluidhouse Ltd. (<http://www.fluidhouse.fi>) is a Finnish Original Equipment Manufacturer (OEM) with over 40 years' experience in the design, manufacturing, and project management of oil lubrication and hydraulic automation systems for challenging industrial conditions. The design and manufacturing of these systems requires a high degree of variability and customization to adapt to diverse needs and applications of a particular customer. Customization and On

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The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement n° 636909, correspondent to the project shortly entitled C2NET, Cloud Collaborative Manufacturing Networks.

Time Delivery (OTD) are both natural parts of the requirements customers place on Fluidhouse. The assembly of lubrication and hydraulic systems also involves the use of a large number of various components, for provision of which Fluidhouse has to rely on a wide network of suppliers.

What makes this case particularly interesting in the context of this paper is that Fluidhouse is a small company (around 30 employees) that makes large and expensive units. A lubrication unit for the use in a paper-making plant can be as big as 40 m<sup>3</sup> [8]. Given a limited production floor space, *just-in-time manufacturing* is the only option for the company. The products have to be assembled as close to the delivery date as possible and shipped away as soon as possible to free the floor space for other projects to use. Unnecessarily early assembly starts or delivery delays may seriously hinder the company's order throughput and thus revenue.

In addition, some of the components coming from suppliers are big in size as well. This, in particular, concerns liquid tanks that can be as big as 10.000 litres. Therefore, Fluidhouse has to aim at receiving the components from suppliers just shortly before a particular assembly starts, otherwise significant inventory costs incur. It is also clear that no SME is willing to receive an invoice of any subcomponent before they can ship the end product to the customer – with an invoice. This fact, combined with the aforementioned high degree of customization needed to each product, which prevents pre-defined Bills of Materials (BoM), requires Fluidhouse to manage its relationships with suppliers as a very dynamic just-in-time process as well.

Limited floor space, limited workforce, limited liquidity and the nature of products and components – all these lead to a need and opportunities for a very dynamic manufacturing process, in which every new customer order is allowed to cause a non-trivial change to the current production plan, and the relevant information related to this order has to be efficiently propagated along potential supply chains to validate a feasible delivery date and to select appropriate suppliers.

### B. Current Issues and the Pilot Goals

Similarly to many existing supply networks, especially those of SMEs, the information exchange of Fluidhouse with its customers and suppliers is not automated. Actually, there is no direct information exchange between the information systems of the involved enterprises. Rather, customer and supplier relations are usually limited to a single person contact and personal communication means such as emails and phone calls. Additionally, these persons change depending on the customer and supplier and thus may have different operation mode and practices.

These practices make communication non-standard, rather slow and the planning processes more rigid than wished for. Updates about a production status, requiring validation or action from the customer or a supplier, are not always conveyed in a timely fashion, causing production delays and other problems. On time delivery of the customer orders is not guaranteed, as a result. When a new customer order arrives, the way it can be incorporated into the current production plan is limited by the fact that making any adjustments to the already

agreed schedules on other orders is a slow and painful process, often not attempted as a result. Thus, the most cost efficient opportunities are routinely dismissed.

The essential problems addressed in the pilot described in this paper, thus, relate to the timely availability of information across the supply network of Fluidhouse, as well as decentralized decision making about production plans and delivery timetables. Specifically, the goals of the pilot are:

- Efficient sharing of relevant information with customers and suppliers, with focus on the visibility of the real-time situation.
- Automated event-based (re-)planning of production, with automated communication of relevant plan data to customers and suppliers.
- Support to decentralized and collaborative decision making about delivery timetables (products to customers, components from suppliers) involved in a production plan.

### III. C2NET APPROACH

Cloud Collaborative Manufacturing Networks (C2NET) project [5] is an EU Horizon 2020 R&D project within the framework of the Factories of the Future (FoF) public-private partnership. The goal of the project is the development of Cloud-enabled tools for supporting SMEs supply network optimization. Such optimization concerns both manufacturing and logistic assets and is based on efficient information sharing and collaborative decision making about demand, production and delivery plans.

To cover different industries and use cases, the C2NET project has four pilots around Europe: i) the Automotive in Spain, ii) the Dermo-Cosmetics in France, iii) the Metalworking SME Network in Portugal, and iv) the Manufacturer of Hydraulics and Lubrication Systems in Finland. The fourth pilot is described in this paper.

