POLITECNICO DI TORINO

Master of Science Degree in Management Engineering

Master of Science Thesis

Evaluating PLM Implementation in a Medium Enterprise

The cuboGas Case Study

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Academic Year 2019/2020

Abstract

The aim of the thesis is to analyze and evaluate the current PLM (Product Life cycle Management) implementation in a medium enterprise. A case study is taken into consideration: Cubogas S.r.l., the company in which I had the opportunity to carry out an internship, will be examined as a real-life example.

The thesis will analyze the whole process of a tailor-made order and its fulfillment paying close attention to the state of the art of the PLM system and its involvement in the facilitation of the activities necessary to manufacture refueling solutions in the field of methane transportation.

The ultimate objective is to test the usefulness of the system in the company through evaluation of effective indicators, to improve the usage of PLM software in Cubogas and to assess the maturity degree of the company relatively to its processes from the point of view of a PLM application.

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Introduction

The thesis has the objective of finding out how much a PLM system is exploited in a real-life case scenario, specifically in Cubogas, a Snam Group company. It also aims to find out ways in which it could be taken advantage of even further in case of already heavy use.

To contextualize, I carried out a period of traineeship in the aforementioned company, after which I came up with an idea for my master's thesis. I started on September 2nd 2019 and I am still working for the company at this time in an extension of the first curricular traineeship for which my mansion was being part of the procurement department. Cubogas is a company operating worldwide in the production of methane gas refuelling solutions for transportation. Its main products, the ones the thesis will concentrate on, are the large compressors: machines powering the systems for CNG (Compressed Natural Gas) refueling stations.

I arrived at the company about one year after it was acquired by a multinational service company: Snam. The ownership change hit Cubogas worse than expected, in fact it has been difficult for a small production company to cope with a giant, well-structured and bureaucratic business. One of the biggest setbacks was the imposition of a different information system with respect to the past. Snam wanted all its subsidiaries to conform to the use of their ERP (Enterprise Resource Planning) system, namely SAP®, therefore replacing what the company was using at that time: Oracle's JD Edwards.

I was hired by Cubogas about 9 months after the switch off of the old systems, however, I realized that JD Edwards was still being used as a read-only database. This caught my interest and I consequently noticed that there was another kind of software that remained after the acquisition but wasn't as useful as before: the PLM system.

PRO.FILE PLM is a computer program that allows to keep track of every piece of information related to each component (and aggregates) of the very complex machines Cubogas produces. In addition to this, it is a progress tracker for projects, a CAD (Computer-Aided Design) data manager, a PDM (Product Data Management), a collaborative tool, CRM (Customer Relationship Management) support and much more. Thanks to its APIs (Application Programming Interface), in fact, it is used to create web interfaces that can be interacted with through any device.

Ultimately, the thesis will give theoretical and practical advices on how to further exploit the existing PLM system. It will also lay the ground for future works and checks on how the solution is performing by identifying specific Key Performance Indicators (KPIs) which can guide the company through process improvement.

The work could be of reference for an actual implementation of the described solution and it should be treated as first guidelines to present to upper management, company's functions and external information systems contractors to study the feasibility and its cost.

The work will be structured in the following way:

- Chapter 1 - Company Introduction
  The company, a brief history about it and the important acquisition will be presented in order to create the grounds to a meaningful contribution in this kind of environment. Furthermore, the business of the company will be outlined through its products and services in order to give an idea of the order of magnitude of the problem which is being faced.

- Chapter 2 - PLM Introduction
  The other important piece is the PLM system. This chapter describes Product Lifecycle Management in general focusing on the product currently used in the company: PRO.FILE. The program's features are highlighted with the objective of giving an overview of what could be potentially exploited.

After the introductions of the pillars of the work the logical analysis will proceed by describing the flow in order to take apart the whole process.

- Chapter 3 - Process Description
  IDEF0 is the analytical tool chosen to better understand how it all works and be able to focus in the successive steps on the most important functions and the ones that need the most improvement.

- Chapter 4 - Analysis of the Current PLM Solution
  The chapter describes what is currently used of the PLM system in the company, by which functions it is exploited and what purpose PRO.FILE serves.

- Chapter 5 - Proposed Improvements
  In comparison to chapter 3 and 4, this chapter analyzes the proposed process improvements by further exploiting the PLM system. Proposals are for both the life of the product while it's being built in the company and for its useful life beyond the company itself.

- Chapter 6 - KPIs for PLM Benefits Evaluation
  In this chapter, some of the Key Performance Indicators that can be used to evaluate the effectiveness of the improvements are laid out. In addition, the case study of a particular function inside the company is analyzed.

- Chapter 7 - Conclusions
  The last chapter describes the takeaways of the work: how a medium enterprise can improve its processes through an informed use of a PLM system.

Chapter 1 - Company Introduction

In this chapter there will be a brief but meaningful overview of the company. Cubogas' parent organizations, history and products are outlined in order to introduce the environment in which the work has been carried out.

Snam

Snam is the main utility company in the gas sector in Europe. Born in 1941 as *Società Nazionale Metanodotti*, since over 75 years, creates and manages sustainable and technologically advanced infrastructures granting energetic safety.

Snam operates in Italy and through subsidiaries in Austria, France and the United Kingdom and it has the biggest transportation network (over 70.000 km) in Europe.

The multinational is a public company quoted on the Italian stock market with a market capitalization of around 15 billion euros (as of 2020).

Fig. 1: Snam's group main business units across Europe

Snam4Mobility: Natural Gas for Sustainable Mobility

Snam4Mobility is a Snam subsidiary. Its mission is to promote improvements in the natural gas for transport distribution network in Italy, through direct investments and agreements with other operators. Its aim is to support the development of refueling systems and to distribute them in a more balanced way in the country's different regions. It also aims to improve the quality of service provided to end-users.

Snam4Mobility currently has 19 contracted service stations and the opening of the first CNG (Compressed Natural Gas) refueling station was scheduled for the second half of 2018 in Pesaro.

Snam's investments in sustainable mobility come from a partnership with Fiat Chrysler Automobiles and IVECO, which intend to further expand their offer of natural gas vehicles.

With its consolidated and world-leading cutting-edge technology, Snam operates prominently in Italy which is the most profitable European market for methane fuel consumption, with over 1 million vehicles currently on the streets and about 1.200 distributors in operation.

Compared to traditional fuels, natural gas cuts down particulate emissions and significantly reduces carbon dioxide and nitrogen oxides, also allowing significant savings when filling the tank.

Snam Invests in Sustainable Mobility: The New Cubogas is Born

In July 2018, Snam, through the newly created company Cubogas S.r.l., wholly-owned by Snam4Mobility, completed the acquisition of the business branch dedicated to technological solutions for natural gas supply stations of M.T.M., a Westport Fuel Systems Inc. company.

Cubogas takes its name from the best-known commercial brand included in the assets acquired. The total value of the transaction was 12,5 million euros.

Thanks to this acquisition, Snam will be able to increase the level of service it offers to investors in natural gas and renewable gas-powered transport, as it will be supplying one of the best technologies for pollution reduction available, one that can meaningfully help in improving air quality.

Acquiring Cubogas was a make or buy decision based on rising maintenance costs: Snam4Mobility is, in fact, a commercial network which leases CNG solutions. Cubogas can help its parent company in their mission by helping them keep maintenance costs low thanks to their expertise and by selling them their complete turn-key packages allowing Snam4Mobility to offer its services for more competitive prices.

Cubogas S.r.l.

Cubogas is a company operating worldwide in the production of methane gas refuelling solutions for transportation. The company is based in Cherasco, Piedmont, and has more than 60 years of experience in the field and has built more than 3.000 stations all over the world. About 65 people are employed as FTE (Full-Time Equivalent) resources and revenues are about 20 million euros.

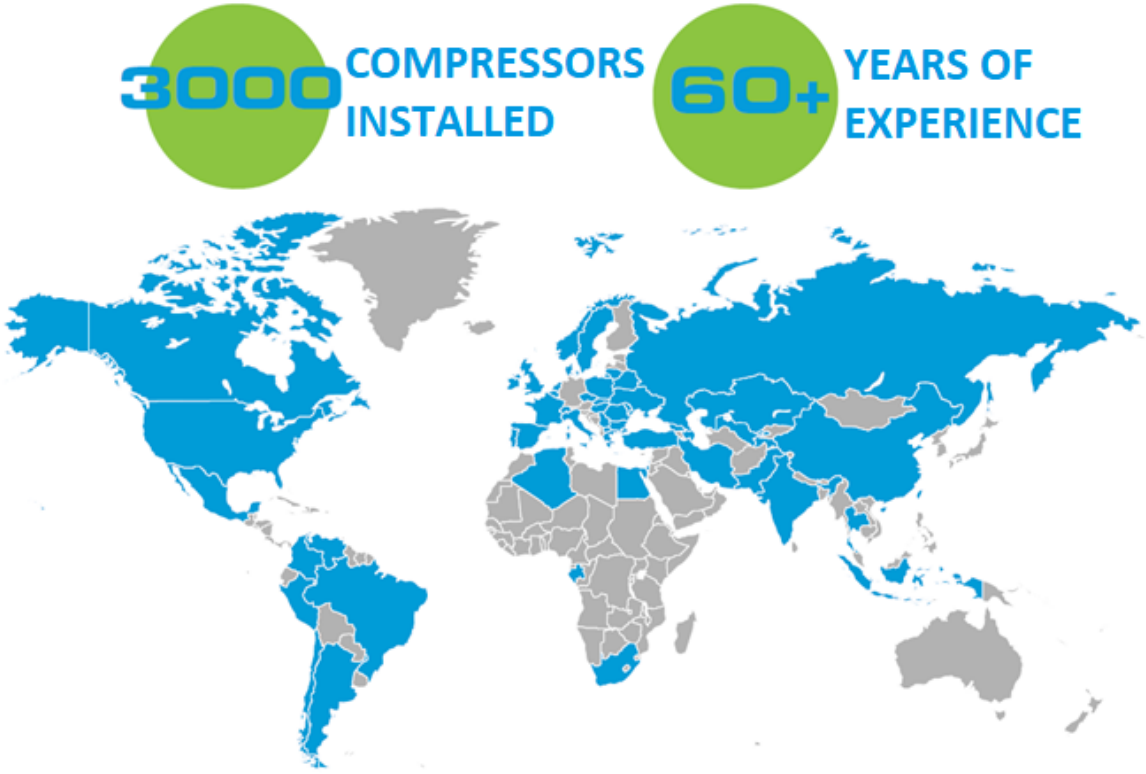


Fig. 2: Cubogas presence in the world

Cubogas operates with the Cubogas and FuelMaker brands:

Timeline

- 1929: Development of the first vertical compressor project for CNG
- 1984: Development of the concept for a Cubogas' vertical compressor
    - More than 2.000 compressor are installed all over the world
    - Focus on the technology for CNG vehicles refueling

- 2004: Nuovo Pignone is acquired from General Electric Oil & Gas
- Until 2012 Nuovo Pignone is the biggest provider of refueling systems for CNG/LPG (Liquefied Petroleum Gas) in the world
    - Expansion of sales of Cubogas' vertical compressors to the whole world (with focus in Iran and Asia)

- 2004: M.T.M. S.r.l. (through the BRC Gas Equipment brand) begins the development of compression and refueling systems of natural gas
- 2009: M.T.M. acquires FuelMaker (both project and brand)
- 2012: M.T.M. acquires Cubogas (both project and brand)
    - M.T.M. S.r.l. becomes the Italian provider leader in CNG refueling systems. It commences development of a network of service companies to offer quick and effective support. It also focuses research on thorough optimization in compressor's design to improve reliability

- 2018: Snam acquires Cubogas from M.T.M.

Cubogas refers to the branches of M.T.M. (part of Westport Fuel Systems Inc.) active in the research, development and production of technological solutions aimed at CNG refueling stations (both commercial and private).

Products

Cubogas, with its turn-key packages, offers state-of-the-art systems that are engineered and designed according to customers' needs. The offer includes:

- Engineering
    - Layout: refueling station analysis and design of possible layout based on standards
    - Design: research and development of a design based on given specifications
- Manufacturing
- Testing: with CNG in real operative conditions in order to release CE (*Conformité Européene*), ATEX (*ATmosphères EXplosives*) and PED (Pressure Equipment Directive) certifications
- Installation and start up: transport, unloading, levelling and positioning of the machine, as well as first start
- Maintenance

These solutions are plug&fill and they are ranked as first degree against solid and liquid particles intrusion in covers and electrical cabinets. Also, the Cubogas Smart system allows to remotely manage and check unit errors and causes of failure.

Even though the company works based on a specific, tailor-made order (as required by the customer) and every final product is basically unique they all follow main trends in the Cubogas portfolio. Hence, the main products are:

- Large Compressors (labelled with the Cubogas brand): vertical compressors and other legacy products (W-shaped and hydraulic). They can be either fueled by methane gas pipelines or by refueling trucks.
  The products in this category usually take 3 or 4 months to be completed from the first interaction with the customer to the final unloading in the site. They are by far the most complex ones of the production. Heavily customized ones can take up to one thousand components.

- The actual manufacturing of a large compressor roughly requires way less time. Usually it takes one week to prepare the majority of components and move them from the warehouse to the building area. Afterwards, one week is dedicated to constructing the compressor, core and most complicated part, to which follows the assembling of the whole large compressor lasting another week. One final week is reserved for testing.
  Since about 30 people work on it, it can be estimated that a large compressor takes 1.000 man-hours of work just to be built. Furthermore, usually about one hundred suppliers are involved in the whole procedure.
  Since a large compressor is a niche product, suppliers have to be carefully selected and certified thus restricting a lot the possibilities. Therefore, the procurement department has to research thoroughly on the daily to expand the list of available suppliers.

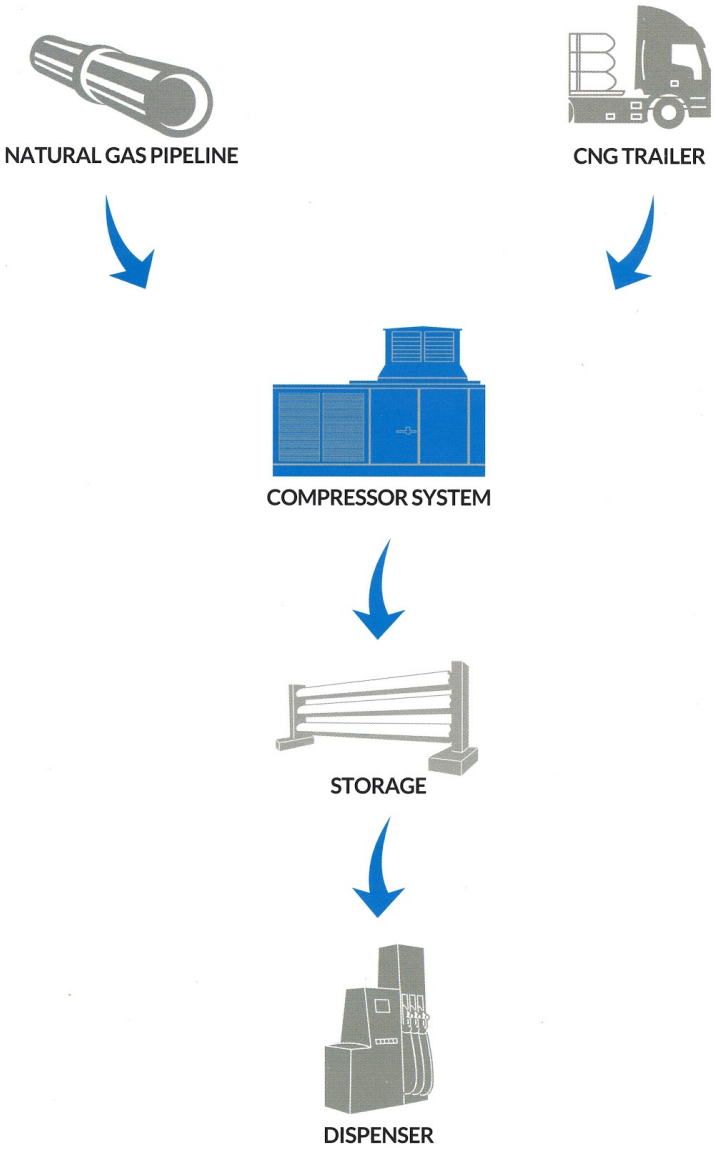


Fig. 3: Cubogas commercial solution

- FuelMaker: Phill (for domestic use) and FMQ 2.5 and 10.0 (for business applications). The FuelMaker family is less complex and therefore takes less time to be built and shipped with respect to a large compressor. While a Phill and an FMQ 2.5 usually take a single day to be manufactured, an FMQ 10.0 takes a couple days instead. FuelMaker is a relatively simple product and it's not customized. The team that builds these machines is made up of up to 5 people. A FuelMaker's product is comprised of a number of components close to 300.

Fig. 4: FuelMaker private solution

Also, Cubogas delivers maintenance services and spare parts for the machines it installed and for third parties' machines.