The architecture and technical decisions implemented in the C2NET platform define an overall framework, within which the needs of pilots are addressed. Without going deep into the details of the C2NET platform, its most important features are the following:

- All C2NET tools are deployed in a cloud and provided as Software-as-a-Service (SaaS) to enterprise networks.
- C2NET defines a general uniform data model for manufacturing and supply network data. It is a relational model and is referred to as C2NET standardized tables (STables). STables include concept tables, such as “Labour”, and link tables such as “Operation\_Labour”.
- The information exchange among enterprises within a given supply network is enabled via i) setting up for each participating enterprise, within the C2NET Cloud, a database with a relevant subset of STables, ii) Extract-Transform-Load (ETL) of relevant enterprise data into that database, and iii) management of access rights and conditions for when and how one enterprise within the network can access data from the database of another

enterprise. The Extract step is performed by C2NET data extraction tools – Legacy Systems Hub and/or Internet-of-Things Hub – deployed in a company’s own network, while Transform and Load steps are then performed in a rule-based fashion by the C2NET components.

- Any relevant plans, e.g. demand, production, delivery, are encoded within the C2NET STables model containing also special multi-concept link tables. Plans can be imported from enterprise systems or produced within the C2NET platform, and then communicated to other enterprises in the network.
- C2NET provides an explicit support for defining planning or optimization problems and for automated execution of various planning or optimization algorithms. C2NET has tens of algorithms solving plans that are classified to source, make and deliver according to Supply Chain Operations Reference Model (SCOR) [9, 10]. The C2NET algorithms are primarily developed in Julia [11], which is a high-level, high-performance dynamic programming language for numerical computing. Time-based, event-based, and manual execution of planning tasks is also supported.
- C2NET provides an explicit support for orchestration and execution of cross-enterprise human collaboration processes, specifically in relation to sharing, modifying and negotiating about various plans.

#### IV. PILOT

The collaborative planning context of Fluidhouse within the C2NET is depicted in Fig. 1. Fluidhouse, its customers and suppliers are meant to interact via the C2NET. Fluidhouse continuously updates to C2NET its current capacity constraints and delivery items. Customers submit their orders (or customer Demand Plans), ideally directly into the C2NET, however, more realistically, via enterprise systems of Fluidhouse or the customers own systems. Based on new incoming orders, the overall Delivery Plan is updated, which is shared with customers via C2NET. Based on the Delivery Plan, as well as stock levels and capacity constraints, Fluidhouse executes a production (re-) planning task. An important subset of the resulting Production Plan are the dates when components have to arrive, which are sent forward to the potential suppliers as Fluidhouse’s Demand Plans. Customers and suppliers may simply accept plans as proposed by Fluidhouse, or suggest modifications, in so starting a collaborative decision making process.

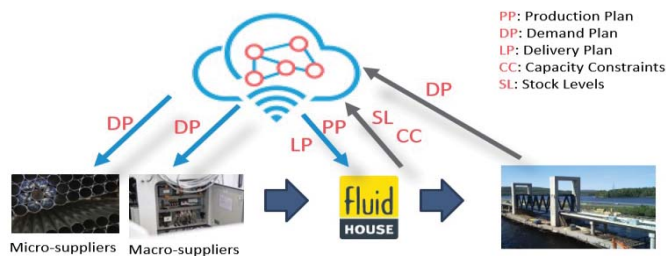


Fig. 1. The collaborative planning context of Fluidhouse.

Production planning is automated via an optimization algorithm executed in an event-based fashion (upon an update to the Delivery Plan) by the C2NET platform. The collaborative decision making is to be managed by C2NET Collaborative Tools. Although not explicitly shown in the above picture, Fluidhouse continuously updates to C2NET Cloud also its progress on implementing customer orders, so that the customers can have a visibility to this information and react if needed.

Within this overall context, the pilot focuses on three specific scenarios from the Fluidhouse point of view: i) Order Reception and Delivery Planning, ii) Production Planning, and iii) Purchase Planning. In other words, the first scenario is about the interaction of Fluidhouse and its customers, the third is about the interaction of Fluidhouse and its suppliers, while the second is about the Fluidhouse internal processes, with a focus though on their linkage to scenarios 1 and 2 as well as their visibility across the supply network.

In this paper we predominantly focus on the second scenario, where the main user roles are Fluidhouse Network Manager, Fluidhouse Production Supervisor, Fluidhouse Purchaser, and Customer. The key activities of the user roles are as following:

- The Network Manager (a person with good knowledge of C2NET) configures the links to Fluidhouse enterprise systems and creates the mapping rules from enterprise data to C2NET STables.
- The Network Manager configures the optimization problem, including its objective and conditions for automated execution. C2NET is responsible for the selection of an appropriate algorithm and the validation that all the required input data is present.
- When C2NET solves a planning problem i.e. executes the planning algorithm, the Production Supervisor receives a notification that a new Production Plan candidate is available.
- The Production Supervisor visualises the planning results, modifies if needed, and accepts them.
- The Purchaser receives a notification that a Production Plan has been changed and, thus, actions related to components purchasing are needed (link to Purchase Planning Scenario).
- The Customer receives a notification if any change with respect to their orders is occurring.

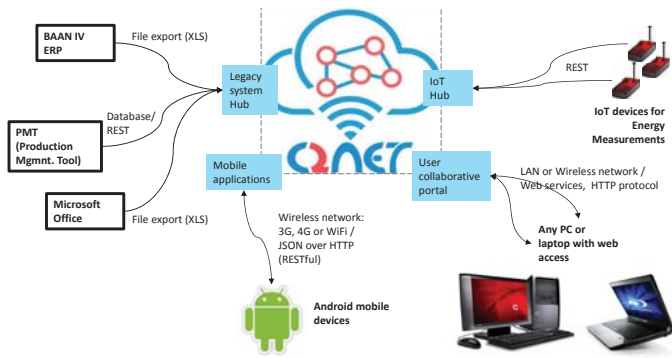


Fig. 2. Pilot interfaces with C2NET cloud.

The interfaces between Fluidhouse and C2NET are presented in Fig. 2. As you can see C2NET is able to retrieve data from various legacy systems via the Legacy system hub (LS hub). The company itself configures its LS hubs and decide what information to file in C2NET. It's obvious that without correct product and order data no optimisation of production can be done. This is the case within collaboration; you need to share information to add collaboration. In C2NET each pilot (four of them) utilises the same service, but the deployment is different. Thus any pilot cannot reach data of another. In addition each company will have own encrypted database although they are using the common C2NET cloud service. User interacts with C2NET via the User Collaborative Portal in a web browser. C2NET sends notifications to users by email and text messages to mobile devices. IoT devices are connected via REST protocol to the IoT hub.

#### A. Representing Enterprise Data in C2NET

This section describes how Fluidhouse enterprise data is transformed for its use within C2NET. For the sake of brevity, we only show here data relevant to the Production Planning Scenario, i.e. the planning algorithm is presented later. The C2NET STables involved in the Production Planning Scenario are listed in Table I. To fill in the STables presented above, the following Fluidhouse enterprise information sources are used:

- A data source with a list of employees and their skills. These data are mapped to Person and Person\_Labour tables.
- A data source with employees' availability in hours per week. These data are mapped to the Person\_Period table.
- A data source with Fluidhouse' Delivery Plan, which includes all relevant data including items to deliver, delivery dates, and estimated assembly and electrical work loads. These data are mapped to the rest of the tables. Each row in the Delivery Plan is represented with a separate Production instance, in so also assuring that each Production has only one type of Part to produce, and thus only has one target delivery date. For each non-zero work load, a row in Production\_Operation is added (note that Operation Stable are for operation classes, not instances).

TABLE I. INPUT DATA FOR OPTIMISATION IN STABLES

STable	Description
Part	A generic thing, e.g. final product, component, or raw material.
Operation	A generic phase for changing a thing from one state to another state.
Labour	Type of work, e.g. design, assembly, electrical.
Person	An individual employee.
Period	A period of time, e.g. a specific week.
Production	A time-limited process of manufacturing a type of products. Includes the possible start date.
Production_Part	States that a Production process has to produce a specific Part. Includes the required delivery date.
Production_Operation	States that a Production process involves performing an Operation.
Operation_Labour	Specifies work load of an Operation in terms of a specific type of Labour, in hours.
Person_Labour	States that a Person is able to perform certain type of Labour.
Person_Period	Specifies availability of the Person in a Period, in hours.