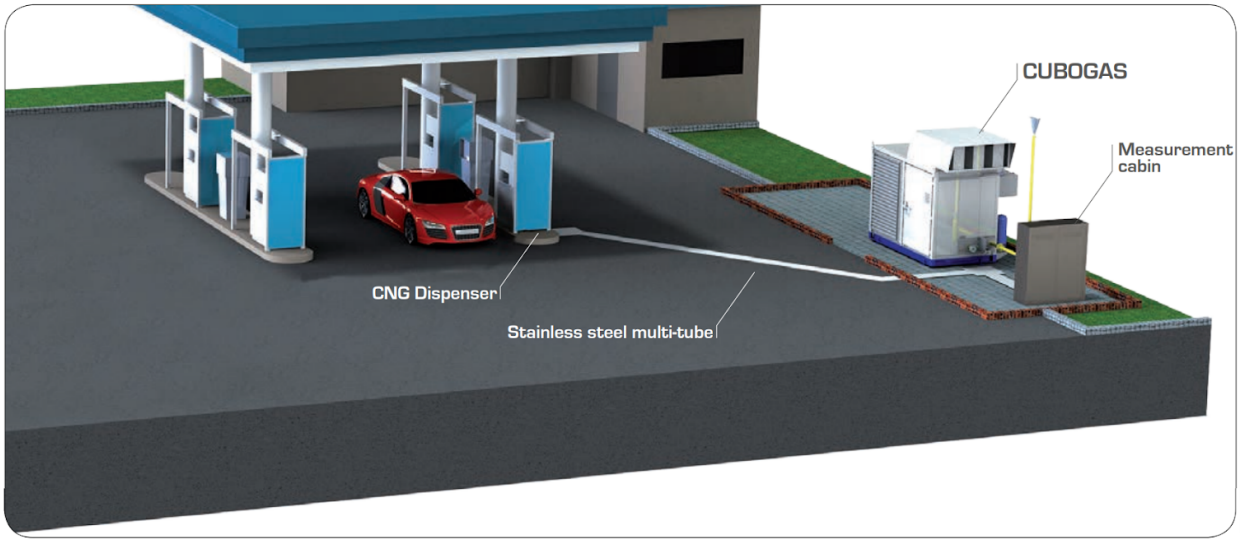


Fig. 5: Cubogas solutions in refueling stations

Large Compressors

Large compressors are Cubogas' most profitable products (making up for about 80% of company's revenue), in the vast majority of the applications conceived to operate in refueling stations. They come in various sizes, power, capacity and degree of integration of the solution.

Cubogas technology allows to greatly improve efficiency and decrease maintenance costs. These compressors are designed to operate 24 hours per day non-stop, even in extreme weather conditions.

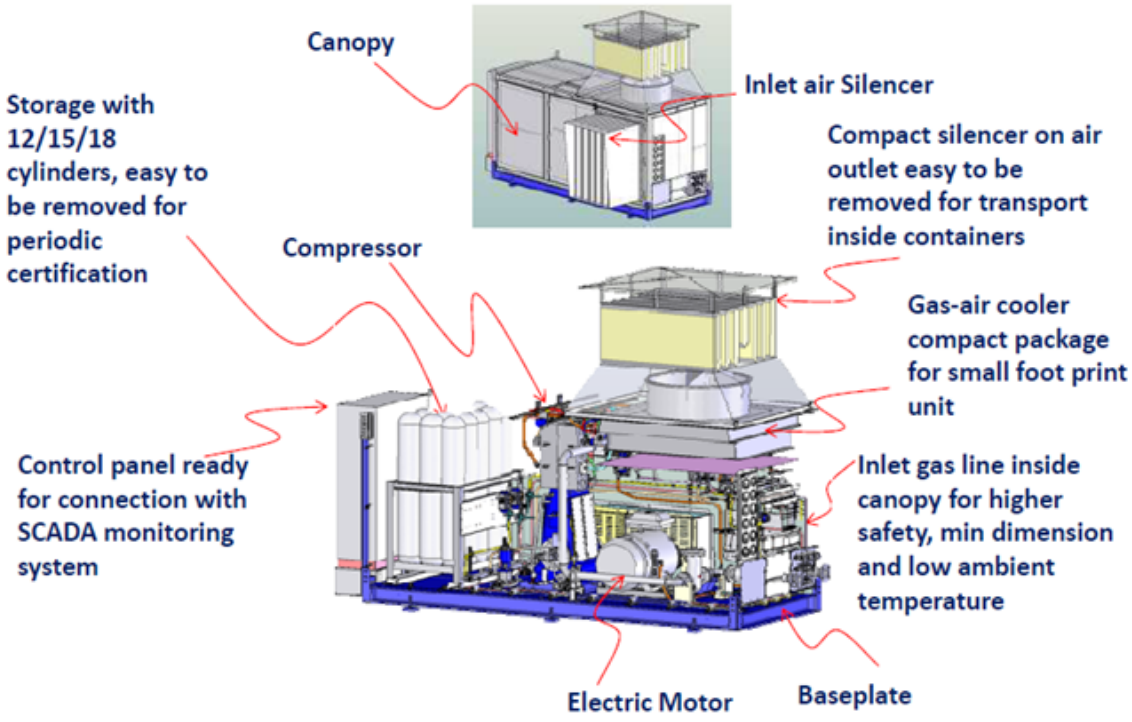


Fig. 6: Section of a Large Compressor

The main shared features among the portfolio of large compressors are:

- Very integrated "Plug&Fill" solutions
- Easy installation and first grade safety
- Cooling system inside the cabinet
- Electric controls with PLC (Programmable Logic Controller) used to analyze the status of the machine and perform some levels of scheduled maintenance autonomously

The A Series and B Series compressors are available in four main configurations:

- Skid only: no external canopy. In this case, the cooling system is mounted vertically to the side of the large compressor
- Steel HT (High Technology): the external cabinet is soundproof and made of steel

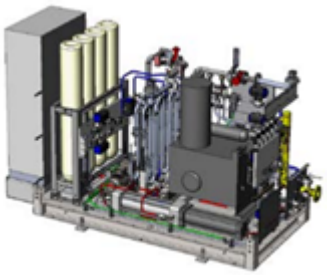
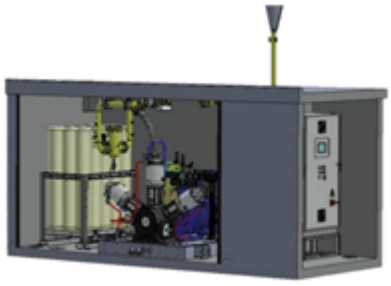


Fig. 7a and 7b: Skid only large compressor (left), Steel HT large compressor (right)

- Concrete HT: the external box is made of concrete
- Double concrete HT: there is a double external cover which can hold two compressors inside



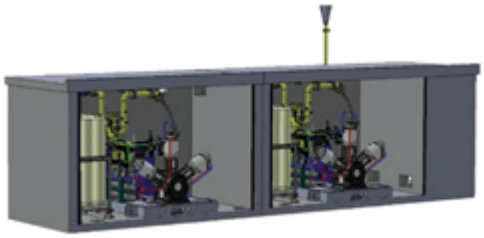


Fig. 8a and 8b: Concrete HT large compressor (left), Double concrete HT large compressor (right)

A Series

Fig. 9: Cubogas A Series compressor

The A Series is a standard Cubogas product. It's suitable for CNG applications up to 110 kW of power. Inlet pressure is up to 100 bar and it has a capacity up to 1900 Sm^3/h. Various customization options are given, for example a soundproof enclosure or the presence of an internal storage. Gas and oil compressor frames are air-cooled.

B Series

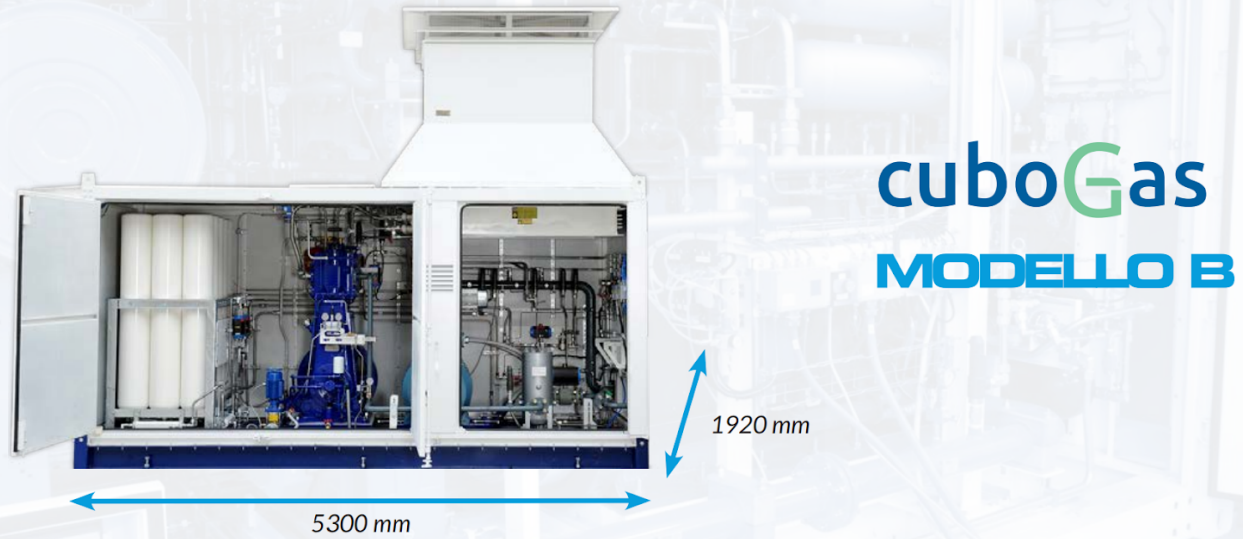


Fig. 10: Cubogas B Series compressor

The Cubogas B Series is the flagship and the biggest series of compressors. It's suitable for CNG applications in a range of 200 to 600 kW of power. Inlet pressure is up to 100 bar and it has a capacity up to 9800 Sm^3/h. Also, water cooling is a possibility.

Pocket

Fig. 11: Cubogas Pocket compressor

Cubogas Pocket has the peculiarity of being a fully integrated unit. It's not only composed by the compressor; in fact, it also includes up to two fill hoses. The internal storage can be up to 640 liters. It's suitable for CNG applications up to 110 kW of power. Inlet pressure is up to 70 bar and it has a capacity up to 1600 Sm^3/h. It's the most compact complete solution and it's easy to install and maintain.

Accessories

Cubogas also sells equipment for refueling stations in order to offer an integrated solution that can be fully customized. End-to-end control of the flow allows to maintain high standards of efficiency and quality which in turns guarantees low operative maintenance needs.

Dispenser

The CNG dispenser features a high-profile cabinet built to withstand harsh conditions while maintaining appealing appearances. It's available in single or dual hose model with flexible tubes inside the internal frame to reduce wear.

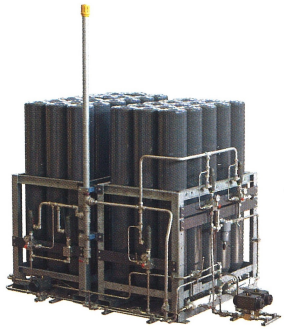
It comes equipped with ergonomically nozzle holders suitable for specific country usage and features multiple pressure levels, flowmeter and electronic temperature compensation.

Fig. 12a and 12b: Simple CNG Dispenser (left), Combined Multi-Fuel Dispenser (right)

Cubogas has always bought dispensers externally to include them in its complete solutions. After a make-or-buy analysis it started designing and developing them internally. This kind of advancement should help the company save about 15% on the cost of the product.

Fig. 13: Cubogas CNG dispenser render

Storage

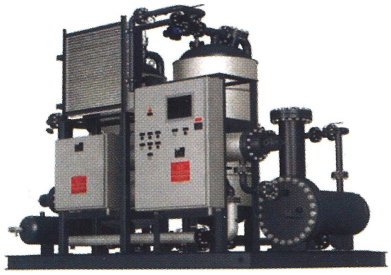


A large variety of storage systems with different capacities are available to provide the best solutions for any type of application. The storage system allows for smooth refueling of vehicles during peak times using stored CNG generated by the compressors during off-peak times.

PED Certified vessels are tested up to 450 bar of pressure.

Fig. 14a and 14b: Old CNG Storage pack (left), new CNG Storage pack(right)

Gas Dryer



A natural gas dryer removes water vapor from methane before it is stored. High water content can obstruct the Compressed Natural Gas in fueling systems and contribute to corrosion in storage vessels and piping.

Fig. 15a and 15b: Old Gas Dryer (left), new Gas Dryer (right)

Chiller

A chiller is an integrated hydraulic group which provides heat recovery for sustainable use of electricity. It is also used to cool down the compressed natural gas to maintain the temperatures needed.

Fig. 16a and 16b: Old Chiller (left), new Chiller (right)

FuelMaker

The FuelMaker portfolio of products is usually dedicated to lighter users such as companies' fleets or private owners. The flagship products are Phill and FMQ. All of these products require no scheduled maintenance, are perfectly safe to use because of many built-in security fail-safes and are very easy to operate.

These compressors don't need particular certifications to be installed since there is no risk of explosion. Notably, the pressure monitoring and control system would immediately block the compression if anomalies were detected.

Phill

Phill is the ultimate stage of compactness when it comes to refueling stations for CNG. In fact, it's a little bigger than 70 centimeters in height, it uses low pressure methane gas from the domestic pipeline and can be put in the garage or outside the house.

Fig. 17: Cubogas Phill

FMQ

FMQ is a compact, integrated compressor made predominantly for business applications such as refuel of a small fleet of CNG vehicles. The FMQ family is also suitable for fast refueling if connected to storage.

FMQ 2.5

The most compact model of the FMQ portfolio is also known as Small Q. It allows for up to two vehicles refueling at the same time and allows for inside and outside use. It's an old design and it will get a complete revamp in 2020 maintaining its capabilities but allowing at the same time for more up to date features: smartphone connectivity, friendly user interface and a more appealing look following what was first introduced by Tesla Superchargers.

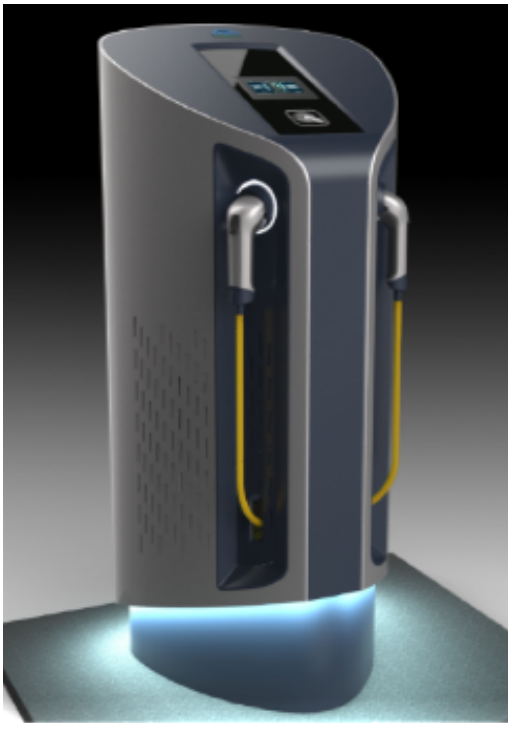


Fig. 18a and 18b: Cubogas FMQ 2.5 compressor (left), Cubogas FMQ 4.0 render (right)

Together with a sleeker design, FuelMaker FMQ 4.0 introduces savings for about 10% on the cost of the product when compared to the old model. Moreover, it adds interactivity through a dedicated application and remote connectivity to safely activate refueling even when not physically there.

Some other optional features will also be implemented for commercial fleets such as: gas consumption accounting and controlled access.

FMQ 10.0

The FMQ 10.0 is a slightly bigger model (also called Big Q) used to refuel up to 4 vehicles at the same time. It is usually operated in small companies that want to have a private and cheaper alternative to gasoline. It's also suitable for outdoor use.

Fig. 19: Cubogas FMQ 10.0 compressor

Chapter 2 - PLM Introduction

PLM (Product Lifecycle Management) is an organizational process that enables the management of a product through its entire lifecycle (design, manufacturing, service and disposal). PLM applications provide a framework for OEM (Original Equipment Manufacturing) companies which allows them to integrate people, data and processes related to the product.

Among the several aims of PLM there are:

- Reduction of TTM (Time To Market) and prototyping costs
- Improvement of product quality and reliability
- Minimization of waste
- Maximization of cooperation among actors within the supply chain

Fig. 20: Product Lifecycle Stages

Introducing and operating a PLM system is very intensive, both on resources and finances of a company. However, after-sales support and customer service are playing an ever more important role as part of the product offering. Data from the product use phase must be linked back to the engineering data to continue to improve machines and make them more efficient and reliable. The ongoing trend of augmentation makes a manufacturer very appealing on the market if its products offer more than the item itself.

Monolithic solutions are no longer adequate in the face of the increased complexity of products and processes. Moreover, no single system is able to cope with all the processes and stakeholders involved in the product life cycle. A PLM architecture has to be based on consistent but extensible structure, while providing functional modules that can be adapted autonomously and flexibly to changing processes and organizational structures.

A successful PLM implementation is more than just a change of application. The new system must be continuously adapted to changing business models and processes. This is only possible in a context of standardized services and role-specific user functions.

The product use phase, about which manufacturers previously had little information, is becoming part of the product life cycle. The optimal PLM system should be able to manage complex product configurations, including electronics and software, and be able to map changes to the configuration in live operation.

The volume of data managed in PLM systems is constantly growing. As a consequence, there is a need to think about how to dispose of out of date data elements and their links even though, to a certain extent, this contradicts the PLM principle of traceability.

Modular product development and modular products are essential, especially in Cubogas, where the aim is to reuse existing assemblies and link engineering with what aims to be a configure-to-order PLM system.