#### B. Production Planning Algorithm

The developed algorithm is a Mixed-Integer Linear Programming (MILP) model for the scheduling of production and human resource. It distributes the work load of production operations among available workers, matching their skills. The output of the algorithm, that is the production scheduling plan, is a four-concept link table as shown in Table II.

Although different variants of the model can easily be obtained by modifying some of the model constraints and/or the model objective, the model exactly as presented below has the following features:

- It treats delivery dates as hard constraints, no late deliveries are allowed.
- It allows overtime / hiring temporary external workers (but does not distinguish these options).
- As the primary sub-objective, it minimises such overtime/external hire cost, thus attempts to meet all the required delivery dates using only available employees within their normal availability.
- As the secondary sub-objective, it schedules productions to start as close to the delivery date as possible, thus minimizing the inventory costs associated with components and final products.
- As the tertiary sub-objective, it favours late idle time for workers to make it easier to accommodate later for new incoming customer orders.

TABLE II. PRODUCTION PLAN TABLE

Field	Description
ProductionID	Link to the Production table, ID of a production.
LabourID	Link to the Labour table, Type of work: assembly or electrical.
PersonID	Link to the Person table, ID of an employee. A special ID is used to denote an external hire need.
PeriodID	Link to the Period table, ID of a period, e.g. week 2017_14
OperationTime	Allocation, i.e. the number of hours that a specific Person will perform a specific Labour for a specific Production within a specific Period.

The MILP model of the planning algorithm is defined as follows. For the sake of brevity, it is a bit simplified here. The model that is actually used, contains additional constraints on the number of workers that can work on a production at the same time, and on the minimum external hire allocation (to prevent the model to suggest very short 'hires').

Sets:

Productions,  $\mathbf{P}$ .  $|\mathbf{P}| = p$

Labours (Work types),  $\mathbf{W}$ .  $|\mathbf{W}| = w$

Persons (Human Resources),  $\mathbf{R}$ .  $|\mathbf{R}| = r$

Time Periods,  $\mathbf{T}$ .  $|\mathbf{T}| = t$

Parameters:

Work load,  $L_{ij}$ ,  $1 \leq i \leq p$ ,  $1 \leq j \leq w$ .

Person skill,  $S_{kj}$ ,  $1 \leq k \leq r$ ,  $1 \leq j \leq w$ , binary.

Person availability,  $A_{kl}$ ,  $1 \leq k \leq r$ ,  $1 \leq l \leq t$ .

Earliest start time (period),  $E_i$ ,  $1 \leq i \leq p$ ,  $1 \leq E_i \leq t$ .

Delivery time (period),  $D_i$ ,  $1 \leq i \leq p$ ,  $1 \leq D_i \leq t$ .

Non-negative variables:

Allocation,  $x_{ijkl}$ ,  $1 \leq i \leq p$ ,  $1 \leq j \leq w$ ,  $1 \leq k \leq r$ ,  $1 \leq l \leq t$ .

Idle time,  $y_{kl}$ ,  $1 \leq k \leq r$ ,  $1 \leq l \leq t$ .

External work (overtime or hire),  $e_{ijl}$ ,  $1 \leq i \leq p$ ,  $1 \leq j \leq w$ ,  $1 \leq l \leq t$ .

Binary variables:

Production start,  $s_{il}$ ,  $1 \leq i \leq p$ ,  $1 \leq l \leq t$ , (1 means the work did not start yet, otherwise 0).

Constraints:

Distribution of production work load:

$$\sum_{\substack{1 \leq k \leq r \\ 1 \leq l \leq t}} x_{ijkl} + \sum_{1 \leq l \leq t} e_{ijl} = L_{ij}, \quad \begin{cases} 1 \leq i \leq p \\ 1 \leq j \leq w \end{cases} \quad (1)$$

Distribution of person availability:

$$\sum_{\substack{1 \leq i \leq p \\ 1 \leq j \leq w}} x_{ijkl} + y_{kl} = A_{kl}, \quad \begin{cases} 1 \leq k \leq r \\ 1 \leq l \leq t \end{cases} \quad (2)$$

Person skill matching ( $M_1$  is any number definitely bigger than a possible sum of allocations for a worker):

$$\sum_{\substack{1 \leq i \leq p \\ 1 \leq l \leq t}} x_{ijkl} \leq S_{kj} * M_1, \quad \begin{cases} 1 \leq k \leq r \\ 1 \leq j \leq w \end{cases} \quad (3)$$

Earliest start constraint:

$$\sum_{\substack{1 \leq j \leq w \\ 1 \leq k \leq r \\ 1 \leq l < E_i}} x_{ijkl} + \sum_{\substack{1 \leq j \leq w \\ 1 \leq l < E_i}} e_{ijl} = 0, \quad 1 \leq i \leq p \quad (4)$$

Delivery constraint:

$$\sum_{\substack{1 \leq j \leq w \\ 1 \leq k \leq r \\ D_i < l \leq t}} x_{ijkl} + \sum_{\substack{1 \leq j \leq w \\ D_i < l \leq t}} e_{ijl} = 0, \quad 1 \leq i \leq p \quad (5)$$

Work can be performed after that a project has been started ( $M_2$  is any number definitely bigger than total work effort on a production at a time):

$$\sum_{\substack{1 \leq j \leq w \\ 1 \leq k \leq r}} x_{ijkl} + \sum_{1 \leq j \leq w} e_{ijl} \leq M_2 (1 - s_{il}), \quad \begin{cases} 1 \leq i \leq p \\ 1 \leq l \leq t \end{cases} \quad (6)$$

A started project must remain started:

$$s_{i,l+1} \leq s_{il}, \quad \begin{cases} 1 \leq i \leq p \\ 1 \leq l < t \end{cases} \quad (7)$$

Constraint 7 is an auxiliary constraint for setting  $s_{il}$  to be 0 for all  $s_{il}$  following the first work allocation.

Objective:

Minimize:

$$A \sum_{\substack{1 \leq i \leq p \\ 1 \leq j \leq w \\ 1 \leq l \leq t}} e_{ijl} - B \sum_{\substack{1 \leq i \leq p \\ 1 \leq l \leq t}} s_{il} + C \sum_{\substack{1 \leq k \leq r \\ 1 \leq l \leq t}} (t - l) y_{kl} \quad (8)$$

Where  $A$ ,  $B$ , and  $C$  are the primary model tuning parameters. It is assumed that  $A > B > C$ .

- $A$  is the weight of “avoid overtime or hire” sub-objective.
- $B$  is the weight of “start close to the delivery” sub-objective.
- $C$  is the weight of “prefer late worker idle time” sub-objective.

After the MILP model as defined above is encoded using JuMP (Julia language package for mathematical programming) [11] notation, it can be executed using several different MILP solvers, including JuMP’s default open-source *Cbc* solver and high-performance commercial solvers such as *Fico Xpress* and *Gurobi*.

### C. Visualization of Production Plans

When a Production Plan has been generated, different interactive visualizations are provided by the C2NET platform. The Gantt chart (Fig. 3.) displays the manufacturing weeks of each product (delivery item) and the work load chart (Fig. 4) the workload of each week.

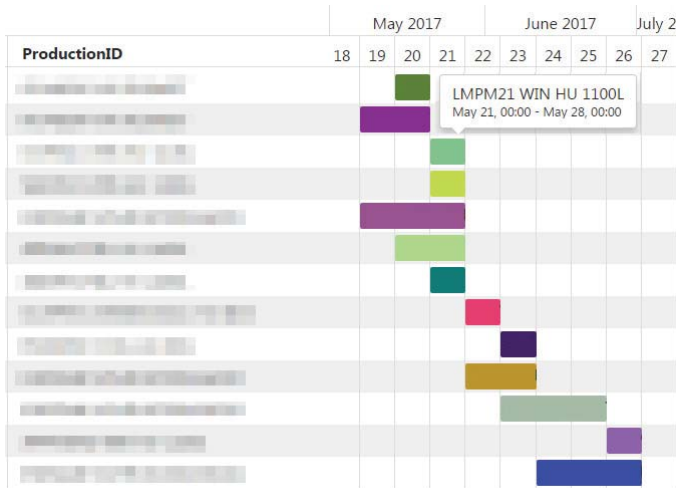


Fig. 3. The Gantt chart visualising a part of the optimised production plan, where rows represent unique delivery items (blurred) and bars the production weeks.