Future PLM stands or falls by the added value it offers users. Developers and design engineers need a working environment in which they can share their work in progress with others without any administrative overhead. This raises the question of how the system can support users better linking information effectively, through the generation of proposals by the system itself and through self-learning mechanisms.

PLM Benefits

The concrete benefits that the investment in a PLM system can give to the company economics are sometimes difficult to evaluate. A PLM strategy, in fact, involves too many components and has an effect on too many different parts of an enterprise to be judged only based on the short-term ROI (Return On Investment) of the company after the implementation of the system.

A PLM system has the aim to allow the integration of many information systems, such as CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), PDM (Product Data Management) and more, together with organizational structure, working methods, processes, routines, people and, last but not least, products. The system's duty is to give a correct access to all the information in the format that every actor involved in the product life cycle needs.

Benefits are hard to measure because changing the labor habits of the employees, implementing the PDM tool and optimizing the workflow are long and complex operations. Milestones may be set but it still remains a complicated and incremental process which can never be deemed as finished.

However, there can be two different categories of benefits:

- Long-term benefits: these have a direct influence on a specific business area. The noticeable improvements are directly reflected on the increased gross margin, improved competitive position and reduced time to market. Also, products' quality should increase as a consequence of better product structure management.
  These kinds of benefits, however, become visible and measurable only several years after the introduction of a strong PLM strategy.

- Short-term benefits: these have a direct influence on low-level processes and routines. The rationalization of the processes bring reduction, for example, in the amount of time spent for everyday activities or in overhead activities. Having a well-organized, well-functioning system which guides an employee in repetitive activities can help reduce costs, avoid human mistakes and has to be evaluated in terms of money time value.
  The efficiency of a PLM system is also found in how fast it allows to retrieve and elaborate information. The improvements of these activities are a reduced cost by themselves, on top of this, however, also reworks tend to cost less when documentation is well organized. Finally, organization is king when it comes to honor deadlines and a PLM system can help set the work and track progress in efficient ways.

A PLM system implementation is hard and not always welcome in a company but when it pays off it does so to a great extent. The improvement of the flow of data has a cascade effect and affects the whole life cycle of future products improving it further in a virtuous effect.

Software Selection Strategy

Back in 2012, Cubogas (then still a branch of M.T.M.) used to manage its projects and related documentation directly in the operating system user: Microsoft Windows through *File Explorer*. There were folders and subfolders for each of the aggregates and components, then, documents were simply stored inside them. However, the situation became unbearable because of the very large amount of data that was being stored this way. In addition to this, not everyone was organizing the structure in a good way and this caused problems at the moment of retrieval of specific documentation.

Finally, the search function in Windows is a very basic one and not suitable for this kind of application because it is very slow and it only works on filenames, extensions and few metadata categories such as date of creation of the document or file dimension. Metadata managed by Windows has to be general purpose in order to work for all types of files, therefore it doesn't work well with the search of specific documents related to components.

This is basically the reason why it was chosen to move all data on a platform that could keep it organized and tidy. As a consequence of a software selection, PRO.FILE was put in place to implement a PLM system software solution. Since then it has been effectively used mainly as a DMS (Document Management System).

PRO.FILE

From the official website: "*PRO.FILE is a Product Data Management (PDM), Product Lifecycle Management (PLM), Document Management System (DMS) solution that enables you to manage, control, and integrate your product data and documents from beginning to end of the product lifecycle. It gives you end-to-end visibility into your organization's processes. PRO.FILE integrates all major CAD and ERP systems in a single PDM/PLM system. Using PRO.FILE as your Product Data Backbone will allow you to build a sustainable and future-proof foundation for the implementation of PLM processes.*"

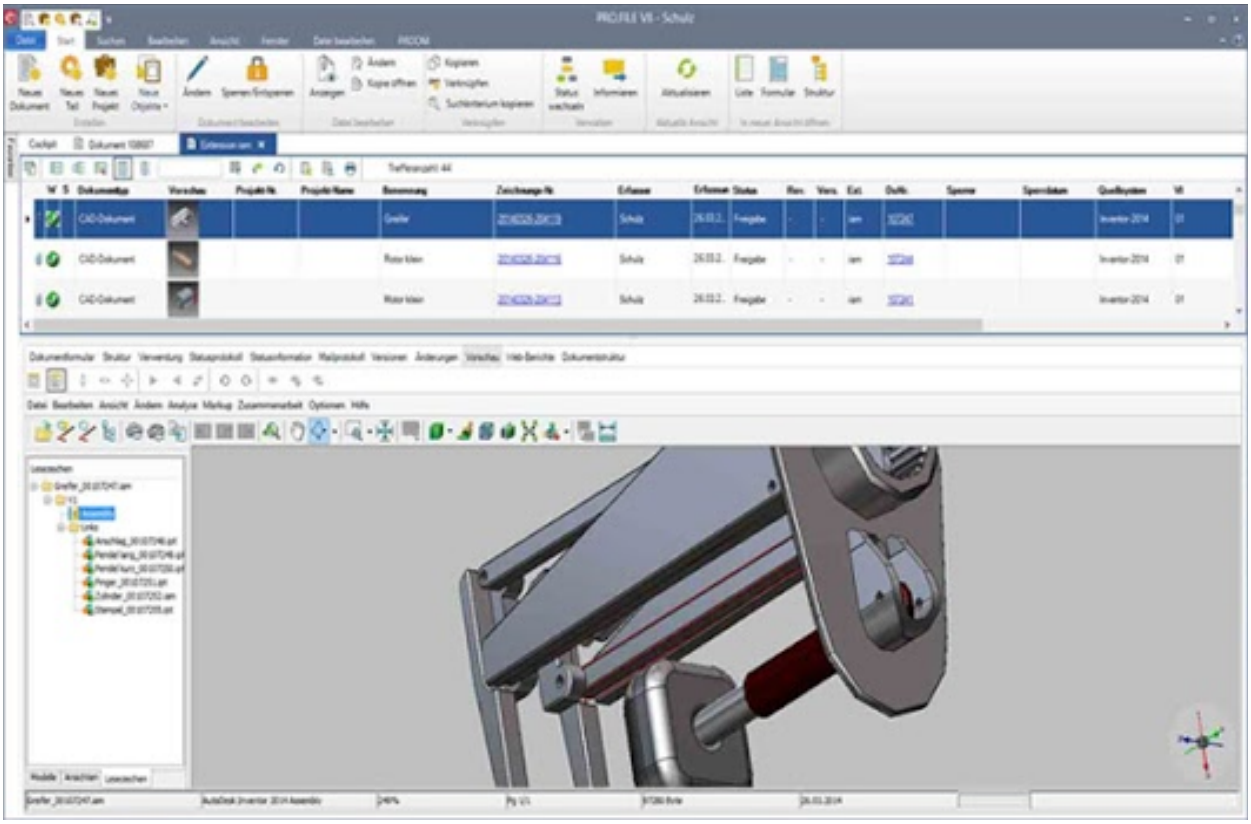


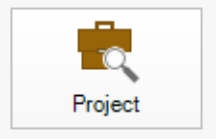
Fig. 21: PRO.FILE User Interface

PRO.FILE from PROCAD is the PLM system used in Cubogas. It mainly allows the engineering department and the procurement department to communicate and exchange information about the items in the bill of materials of a machine. In addition to that, PRO.FILE keeps track of all the documents related to any component at any level of detail.

Cubogas uses the PLM system mainly in two ways: to reduce the time of manufacture of its products and as a PDM system. Since Cubogas works upon specific order by the client it's important that it offers sensibly shorter lead times with respect to competitors in order to be more appealing. Also, it's worth noting that the technology and the market are mature in this environment. As a result, there is no groundbreaking new product introduction with a regular frequency. There is, however, still room for improvement on the current contractual work Cubogas performs.

The main categories or levels of abstraction that PRO.FILE can manage are *Projects*, *Parts* and *Documents*. The first one is related to the whole order and it is practically the biggest container since it contains iterations of the other two categories. The second one is related to components, single items, and all there is to know about them: data sheet and technical documents are, together with metadata, kept track of to better describe and digitize a component. The third one is about single pieces of information: at a request, the system can look for a specific piece of information whether it is an email, a *.pdf*, an excel file or anything else.

Projects



The highest level of abstraction is related to the order Cubogas receives. It is searchable through the *Project* button and gives an overview of the whole project.

Fig. 22: PRO.FILE Search Project button

For example, for order 2777 what comes out at a glance is the project's number (arbitrary), name, type ("*COMMESSA COMPRESSORI*" refers to the Large Compressors products), the actual incremental project number assigned by PRO.FILE (11185 in this case), relevant dates and total presumed hours.

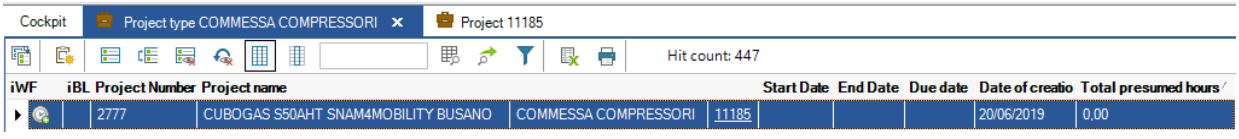


Fig. 23: PRO.FILE search results for project 2777

As can be seen from the figure, no dates were assigned to this project. Since it was created in mid-June 2019 and orders like this one usually take about 4 months it is a finished order at this point in time.

The next step is to have the PLM system show the top-level documents and parts related to the order: the main clusters of which the bill of materials is composed will be now shown together with important documents such as the new layout of the refueling station in a *.pdf* document and a *.dwg* drawing, the *.docx* document related to the technical chart of the machine that will be built and the *.msg* email related to the kick-off meeting for the project.

	2777	CUBOGAS S50AHT SNAM4MOBILITY BUSANO	COMMESSA COMPRESSORI
▷	SOP88010055	FOUNDATION CUBOGAS 2A HT WITH	MEASURE BOX
▷	SOP88010057	CLASSIFICAZIONE AREE AVTN HT	VERSIONE S CON CABINA
▷	CD8811148	CABINA MISURA S4M BUSANO	
▷	SOP2446855	2AVTN-FORCES AND MOMENTS	DYNAMICALLY ACTING ON FUNDATIO
▷	E88S050AHT021	CUBOGAS S50AHT SNAM4Mobility ENI BUSANO	
▷	SOP880000058	SPECIFICA INGHISAGGIO CUBOGAS	
▷	SOP0080299	POSA TUBAZIONI INTERRATE	
▷	CD8810907	DISPENSER HELIX 6000 2 LIVELLI	2 MANIC. NGV1 MOD. SELF
▷	DRSNO30302799	KIT CHILLER 60+2 MTA X AVTN/HT	
	Compressori VALIDATO	CNG Generico	Capitolato tecnico SNAM
	Compressori VALIDATO	CNG Generico	2777- Minuta KO meeting BUSANO- S4M
	CNG1-Documento Redatto	CNG Layout	Layout Stazione 2777
	Compressori VALIDATO	CNG Generico	Ordine fornitura S4M BUSANO
	CNG1-Documento Approvato	CNG P&I	2777.D2.D3.D4.001
	Commessa in lavoro	CNG Specifica di fornitura	specifica fornitura S4M BUSANO
	Compressori VALIDATO	CNG Generico	2777.D16.001_Technical Chart_CUBOGAS SRL_ITA
	Compressori VALIDATO	CNG Generico	2777_Relazione Tecnica_CUBOGAS SRL_ITA
	Compressori VALIDATO	CNG Generico	collaudi macchine simili
	Compressori VALIDATO	CNG Generico	progetto esecutivo 2777 dwg
	Compressori VALIDATO	CNG Generico	progetto esecutivo 2777 pdf

Fig. 24: PRO.FILE overview structure for project 2777

Starting from the left, the icons identify the type of entry in the table. Following from there: presence of the entry in SAP, code of the item if available, description and category (or description 2 if a category is not available).

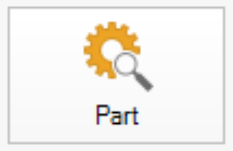
The most important entry is the *E88S050AHT021*, this code represents the basic bill of materials for the Cubogas, the large compressor the company has to deliver to its client, Snam4Mobility in this particular case.

E88S050AHT021	CUBOGAS S50AHT SNAM4Mobility ENI BUSANO	
PR8811571	COMPR 2AVTN3 Ø80-42 950 RPM	C/POM/EL (2015)
DRRMO2012000000	MOTORE ELETTRICO EEX-NA 75KW	
DRRPO0004299	PULEGGIA 250MM 6 GOLE FORO 75	
DRTLO26802-1	CINGHIA MULTIBANDA XPB2530/3	QUAD-POWER II POWERBAND GATES
DRWT004080CINT7040	BASE PLATE AVTN HT PHASE II	(V. 7040)
DRWT004373/7040	AIR OUTLET CONVEYOR PHASE II	(V. 7040)
DRWT004363-1C/7040	CABINATO (CANOPY) AVTN HT	FASE II 4MM ITALIA (V. 7040)
DRWT004435	KIT TETTOIA RIPARO QUADRO	ELETTRICO AVTN HT
DRWT008152	PANEL SOUND PROOF FOR DOOR	AVTN-HT
FE8811449	GRIGLIA PORTA	
DRSNO450001699	MATER. BLOCCAGGIO COMPR. AVTN	
DRTLO1534795	SPINTORI AGGIUNTIVI	
DRWT003332/5002	SUPPORT FOR MOTOR 280SM	BELT STRETCHER (V.5002)
DRSRO0018999	AIRCOOLER 2A3 HT SIZE L (WSK)	
FE8812183	COPERTURA AIRCOOLER	
DRRVO0021599	VENTILATORE 4500M^3/H	KW 1,1 MORO
CD8810128	ELETTROVENTOLA ASPIRANTE	ATEX (X SCAMBIATORE CD8810104)
PR8813745	KIT COMPRESSORE ARIA BALMA/ABAC S.PRES.	
DRWT009496	BOX AIR-COMPRESS. & DRYER	
FE8812785	SUPPORTO BOMBOLA ESTERNA	
DRSOP0078699	LIGHTING SYSTEM 32W	
DRRRO0000999	ELECTRIC HEATER 0.2KW	230V 50HZ
PR8811535	DISTINTA RACCORDI ARIA	CUBOGAS AVTN-BVTN
PR8811146	STOCCAGGIO 15 BOMBOLE	(12-2-1) INOX
PR8811213	DISTINTA VENT 3" ANSI 150	ESTERNO CUBOGAS (VERS. ITALIA)
CD480044-1	FILTRO GAS MSTC4350-G20 MFO	
TA8800431	TARGA CUBOGAS ALLUMINIO 2777	
TA8800432	PANNELLI AREA TECNICA 2777	
PR8814070	DISTINTA STRUMENTAZIONE 2777	

Fig. 25: PRO.FILE first part of the bill of materials for Cubogas E88S050AGT021

The entries in this partial list that have a green check symbol instead of an arrow tip have in turn a component tree and their own bills of materials together with the documents linked to them specifically. The complexity of the system is evident when most components go five or six levels in depth.

Parts



The lowest level of component trees are the leaves that represent single parts. There are two macro areas when it comes to parts: they can either be commercial or custom.

Fig. 26: PRO.FILE Search Part button

Usually when analyzing a commercial part, the most important document that can be found in the PLM system is the technical sheet. It is sent by the part manufacturer and fully describes the item in each feature.

An example could be the electric motor used in the very same large compressor:

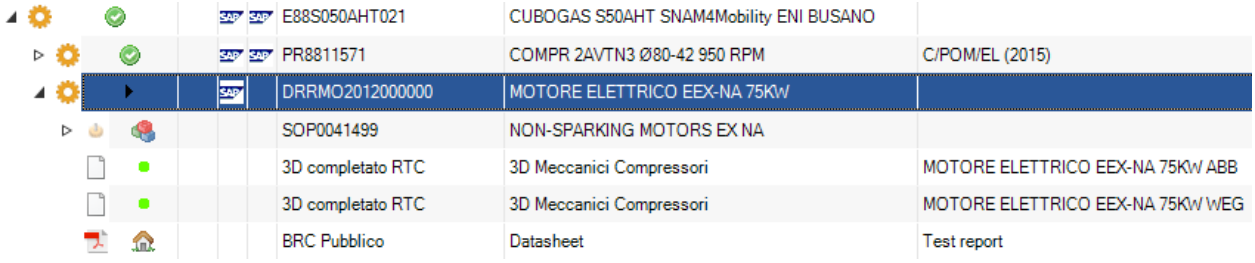


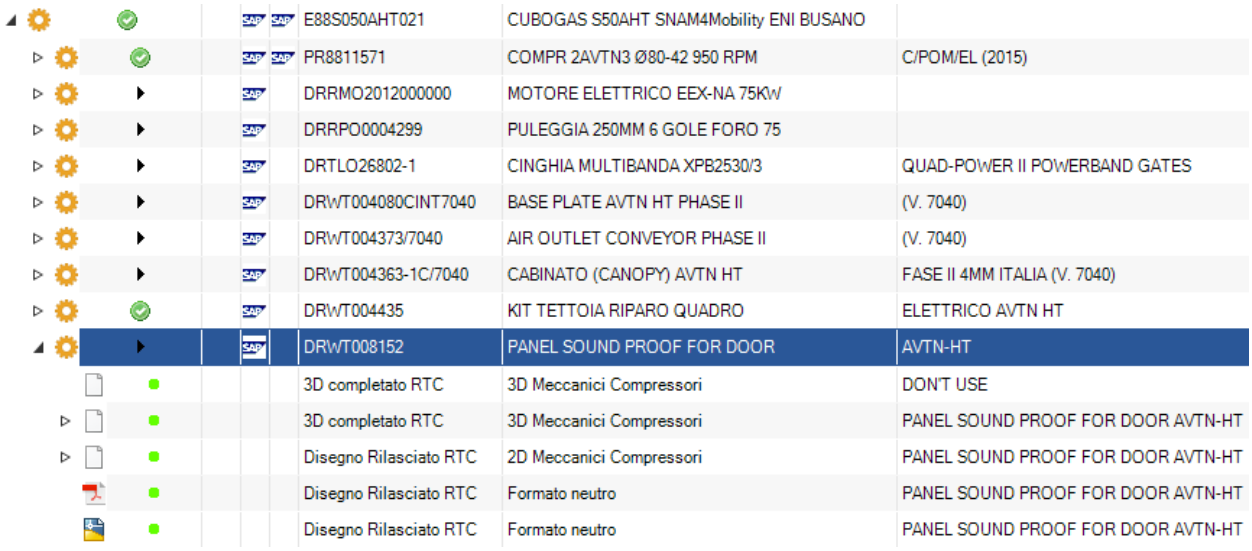
Fig. 27: PRO.FILE documents related to part number DRRMO2012000000

DRRMO2012000000 is a 75kW electric motor that uses a pulley to activate the piston which allows the compression of the gas.

The datasheet usually contains, in addition to technical data related to the performance of an item, identification numbers pertaining to it or its components if it's a complex product (serial number) and results of tests that the item underwent.

Some other parts are, instead, completely customized and designed internally in the company to satisfy specific needs. As an example, the soundproof panel for the door of the cabinet is always customized.

In fact, there is a need for complete cover of the whole surface and it wouldn't be practical for a manufacturer to make all kinds of different measurements available commercially. Therefore, designers draw the piece in 3D using SolidWorks and then the procurement department inquires a carpentry to have it manufactured.



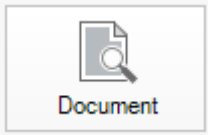
E88S050AHT021	CUBOGAS S50AHT SNAM4Mobility ENI BUSANO	
PR8811571	COMPR 2AVTN3 Ø80-42 950 RPM	C/POM/EL (2015)
DRRMO2012000000	MOTORE ELETTRICO EEX-NA 75KW	
DRRPO0004299	PULEGGIA 250MM 6 GOLE FORO 75	
DRTLO26802-1	CINGHIA MULTIBANDA XPB2530/3	QUAD-POWER II POWERBAND GATES
DRWT004080CINT7040	BASE PLATE AVTN HT PHASE II	(V. 7040)
DRWT004373/7040	AIR OUTLET CONVEYOR PHASE II	(V. 7040)
DRWT004363-1C/7040	CABINATO (CANOPY) AVTN HT	FASE II 4MM ITALIA (V. 7040)
DRWT004435	KIT TETTOIA RIPARO QUADRO	ELETTRICO AVTN HT
DRWT008152	PANEL SOUND PROOF FOR DOOR	AVTN-HT
3D completato RTC	3D Meccanici Compressori	DON'T USE
3D completato RTC	3D Meccanici Compressori	PANEL SOUND PROOF FOR DOOR AVTN-HT
Disegno Rilasciato RTC	2D Meccanici Compressori	PANEL SOUND PROOF FOR DOOR AVTN-HT
Disegno Rilasciato RTC	Formato neutro	PANEL SOUND PROOF FOR DOOR AVTN-HT
Disegno Rilasciato RTC	Formato neutro	PANEL SOUND PROOF FOR DOOR AVTN-HT

Fig. 28: PRO.FILE documents related to part number DRWT008152

DRWT008152 being a custom piece is highlighted by having both a technical drawing in a SolidWorks format (last entry) and an export of that same drawing in pdf format.

These two kinds of files are neutral formats because they can be interpreted and translated between different CAD systems in order to share data.

Documents



The atomic level of detail and what the whole PLM system revolves around are documents. The basic effectiveness of a system of this sort is measured through how good it is in retrieving the right information when requested. This information usually comes in the form of documents related to a specific part.

Fig. 29: PRO.FILE Search Document button

The UI (User Interface) of the program helps in doing this search by applying filters, thus giving the user the ability to retrieve a specific document without knowing its name.

There are three levels of searches to maintain high flexibility and effectiveness:

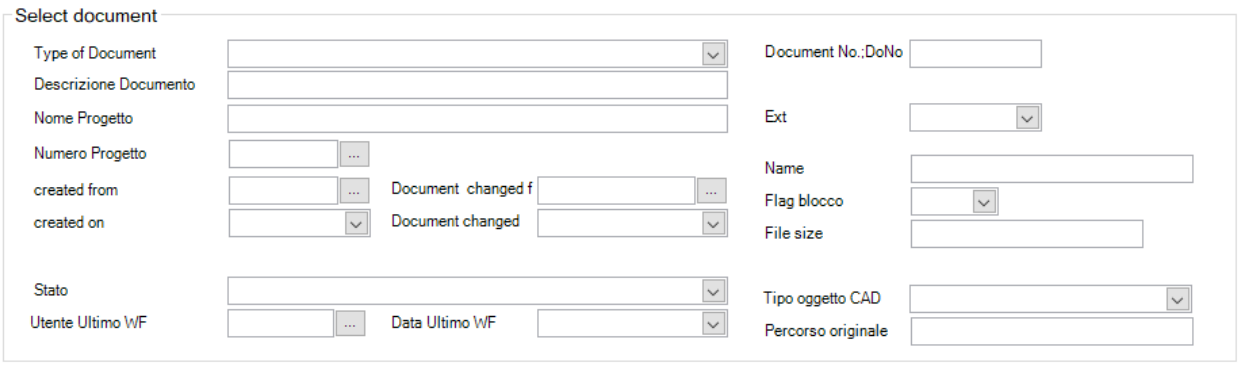
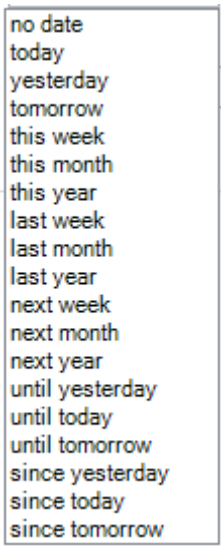


Fig. 30: First level: Select document

The first level comes into play when a user wants to find a specific document without having at hand other details regarding what it is related to. A good point to start from would be the *Type of Document* which is usually known when using these kinds of filters.



In addition to this, the author of the document can be set through the *created from* text field and so on and so forth with both *created on* and *Document changed*.

These two fields are very interesting, in fact, they would usually be blank and would have to be filled up with a date in a certain format.

Instead, they have a drop-down menu which allows to retrieve documents that were created or modified within a certain period of time. This way is much more intuitive and user friendly than a beginning and an end date.

Fig. 31: Drop-down menu for date insertion

Fig. 32: Second level: Search document by connected Article

The second level is related to parts. It is very simple and basically it retrieves all documents connected to a single component given by either code or description. It's worth noting that this second level goes on top of what presented before: this means that if multiple fields are not empty the search uses multiple filters to retrieve the results.

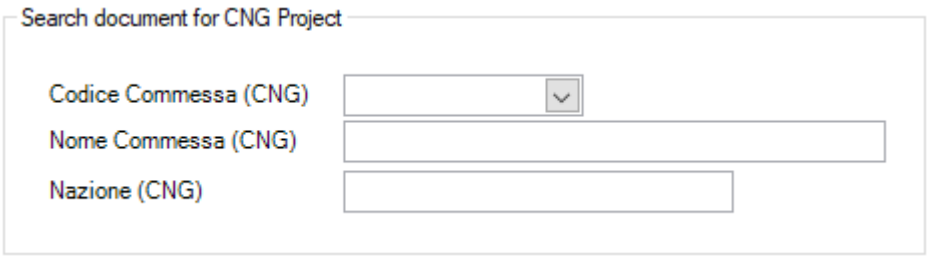


Fig. 33: Third level: Search document for CNG Project

The third level are projects as in the aforementioned main distinction. The project can be found through:

- Code, 2777 as an example
- Name, usually it is difficult to remember exactly. Here is where wildcards help the most, for example “CUBOGAS S50AHT SNAM4Mobility ENI BUSANO” can be found inputting the string **BUSANO** as the * symbol act as a “anything”
- Nation, easy to remember filter but also very inclusive one

Giving many possibilities to a user is the right way to facilitate him in his job. In fact, it is never known a priori which shortcut the user will take to get to what he needs, it is therefore very helpful to give him a high number of possibilities which in turn creates flexibility and time saved as a consequence.

Extensions

Since, as said in the beginning of the chapter, a PLM solution has to be able to integrate many information systems in order to “give a correct access to all the information in the format that every actor involved in the product life cycle needs”, PRO.FILE has some extensions that allow to connect it to other popular and useful computer programs.

MRP Integration: SAP

The connection to the MRP is fundamental when using a PLM. In fact, it is very important that the program that organizes every bit of information about components is well integrated with the program that organizes physical movements of those components.

The integration with SAP should work automatically in the sense that SAP reads PRO.FILE when a new item is created. Some information can be added in the PLM while other information related to the accounting of the part has to be inputted from the MRP. After its digital creation, the component becomes available in SAP. There, it can be associated with a supplier, put a price on and purchased by the logistics department when needed.

This kind of communication is almost one way. In fact, SAP can’t interact with PRO.FILE and it doesn’t share information strictly related to the MRP.

Fig. 34: PLM system shows that the piece is created in SAP and available in it

Documents Integration: Microsoft Office Suite

PRO.FILE can facilitate the upload of Microsoft Office documents to its repository through the official extension located in the *Ribbon*.

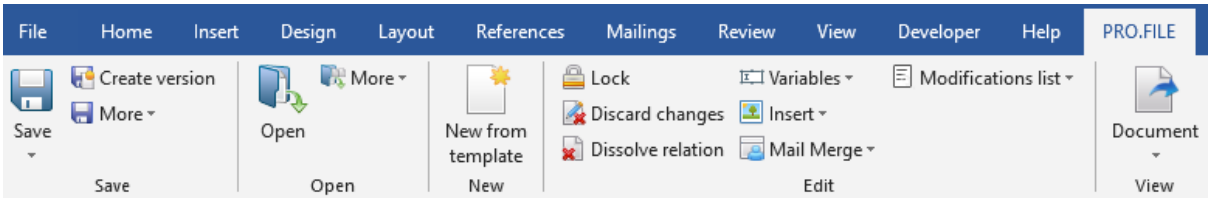


Fig. 35: Microsoft Office integration with PRO.FILE

As can be seen, the extension offers various shortcuts through which the user can interact with PRO.FILE without interrupting the editing of a document. As an example, after saving the document to PRO.FILE new versions can be created to keep track of changes, also, a file can be opened with an arbitrary version, the released one or the latest.

Schedule Integration: Microsoft Project

Another very important integration is the one that could happen with Microsoft Project. This kind of connection would allow the PLM to be kept up to date on the development of its projects. On the other side it gives the user a more specific and precise tool to track the progress of a machine being manufactured in this case. Either way this implementation is not exploited anymore as the company abandoned Microsoft Project in favor of more traditional and basic tracking tools like an Excel file.

Email Integration: Microsoft Outlook

An often-overlooked feature is the possibility to have an email handler.

In this case, PRO.FILE offers a service that asks the user to fill up an interface with internal and external email addresses and a message. At this point the system generates an email with any selected content attached to it.

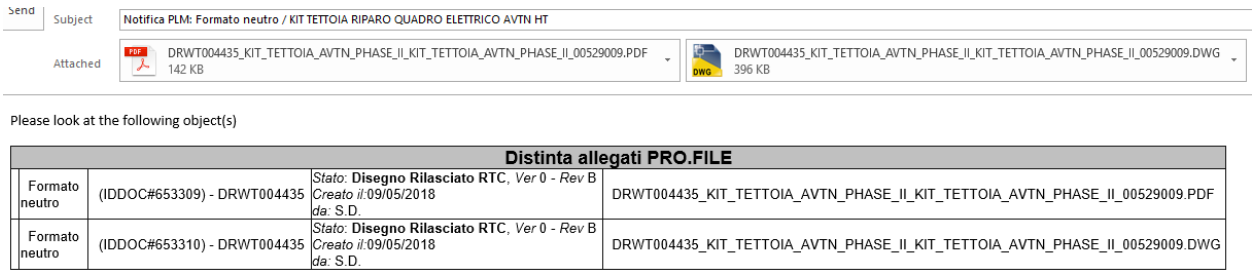


Fig. 36: Email generated from the PLM system

This feature is very useful when interacting with a supplier to whom technical drawings have to be sent in order to receive an economic offer. The body of the message shows, from left to right, the type of file, the internal identification number in PLM and related BOM (Bill of Materials) code, status in workflow together with version, revision, date and creator and finally file name.

Chapter 3 - Process Description

This chapter will analyze the whole process of an order and how Cubogas manages it from the placement by a customer to the shipping to him of the finite product.

The whole process will be described through the IDEF0 methodology in order to focus on different stages at the same level of detail.

IDEF

IDEF (Integrated computer aided manufacturing DEFinition) is a function modeling methodology for describing manufacturing functions. It offers a language for the analysis, development, reengineering and integration of processes.

These models have multiple purposes: system analysis and design at many levels of information; documentation crafting as a base for integration of the ISO 9000 standard; improvement of communication between analysts, designers, users and managers; teamwork discussions; management of large and complex projects.

IDEF0 is about *Function Modeling*. A function is represented by a box to which a number is associated in order to facilitate the exploration of the whole model. In fact, each function is usually made of subfunctions structured the same way. The depth of the analysis depends on the purpose of the model.

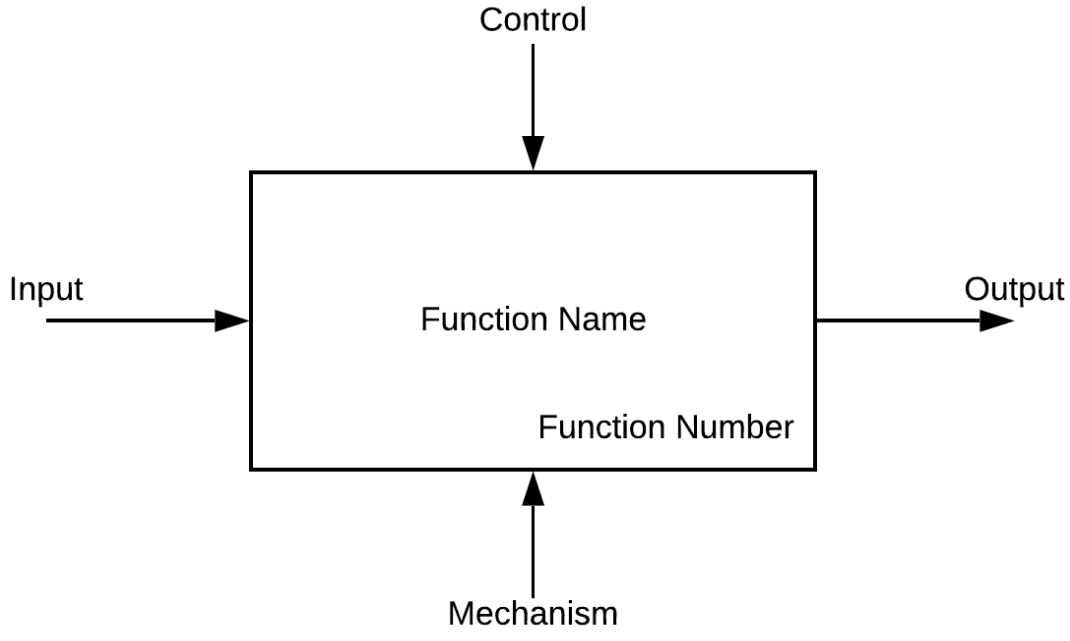


Fig. 37: IDEF0 basic design

Arrows coming in or out of the box have a specific meaning depending on the side they are on:

- On the left there are inputs, something used in the activity to accomplish it. It usually represents material or information which is then transformed into an output.
- In the upper part there are controls (conditions) which are imposed on the activity. They regulate if, when and how the activity will be performed, therefore every activity must have at least one control arrow. Usually, they are in the form of standards or rules.
- In the bottom part there are mechanisms (resources), for example employees performing the given activity or physical hardware used for it. Resources don’t wear down over time hence why they are workers or equipment.
- On the right there are outputs, with their arrows pointing outwards, the results of the activity. Output can be materials or information. Each activity which does not create an output is not to be modeled.