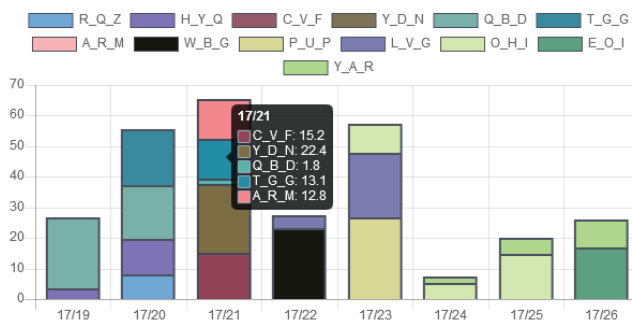


Fig. 4. The work load chart displays the scheduled delivery items (anonymised) and work hours for each week.

Such visualizations greatly facilitate collaborative decision making about the plan. The visualization of solved plans was

requested by Fluidhouse as its personnel are accustomed to work and visualize delivery items in the form of Gantt charts. Additionally, the work load chart allows Fluidhouse to analyse the distribution of labour in an easier manner, further highlighting how efficient the resource allocation is. In Fig. 3. the product names have been blurred as real Fluidhouse data was used as input to the optimization algorithm and anonymised in Fig. 4.

### D. Architectural view

As aforementioned, the C2NET project will provide a smart solution for the chain supply interaction in a cloud-based manner. This objective can be achieved with the platform architecture, which is shown in Fig. 5. The components that are needed in the implementation of the Production Planning scenario are highlighted with red boxes and will be briefly introduced next.

As depicted in Fig. 5, the Data Collection Framework (DCF) is designed to translate and store the companies’ data in the Knowledge-Based (KB) data base. Data can be retrieved from IoT devices or from various legacy systems. If the data is retrieved via Legacy System Hub (LSH) or IoT hub depends on the data resource. Another main component of the C2NET is the Optimizer (OPT), which is responsible for the management of optimization problems. In other words, the OPT allows the user to add optimization algorithms, configure the optimization problem, select input data and run the optimization case. In general the migration steps are initialising, configuring, data processing and (control) executing [12]. Meanwhile, the Data and Knowledge Based Store (DKBS) store both the configurations and the results of the OPT.

The Collaborative Network Management (CNM) and Access Control & Security (AC&S) provide facilities for the overall management of the users and networks in the cloud. In the presented plan optimization, both the CNM and AC&S are needed for allowing the user to access the platform and guaranteeing the privacy and the security of the company data. Finally, the User Collaborative Portal (UCP) represents the user gateway for interacting with the platform. As shown, the user may use a web browser or a mobile app for accessing the platform and exploiting its features.

Aside from the described components, the Platform as a Service (PaaS) provides the deployment of the project components and applications. Meanwhile, the Infrastructure as a Service (IaaS) represents the physical infrastructure of the platform including the computers, servers and network devices. It is important to mention that the production planning scenario does not exploit the functionalities of the Collaborative Tools (COT), which provides both modelling and planning adaptation, and modelling and planning monitoring. This is why the COT is not highlighted with red colour in the figure. Also the Third Party Mediator (TPM), which allows the platform to use a third party services, is not used in this case.