IDEF0 Cubogas

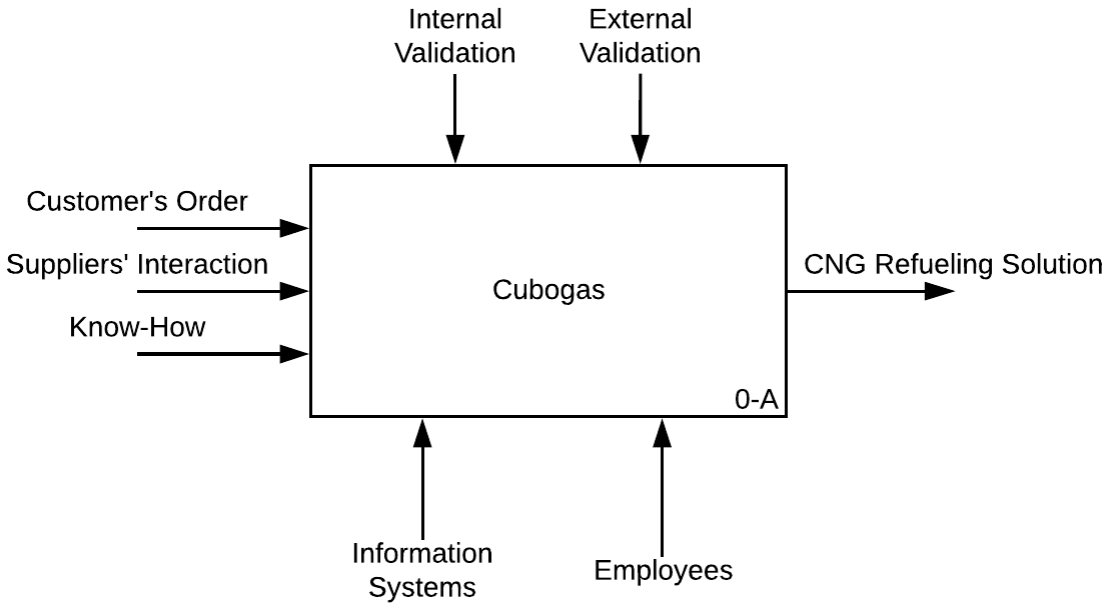


Fig. 38: IDEF0 Cubogas Level 0

The most high-level function is the company itself. It receives a client’s order as an input and operates upon it while respecting the client’s needs and standards compliance.

Cubogas' resources are all its information systems, its employees and the base bill of materials which comes from past knowledge.

The most important output at this level is a complete CNG refueling solution, the company's main product.

The function 0-A can be exploded into lower level activities representing more details and allowing the user of the documentation to better understand how inputs become outputs.

0-A Cubogas

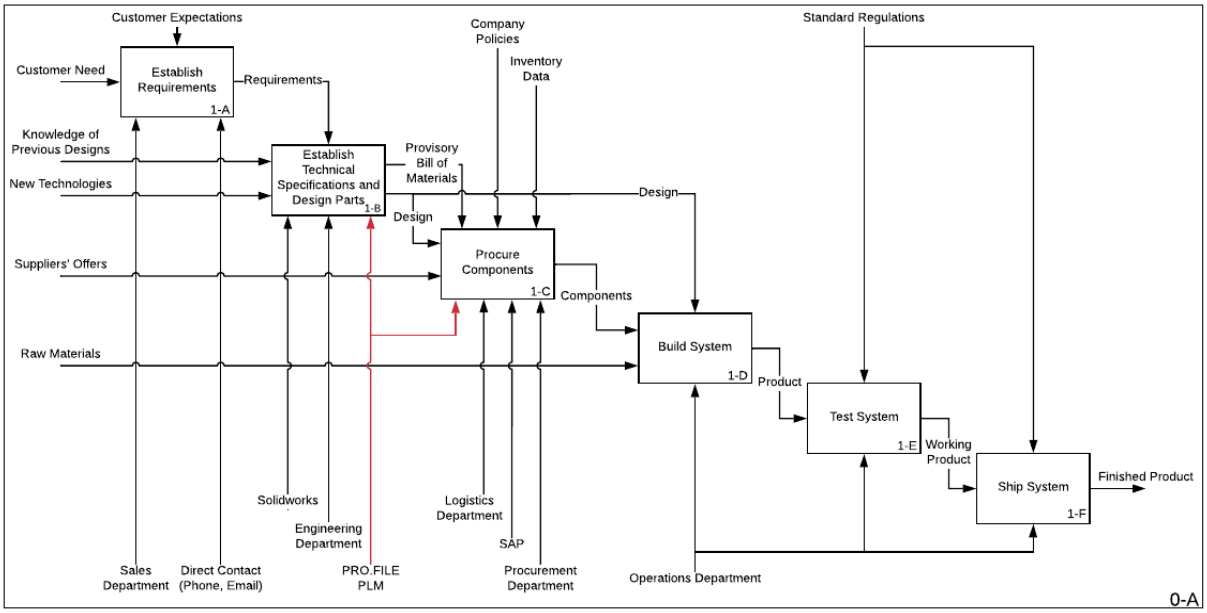


Fig. 39: Inside Cubogas Level 0

The scheme represents the flow of an order inside the previously analyzed top-level function *Cubogas*. Inside this function, a neat distinction can already be carried out between departments and their duties.

The sales department is the contact point between the company's operators and the customers. The successive steps are design (of which the engineering department is in charge), procurement and logistics activities (each owned by the homonym departments) and finally production is executed by the operations department. The whole process will now be analyzed in order to give a better understanding of how things work. Later, the role of PLM will be analyzed in each of these main activities.

While the company's process is basically the same for each of its products, the thesis will concentrate on the manufacturing of a large compressor. Being it the most complex product, it is also the one that carries the most problems. In fact, it is very rare, for example, to find out during production about a missing component for a standard and relatively simple FMQ 2.5. The most frequent complications happen with custom large compressors and some of those are problems that an informed use of a PLM system could help avoid.

1-A Establish Requirements

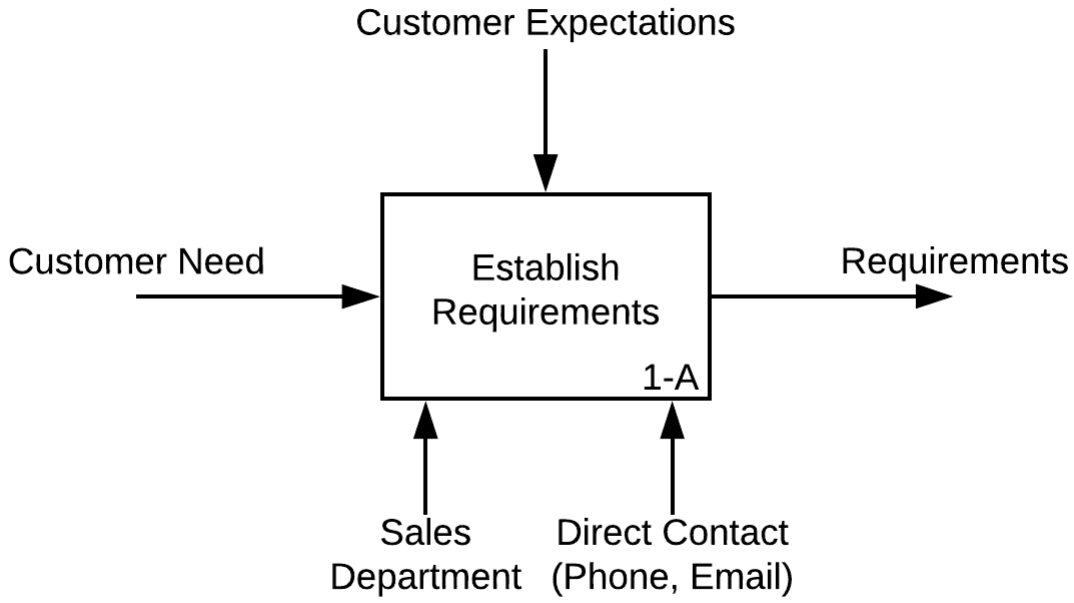


Fig. 40: 1-A Establish Requirements

The whole flow starts from a *Customer Need* which could be originated from different wills, for example:

- Comply with the law: some countries require investments in a non-fossil fuel alongside fossil fuels when building a new refueling station
- Start a new business: methane is nowadays very popular around the world. In Italy, there are around one million cars on the streets, therefore it could turn out as a profitable business
- Save money on the company's fleet: some enterprises go private in refueling their vehicles and they do that through Cubogas products. One of the most interesting cases comes from China where Disney chose methane for the vehicles moving around one of their entertainment parks
- Go green and refuel at their own house: FuelMaker, as previously mentioned, is the perfect solution

Following a need, either a customer reaches out to Cubogas or Cubogas' sales department scouts for potential customers. Afterwards, a kickoff meeting is organized to discuss the product, its details and the extent of services to which the customer wants to inquire Cubogas for.

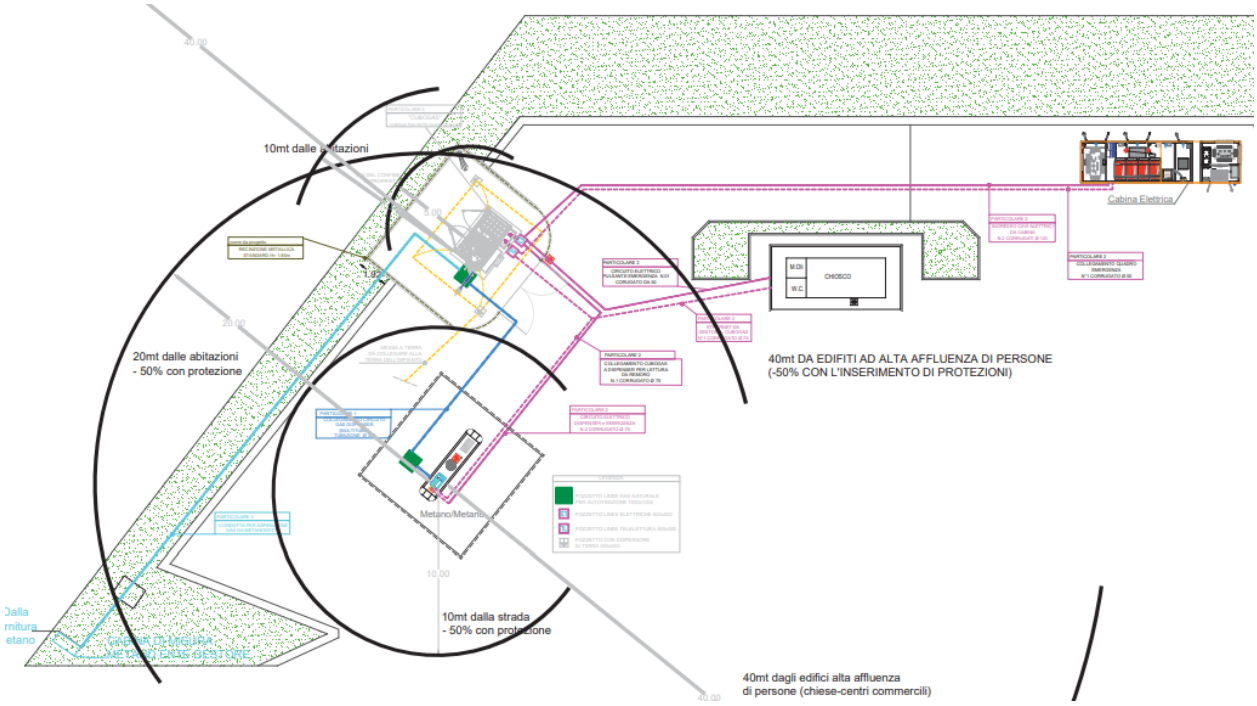


Fig. 41: 1-A Creating the layout for a new station

As the meeting wraps up the machine production is scheduled inside the company's planning and a project manager (usually an engineer from the engineering department) takes responsibility for the project's supervision.

1-B Establish Technical Specifications and Design Parts

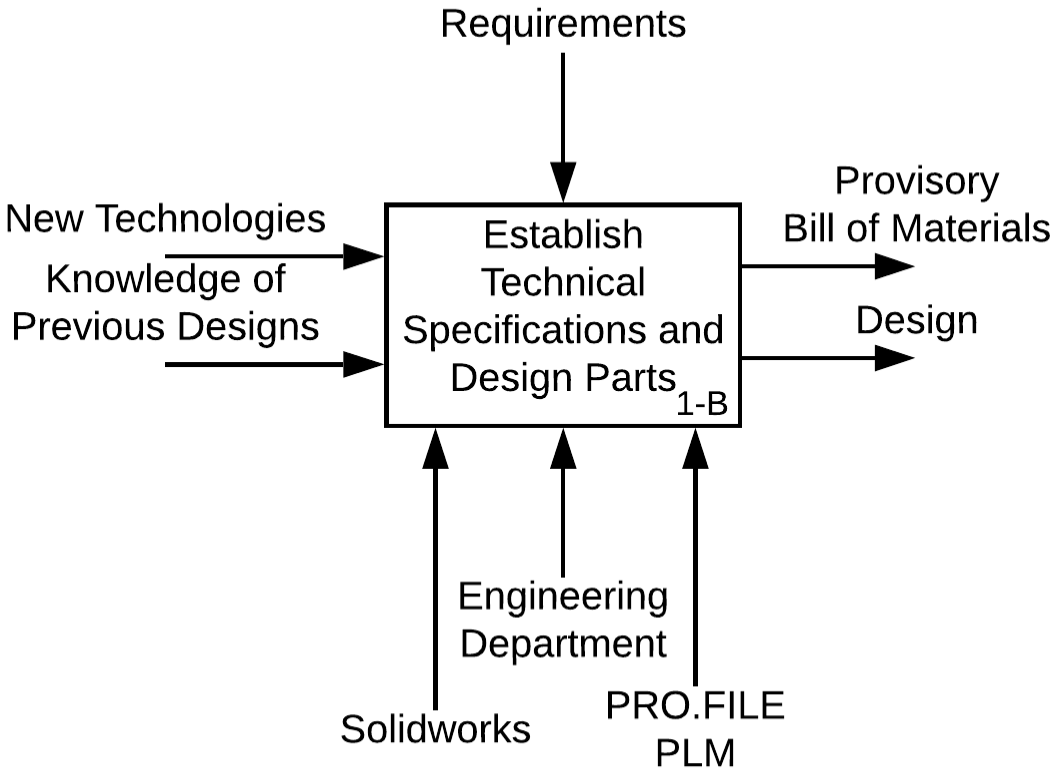


Fig. 42: 1-B Establish Technical Specifications and Design Parts

The project manager brings what resulted from the previous meeting to the engineering department where, together with other engineers, the technical specifications of the machine will be established.

The starting platform for the machine always comes from past designs. Cubogas exploits a shared modular design construction for its large compressors in order to standardize production as much as possible. Many of them require adjustments mainly in order to cope with policy regulations adopted by the destination country but also with climate conditions of the environment the machine will operate in or with special requirements (requests made directly by the customer or deemed necessary by the engineers). Usually, about 10% of the standard bill of materials for these machines is modified, while the core 90% stays the same.

The trend in Italy nowadays is that the majority of large compressors is operated in refueling stations. On the contrary, in foreign countries, they are bought by companies with the need of refueling their private fleet. As an example, in 2019, "*Snam won a tender through Cubogas for natural gas filling stations for buses in Paris*" (for the public transport company RATP).

Some requests made by customers were about the location of the electrical cabinet (inside or outside of the compressor's canopy. Usually, the choice is dictated by harsh climate conditions), others about the carpentry works (cover of the machine, custom piping and so on).

Sometimes new technologies are applied to the products. As an example, the aforementioned new dispenser, which will be now made in-house, was entirely developed by Cubogas. It will help save on the cost of the machines therefore allowing for better margins or more competitive prices.

The outputs of this function are the provisory bill of materials (which should be confirmed as definitive in the best case) and the design for custom components. The BOM is uploaded on the PLM system PRO.FILE which fulfills its main function starting from here. It is, in fact, used inside the company as a BOM tracker and a PDM system. Each piece of information produced (data sheets, drawings, but also emails, price offers, etc.) is linked to the correspondent component it affects.

The definition of the exact flow is a bit fuzzy and not always linear, as it happens in real cases. In fact, while the basic requirement for the work to proceed is the bill of materials, other elements such as technical drawings for custom components can follow at a later time. The procurement and logistics department will commence work on what is already there, then going back to retrieve what was missing.

1-C Procure Components

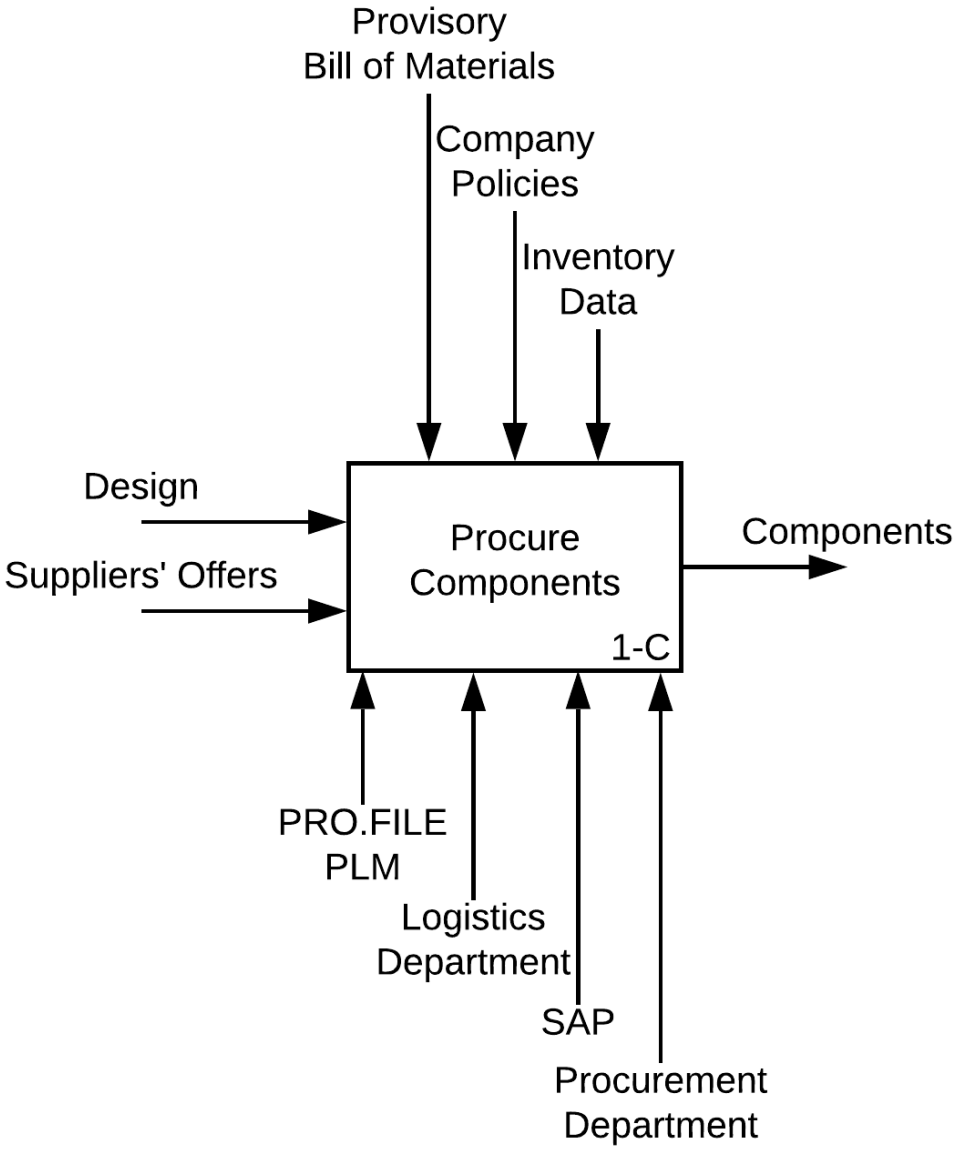


Fig. 43: 1-C Procure Components

What comes out of the engineering phase is shared across departments that have access to the PLM software, primarily the procurement department and the logistics department. When a new BOM is created the MRP software SAP (which is linked to PRO.FILE) retrieves and matches up codes of components identifying what's already in stock in the warehouse and creating a report of what has to be bought or "contractualized".

At this stage the procurement department, the one I worked in for my traineeship, has to elaborate the requests of pieces from the logistics department. The office is usually organized by differentiating between custom components, commercial components and back-office jobs: this helps in dividing the work among team members and also works towards facilitating communications and interactions with external actors, most importantly suppliers.

There are two main reasons for which the procurement department is consulted:

- The price currently available in the company's database doesn't match what the supplier is asking in the invoices
- The item is not in MRP software altogether (these have to be contractualized for the first time)

The last reason sparks the "contractualization" process which must be activated every time a new item is needed somewhere in the production flow. It is analogue also for services or for works a component could undergo.

First of all, the supplier Cubogas is interacting with has to be subscribed to the *Register of Suppliers*. Since Snam is a structured company it requires that all its eventual suppliers comply with some internal policies. In order to enter the register, the supplier has to access a website upon which they can upload all necessary documents. Some are about the company itself, for example production values, legal office address and organizational structure, while others are certifications that can be obtained from Italian governmental bodies such as *Camera di Commercio*.

Once the registration (carried out in Snam head offices in Milan) is approved, Cubogas can start having business with that supplier. At this point, to facilitate the procurement process and to divide the work allowing the resources to be focused only on one kind of supplier, a distinction is made between custom and commercially available components. The procedures are analogue but worth being distinguished:

Custom Components	**Commercial Components**
Download of technical drawings (as created by the engineering department) from the PLM system	Download of either technical data sheets, accurate descriptions or photos from the PLM system
Ask RFQ (Request For Quotation) to the supplier with any technical or commercial document available in order to clarify the specifications of the identified component	
Analyze received bids by comparing the prices to other similar items known prices. Also, ask for economic batches' quotation in a way that if a high number of pieces is bought the price per piece will decrease (economies of scale efficiency)	
Archive bid to the PLM system	Archive bid and eventual additional information, technical drawing or data sheet if not present before
Upload price and other economic/logistic information, such as MOQ (Minimum Order Quantity), batch amount and approximate lead time for the component, on the ERP system	

Finally, the logistics department is able to emit the order towards the supplier. After the confirmation, the goods are expected to be delivered within the promised lead time. The components are then checked by the quality department in samples and stored in the warehouse or directly sent to production (usually if it’s a late component).

When the components arrive in the company, they are registered on the MRP and they become available for other units to use and progress with the flow.

1-D Build System

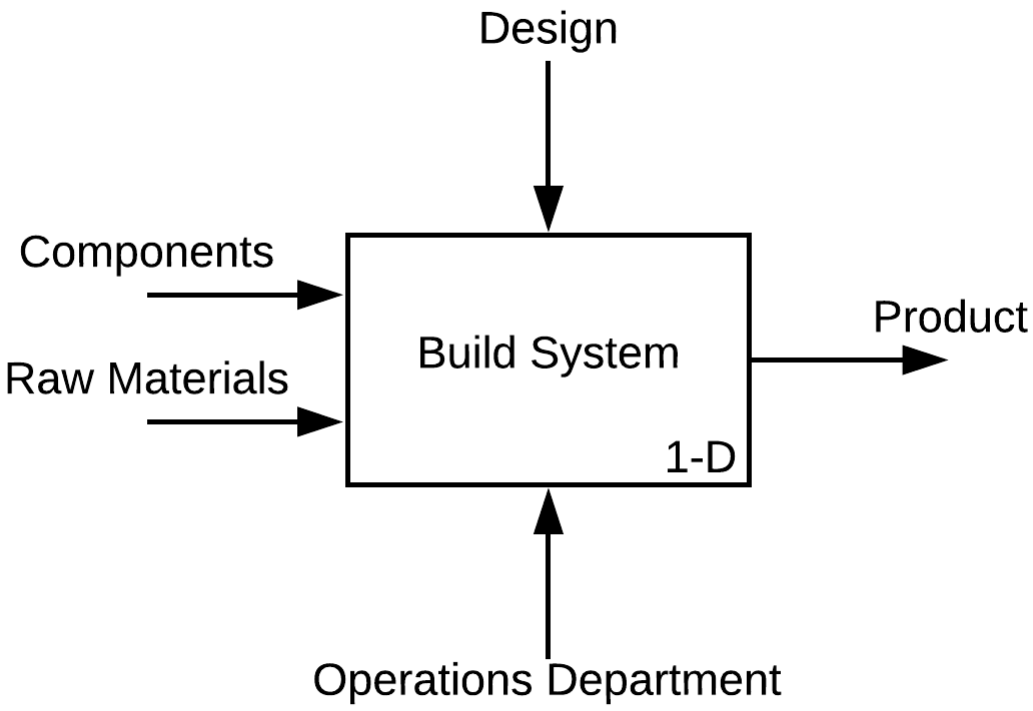


Fig. 44: 1-D Build System

The build system function is pretty much self-explanatory. Necessary components are retrieved by the warehouse employees and brought to the production area in about a week's time. There, following the design given by the engineering department and the expertise of the operators, under the supervision of the project manager, the manufacturing of the machine takes place.

This is a very practical function and one in which the use of software systems is often underestimated. It may be one of the areas in which the introduction of a PLM system could strongly help in improving the process.

Just to put phases in perspective, the building process for a new large compressor lasts usually about 2 weeks.

1-E Test System

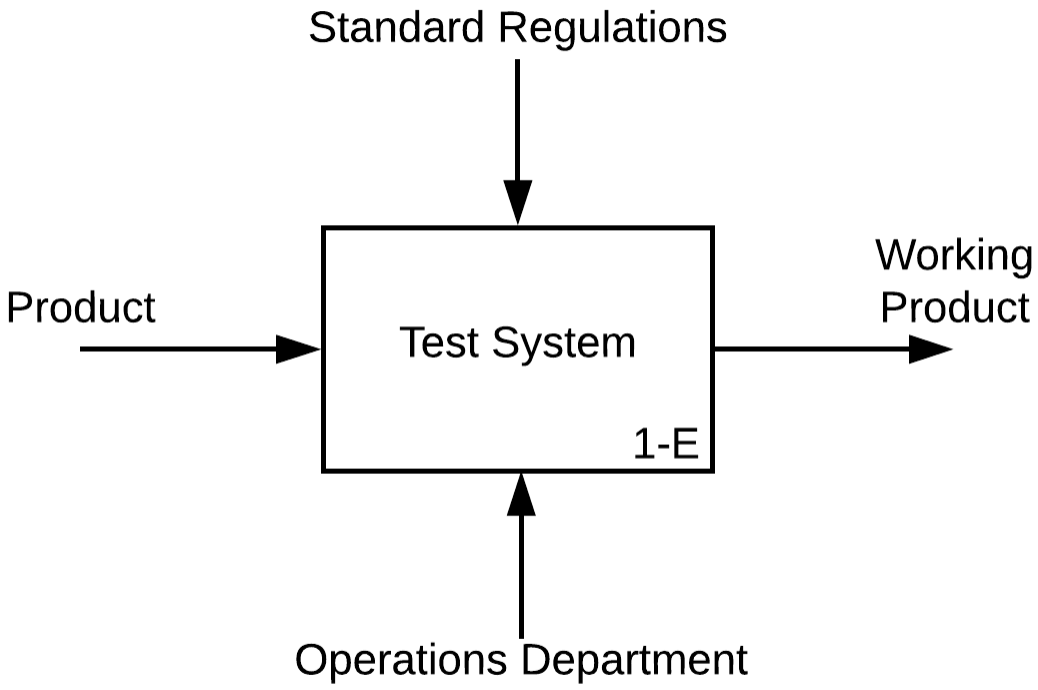


Fig. 45: 1-E Test System

After the system is finished being built, its testing process starts. It is brought in a special area where it undergoes some dry tests and then some real working condition tests.

It is very important that these stress tests are accurate and carried out with attention to details since the machines Cubogas produces, especially custom large compressors are dangerous ones. The natural gas is compressed at up to 330 bars of pressure in the vessels and everything has to go right.

Fig. 46: Pack of vessels (left), Electric system of a large compressor (right) being tested

Complete testing usually lasts for about one week on all different parts of a machine combined. The area allows the testing of two large compressors parallelly.

When the testing phase is over the machine receives the PED and ATEX certifications given the grade of delicacy of operations.

1-F Ship System

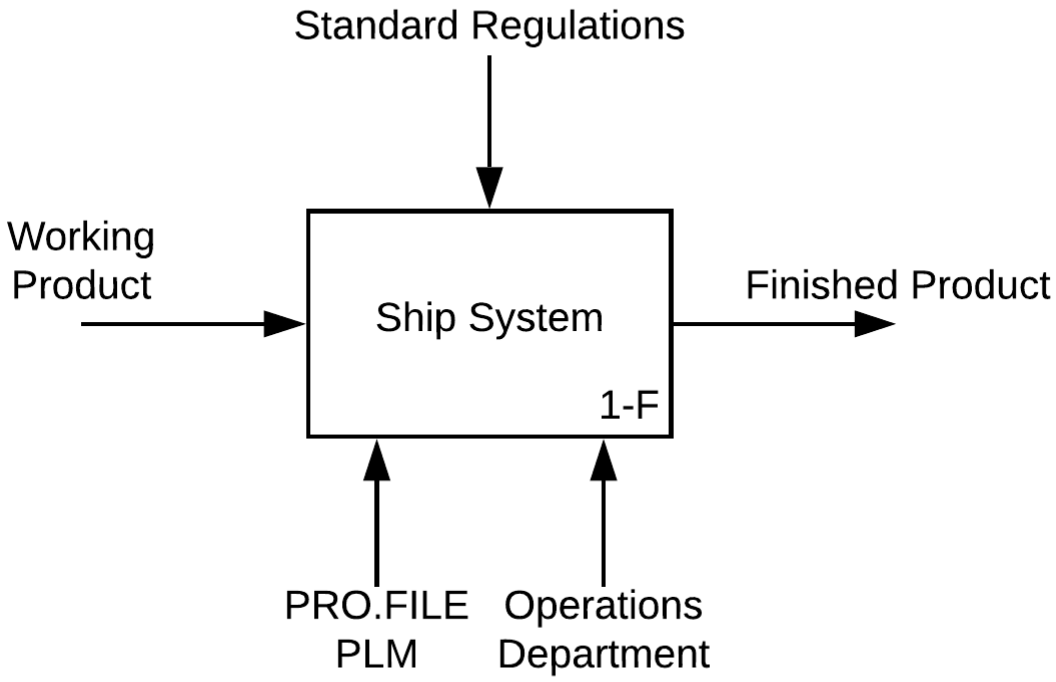


Fig. 47: 1-F Ship System

Finally, after receiving the due checks and necessary certifications the large compressor is ready to be shipped to the new owner. Usually these systems take their place in a newly constructed refuelling station and are unloaded directly into a construction site. The suppliers chosen to execute this kind of maneuver have to be certified ones. Cubogas chooses them and takes care of this activity too, thus offering the final user a complete turn-key package. The incoterm to apply here is DDP (Delivery Duty Paid) plus unloading operations at destination.

Chapter 4 - Analysis of the Current PLM Solution

The process of fulfillment of an order presented in the last chapter will now be examined from the point of view of PRO.FILE paying close attention to how it is taken advantage of. In this chapter, the current usage of the PLM system will be analyzed through the only functions it is currently used in: “1-B *Establish Technical Specifications and Design Parts*” and “1-C *Procure Components*”.

1-B Establish Technical Specifications and Design Parts

The PLM system’s role in the flow starts in the engineering department.

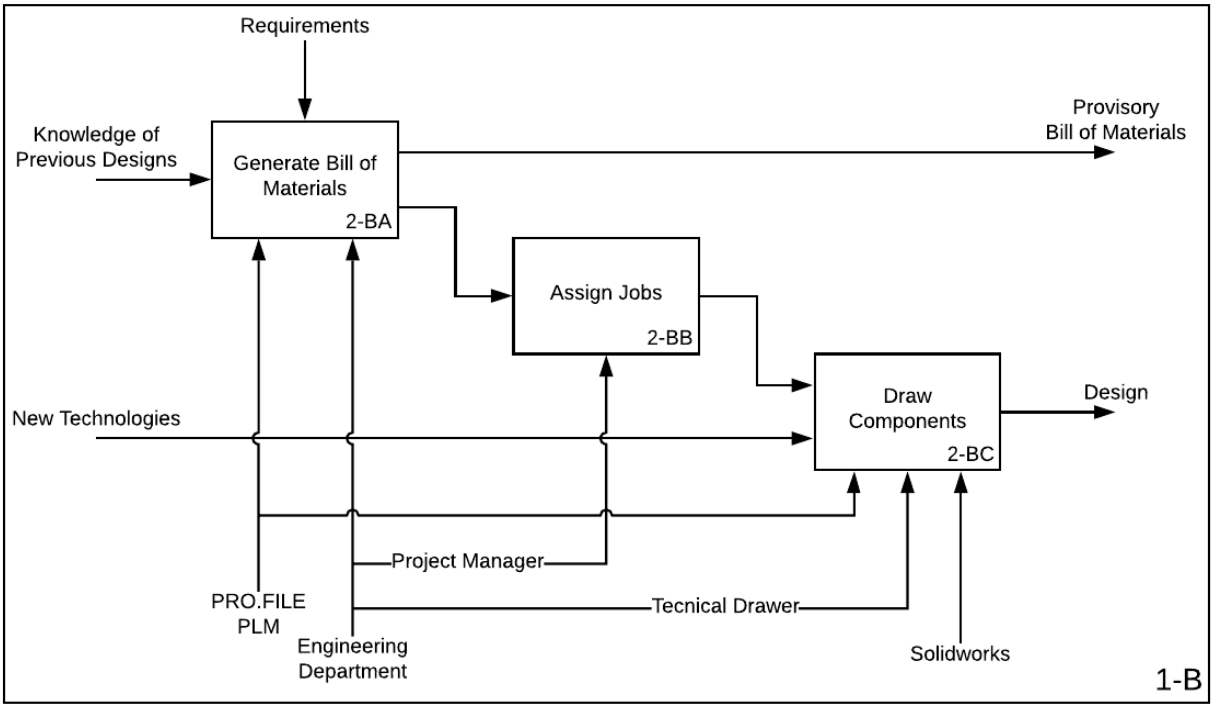


Fig. 48: 1-B Establish Technical Specifications and Design Parts: Current PLM Solution

Here, PRO.FILE is used to generate a provisory bill of materials based on a similar past design. Furthermore, it is used to archive every kind of document through its DMS capabilities. Lastly, it merges these two features, therefore indexing the parts and each piece of information related to them, both data and metadata.