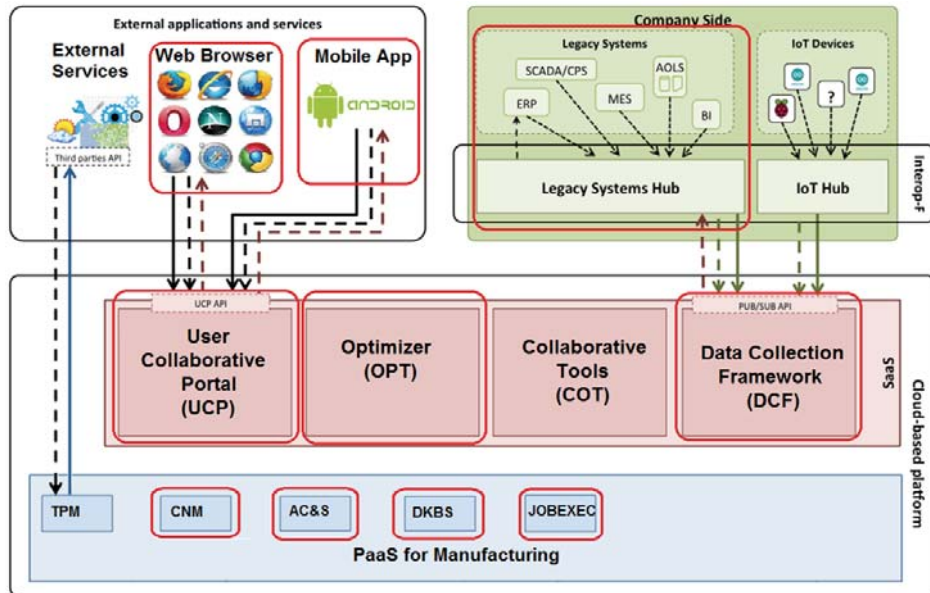


Fig. 5. The components of C2NET that are used for the Production Planning are highlighted with a red rectangle, modified from [13, 14].

## V. VALIDATION

The validation of the production scheduling optimisation use case presented in this paper has two viewpoints: i) validation of optimisation, ii) expected added value of better production planning.

In order to validate the optimisation algorithm, real data exported from the legacy systems of Fluidhouse was used from the very beginning. This enabled us to analyse and develop the optimization algorithm with non-idealized data. The problems with data and intermediate optimisation results were discussed in several sessions between research and industrial partners. Alternative sets of constraints were experimented until Fluidhouse considered the result interesting enough. The results were also analysed by the top management of Fluidhouse.

The developed algorithms has been run exploiting real Fluidhouse data with several solvers like JuMP's default open-source *Cbc* solver and high-performance commercial solvers *Fico Xpress* and *Gurobi*. The experimented commercial solvers were found to be about ten times faster. Gurobi has a more mature connector to JuMP, is more stable and feature-rich (compared to Fico Xpress).

The final validation of expected business impacts will take place during autumn 2017 when both this scenario and the remaining two scenarios will be experimented at Fluidhouse. The expected business impacts are [15]:

- Number of client inquiries will increase 20%;
- Customer satisfaction will increase by 20 points following the customer satisfaction questionnaire;
- On-Time-Deliveries will increase over 5 %;
- OTD deviation will decrease by 2-5 days;
- Number of reclamations will decrease by 10-15%;

- The average time period between order confirmed and order delivered will decrease 20 %;
- Electrical energy consumption in product test area will decrease by 15%;
- Electrical energy consumption in calibration system will decrease by 15%;
- Time spent in rework/repair will decrease by 10-15%.

The final evaluation of expected business impacts will be difficult as the production oscillates depending on demand and all positive impacts may not depend totally on the developed optimisation solution. Anyway, already now it is expected that the goals related to OTD will improve. Optimisation of production schedule enables better resource allocation, minimises space and time allocation for each order as the components needed are available when manufacturing should start, and minimises also the invoices of subcomponents before the product itself is ready to be delivered and invoiced.

## VI. CONCLUSIONS

C2NET platform is capable of addressing the needs of SMEs with respect to information exchange and visibility across a supply network, coupled with automated and collaborative production planning and supply management.

Fluidhouse sees a great potential in the C2NET platform, as it provides the opportunity to increase visualization and collaboration possibilities with customers and suppliers. Once the platform is ready for full deployment, these opportunities are more likely to become feasible. However, before that point is reached there is still future work to be done, including:

- Focus on the other two scenarios of the pilot, i.e Order Reception and Delivery Planning, and Purchase Planning scenario.

- Mobile notifications to customers about production state changes.
- Exporting the optimised Production Plan back into Fluidhouse enterprise systems.
- Exploiting C2NET Collaboration Tools for collaborative decision making with customers and suppliers.
- Developing UIs to the end users on factory floor, including visualizations.

Upon the completion of the aforementioned future work Fluidhouse plans to exploit the projects results by i) improving business relationships with suppliers and customers, ii) evaluating which suppliers fulfil Fluidhouse's requirements and are there worth collaborating with and, iii) further standardising plans and datasets so that integration to legacy systems becomes easier. This will amend the overall optimization of Fluidhouse's production processes and appear as potential increase in the turnover.

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