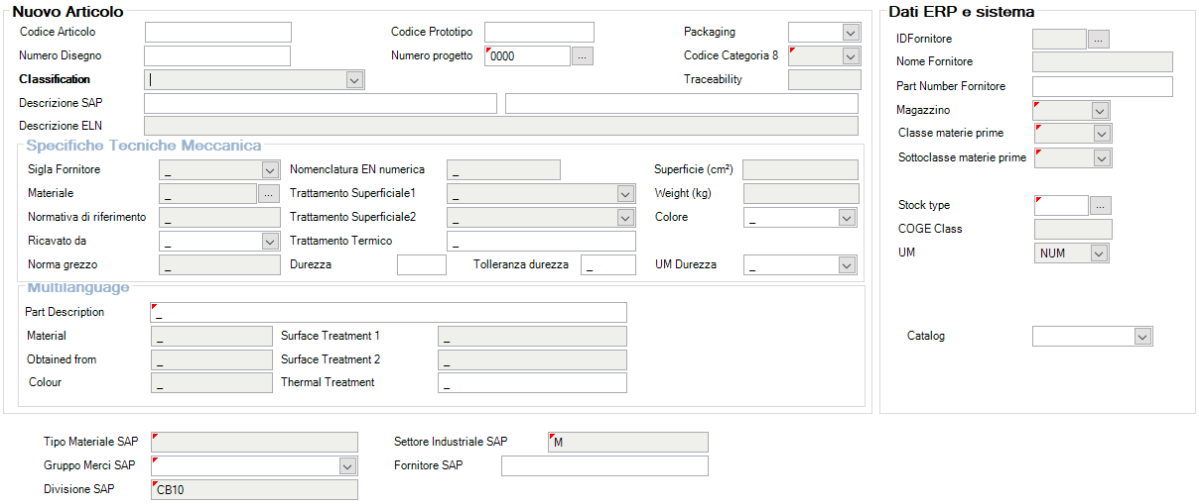


Fig. 49: Component Creation in PRO.FILE PLM

Metadata is a set of data which describes and gives information about other data (a component, in this case). It is used to better describe the digitization of a physical piece and is held by PRO.FILE in the "*part form*" card related to an item.

Information which can be supplied includes but is not limited to: supplier, material, regulatory policy, surface treatment kind, hardness, weight.

Another important feature shown here is the ERP integration. Both in the right and bottom part of the form for component creation there are information related to SAP:

- ID Supplier: from which supplier this part can be obtained
- Warehouse: to which warehouse this part has to be delivered (if a company, like Cubogas, has more than one: large compressors' warehouse and FuelMaker's warehouse)
- CO.GE Class: where the part should be located with respect to the general accounting of the company
- UM: unit of measurement of the component (meter, piece…)
- Goods Category: used to group goods in different categories thus better organizing them physically, cost-wise and so on. As an example: BB01AB25 corresponds to *Pneumatic Valves for CNG Compressors*

Aside from the ones just listed here, there is no further exploitation of the PLM system at this time in the engineering department.

1-C Procure Components

The only other function affected by the PLM system at this time is supply chain. In particular, only the procurement department regularly uses PRO.FILE.

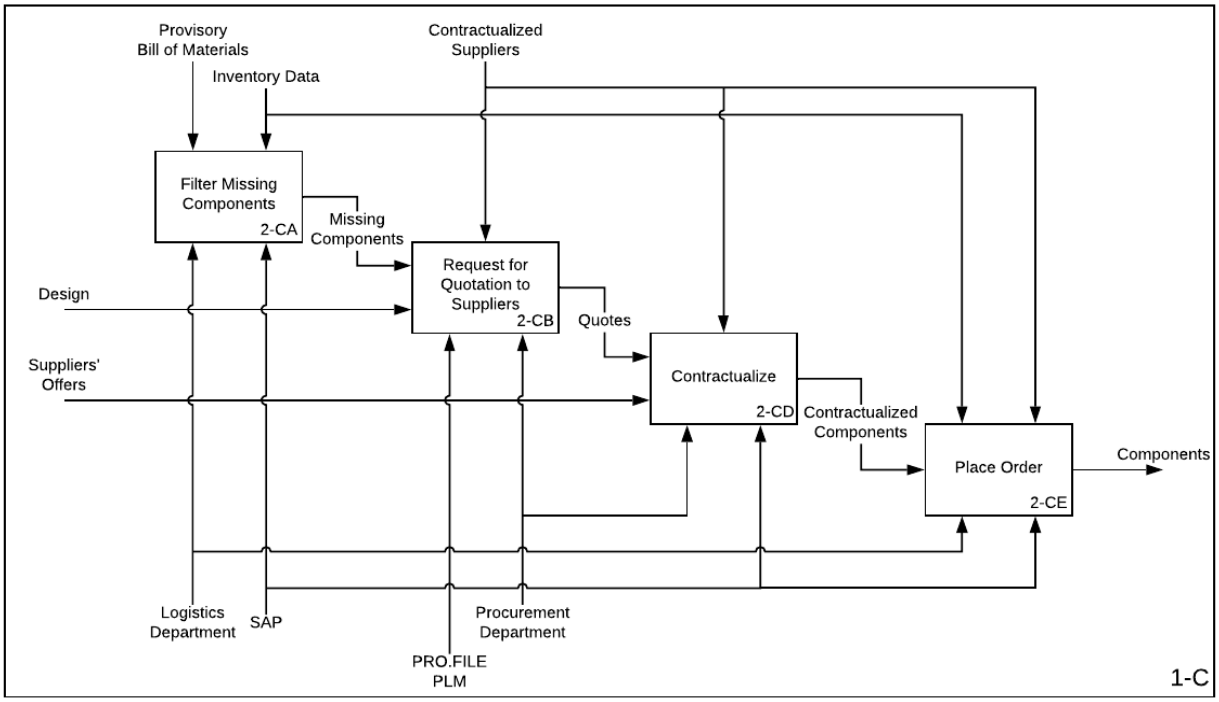


Fig. 50: 1-C Procure Components: Current PLM Solution

The only use for which PRO.FILE is exploited in the procurement department is as a DMS. In fact, the most common use case scenario at this point of the flow is for the program to offer a framework for document exchange between the engineering and procurement department.

The latter has to entertain relations with suppliers and be well informed of the pieces it is asking economic quotations for. The PLM system serves as a document retriever. In particular, given the identification code of a piece, a procurement operative downloads the related technical drawings (usually both a *.pdf* and a *.dwg* file) in order to send them to the supplier.

The supplier will then examine the piece and send back the price and other related information as previously mentioned.

All in all, this is the extent of the usage of PRO.FILE in Cubogas. The next chapter will evaluate how to improve existing PLM processes and implement new ones.

PLM Maturity

The graph in the figure below represents the current state of maturity of the PLM system in Cubogas. The categories refer to the stages of the lifecycle of the product and they are graded on a scale from 1 to 5: where the lowest grade is given to stages with little to no usage of the system and highest grade is given to stages where there is plenty of usage of the PLM system.

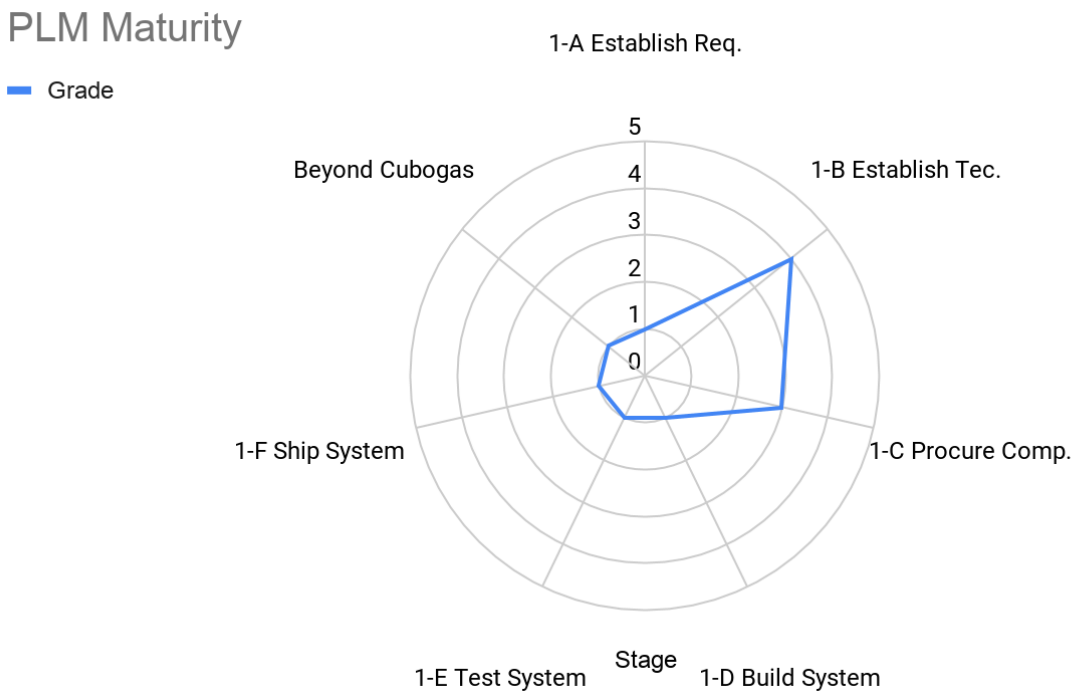


Fig. 51: Overall PLM Maturity: Current PLM Solution

After the proposed improvements will be presented in the next chapter the graph will be discussed again in order to have a qualitative comparison of the benefits that could be exploited from the system.

Chapter 5 - Proposed Improvements

Starting to use the PLM system in the engineering department already creates an efficiency loss. In fact, it could be exploited even in the first function in order to provide support for the kick-off meeting and every detail that follows.

This chapter will propose improvements upon the current PLM solution analyzed in chapter 4 by extending it to the other functions thus creating a framework to support the fulfillment of the whole order instead of a few steps.

Each new connection in the IDEF0 representation will be highlighted in red. It will be then explained from the point of view of implications and impacts on the flow of the order and eventual benefits which will follow.

1-A Establish Requirements

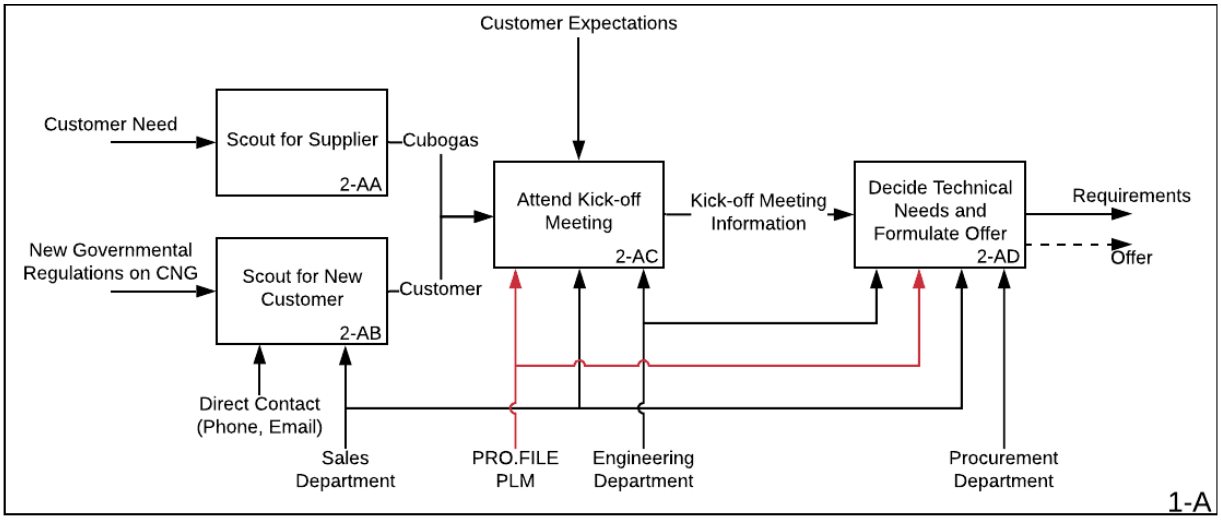


Fig. 52: 1-A Establish Requirements: Improved PLM Solution

The sales department, starting from the first contact with the client, should start using the PLM system to collect useful data. As an example, usually when the first customer of a certain nationality comes around more will follow. The reason why is that established companies and new business opportunities usually invest in CNG in bulk when a regulation changes or incentives are granted at a governmental level.

Hence, it is useful to track where new customers are from, what happened recently in that country and why they chose Cubogas, in order to start from those locations when new scouting for clients is needed.

In addition to this, PRO.FILE would be a much more efficient way to keep every document organized and tidy and on top of that, marked as confidential, or public, for example. This feature can be exploited truly at every step of the flow because it is more convenient then just simply putting documents in folders or, even worse, keeping them in the personal email client.

A little more effort in the document creation (such as inputting metadata) pays off. The system just needs to guide the user in his day-to-day operations and facilitate communication among different actors.

A PLM system has a virtuous effect on its usage, in fact, the more it's used the more it's useful and in turn becomes used by all kinds of different stakeholders. In this regard it's important to involve external subjects in the flow, mainly suppliers and clients.

1-B Establish Technical Specifications and Design Parts

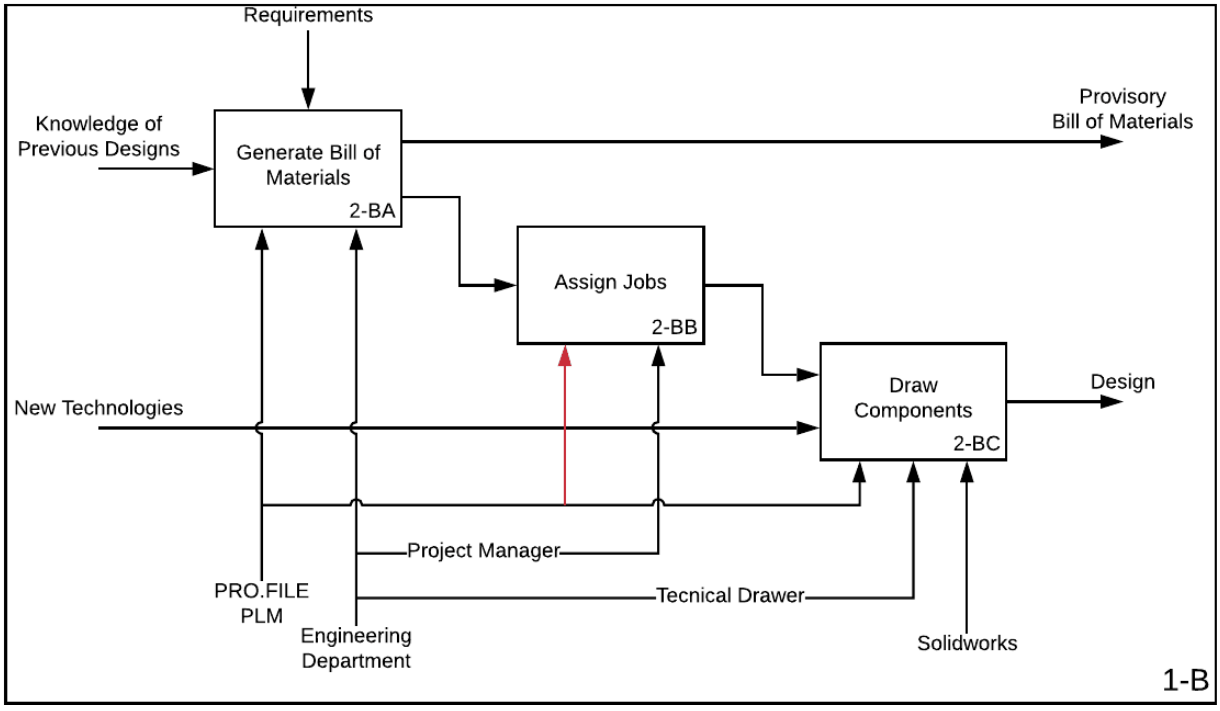


Fig. 53: 1-B Establish Technical Specifications and Design Parts: Improved PLM Solution

The engineering department already uses PRO.FILE in most of the activities in which it can provide support. However, three main improvements could add further value to the software system:

- Assigning jobs: both the project manager and technical drawers would be facilitated if jobs could be assigned through software. Firstly, there would never be miscommunication among the parts. Secondly, jobs could be tracked in terms of time spent on a certain task (the benefits are better explained in the next point). Finally, a Gantt chart would be very useful and easy to use to closely follow the progress of the project, monitoring and controlling it with crashing actions when necessary.
  A tool like this one could help Cubogas stay on track for its longest and most complex processes and the benefits of this improvement can easily be computed in monetary terms since some of the supply contracts Cubogas stipulates with its customers include penalty clauses for delays. A daily fee for this kind of situation can go as high as 1.000€. Since the price of a large compressor (complete package) is, on average, estimated at 200.000€, it would mean that 0,5% of margin is lost each day of delay.

- Track times: not only it's well worth keeping track of a certain project from the timing point of view but it's very useful to know if it's being highly resource requiring or, on the contrary, it is standard enough that it can be quickly processed and sent to the next step.

- Track costs: as a consequence of time tracking, another important improvement would be to refine indirect costs tracking. It wouldn't be retroactive because the price of a large compressor is bargained before these activities take place but it would help for the next machines that have to be built.
  At a certain point there will be enough data to find patterns which link the requests of the client to what they mean in terms of personnel's effort cost on a task. The best result is that formulating an offer to a customer will be more accurate, hence providing higher margins.

1-C Procure Components

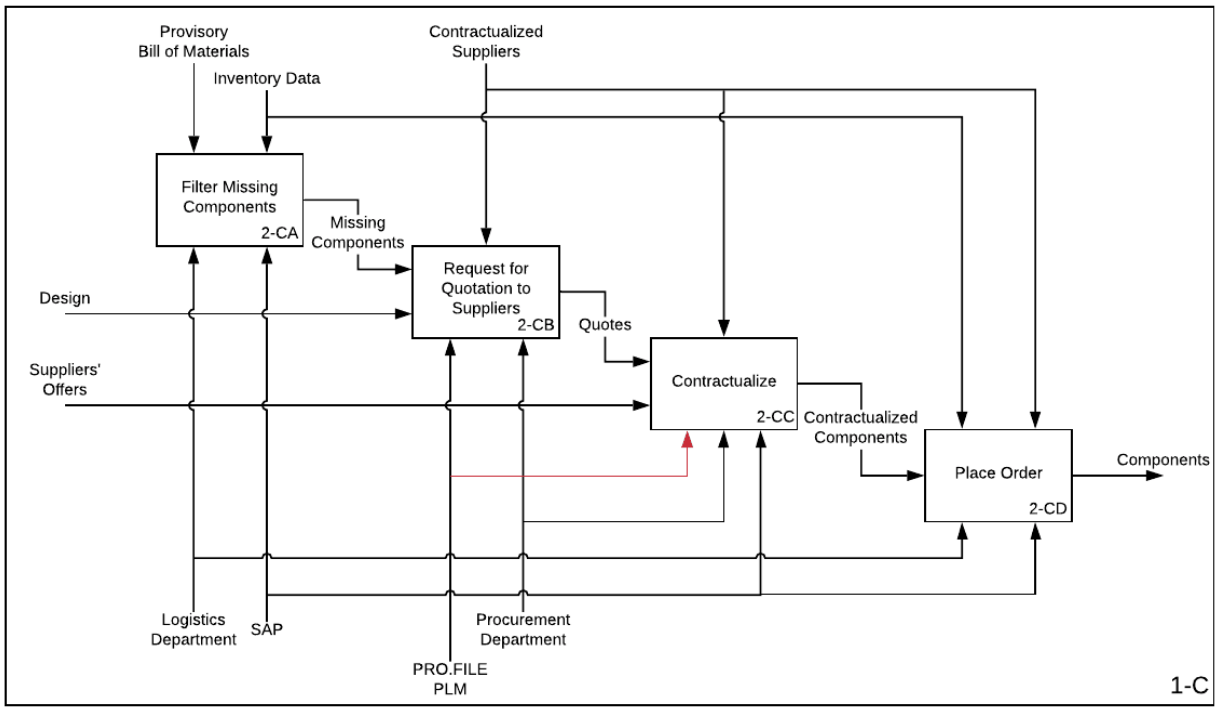


Fig. 54: 1-C Procure Components: Improved PLM Solution

The PLM is somewhat highly used in the function related to the supply chain. Not only is it integrated with the ERP letting the logistics department work only on the latter software but it is also available to the procurement department for the reasons and with the uses explained in chapters 3 and 4.

However, the benefit that would be enjoyed from a further exploitation of the system would be highly disruptive for the current internal routines of the procurement department. In fact, a lot of time could be saved if PRO.FILE automated a job that is performed manually at the moment: sending technical drawings to suppliers and, even more, receive prices related to those requests for quotation and input them in the ERP system.

Here is how it would work:

1. Every time a new piece is in the bill of materials of a machine in the procurement phase and the status of its technical drawings documents is marked as *"final, released"* the next step triggers
2. At the moment of creation, the component is associated with a particular category of goods. The same categories are assigned to suppliers when contracts are stipulated with them. Therefore, using the *Email Connector* integration service an email is sent directly to supplier with a ready-made message asking to check out the new designs and formulate an offer for them
    - The procedure could stop here, the procurement department would input received prices in the ERP system and the flow would continue as normal

3. To capitalize on the PLM system even more, the email sent to suppliers should contain a link to a web page in which they can input the quotations of the component they have been asked to price. The link would be unique, created specifically for them so there wouldn't be security concerns
    - The automatic input of quotations received through PRO.FILE to SAP could be without supervision or subject to the procurement department approval

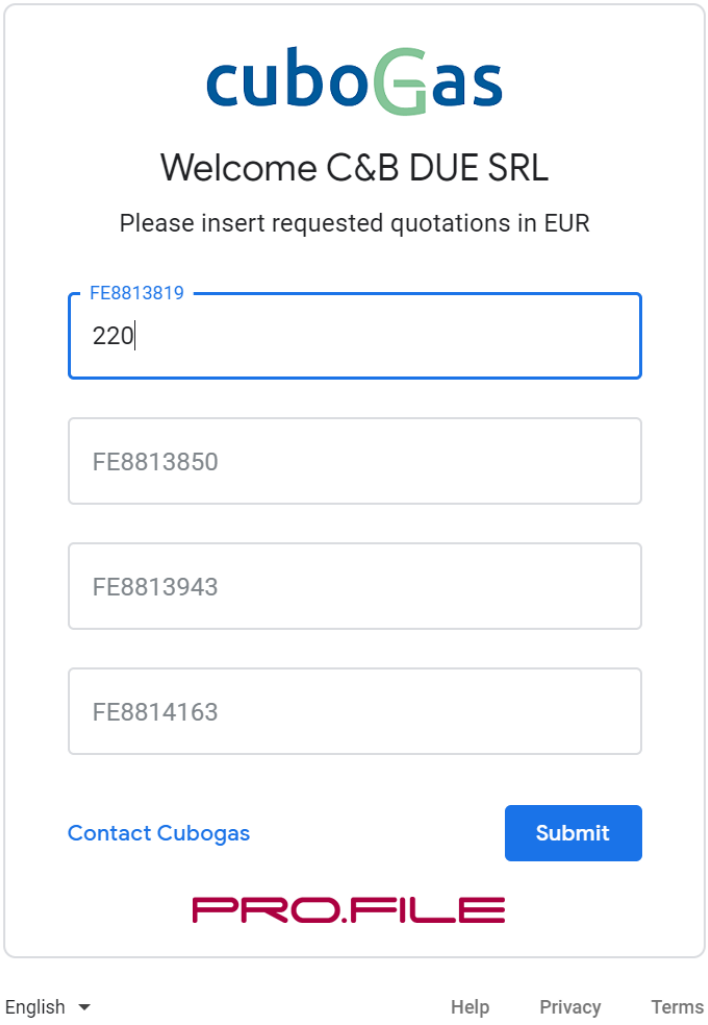


Fig. 55: Mockup of the web page in which a supplier would communicate quotations

Time saved by the procurement department resources could be redirected towards more important activities such as scouting for more suppliers or better performing ones.

Another major implication must not be overlooked: less time to complete current activities means way more suppliers will be added to the roster which in turn means more competitive prices.

The key to save money on components (which make up for roughly 65% of the cost of the product) is, of course, having multiple possibilities to choose where to buy them. This perk comes through an enhancement of the current PLM system and no additional resources cost; it is, therefore, worth considering.

1-D Build System

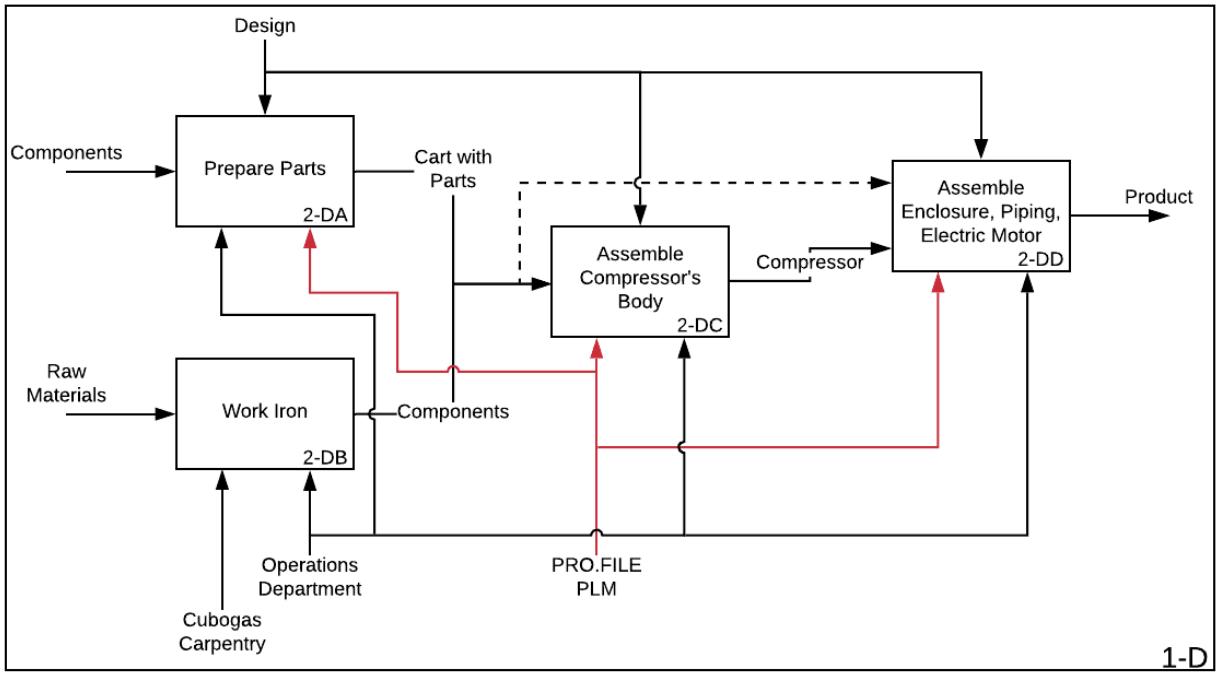


Fig. 56: 1-D Build System: Improved PLM Solution

At this stage, the PLM system should basically be used to perform two activities.

- Contain:
    - helpful information to identify and select parts if anything doesn't work with the system organizing the warehouse
    - guides on how to build the compressor
    - special instructions by the engineering department

All the paper and all the loss of efficiency attached to manage it in a mechanical workshop would be therefore avoided, not to mention the movement of highly classified information related to Cubogas intellectual property and know-how.

- Track:
    - times of all tasks and subtasks. Not only these are useful to grade an order based on difficulty thus pricing similar future machines differently but it is also handy to keep an eye on indirect costs
    - status of the project. Following advancements on the overall order is convenient to be able to control it in a very precise way. In fact, this information could allow to prioritize late machines over on-track ones by assigning more resources to them thus crashing late activities
    - eventual problematic routines. Improving processes is a never-ending operation and it's always a good practice in a company. Direct operators' feedback and data gathered in the PLM system would greatly help

1-E Test System

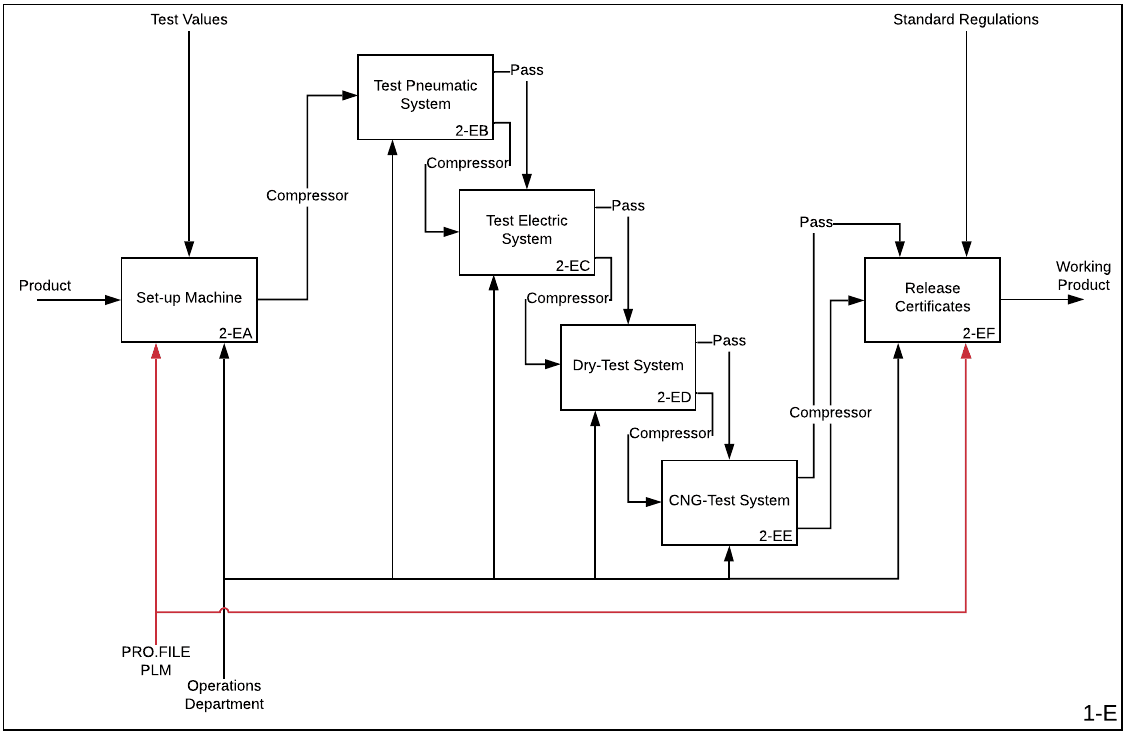


Fig. 57: 1-E Test System: Improved PLM Solution

The fundamental improvement the use of the PLM system could bring in the testing stage, let aside for the document management system of the certificates related to a machine, would be the automation of the set-up activity.

Every machine goes through a customized series of tests of four main categories: pneumatic, electric, dry and CNG (operative scenario). Each of these tests are initiated by a software which receives specific set-up parameters in order to correctly execute the necessary checks. Currently, an operator manually reads the aforementioned parameters off a piece of paper and inputs them in a machine.

Since this operation is a delicate one and human mistakes would be very expensive and very dangerous at the same time, it would be of great advantage to automate the communication between the engineering team and the software managing the testing instead of having a middle-man with no added value.

Ultimately, PRO.FILE should just let the testing operator visualize the parameters for a last minute check before initiating the procedure.

1-F Ship System

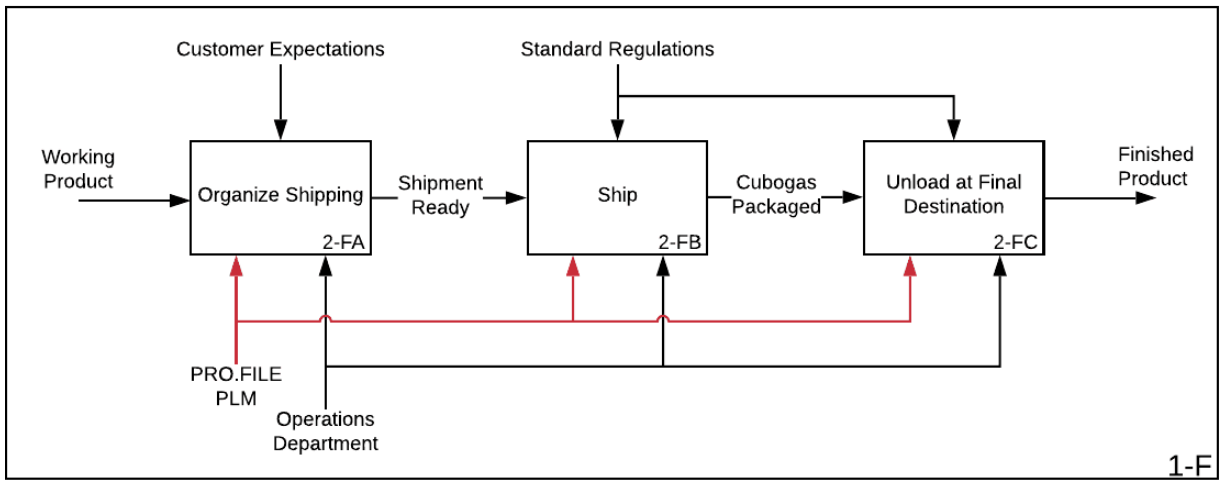


Fig. 58: 1-F Ship System: Improved PLM Solution

Finally, PRO.FILE could improve the shipping phase by recording and making available at the right moment data related to the compressor that has to be shipped. As an example, given what the PLM system should already know from previous phases, the place of delivery and the estimated weight and delivery date could be used to make inquiries to all known suppliers in a certain range. As before, multiple choices available mean high competitiveness which in turn implies economic saving on the activities.

Once found the supplier and shipped the product, all output data could be recorded on the PLM system in order to have it for future references, estimate costs more precisely and rate the shipper.

Beyond Cubogas

The PLM system aims at covering the whole life cycle of a product; therefore, it continues to exist beyond Cubogas where it should operate for 99% of its life cycle. It's worth noting that the product, when it exits the company, starts to bring value to the customer as a physical good in itself but it also continues to bring value to Cubogas: firstly, through the initial sale and then through the maintenance and spare parts services.

Operative Stage

The working stage in which the product operates in real conditions is the most revelatory about the engineering, design, endurance, quality of the single parts and the system overall.

Making it possible for the machine to connect to the PLM system and record data would be a huge improvement towards improving the quality of the machine itself but most importantly of future productions.

Some more indirect implication would be to reward a supplier for reliable pieces, high quality carpentry, long-lasting paint or go to someone else when they do not meet requirements.

Profitability

A need for work hours tracking has emerged in some of the previous paragraphs of this chapter. Implementing a system of fine cost tracking would allow the PLM software to help Cubogas in being profitable.

In fact, if most production costs would be accounted for while the machine is being built, Cubogas could improve not only the profitability of future machines but it could also evaluate the distribution of resources in the company overall.

Information, especially in large amounts, is fundamental when trying to streamline a process in order to improve margins or undercut competitors and a PLM system is a good way to provide it.

PLM Capability

As a comparison with the current situation, the graph in the figure below highlights process improvements related to a more informed usage of the PLM system. The inner blue grading represents the existing situation, the outer red grading is, instead, the desirable to-be scenario.

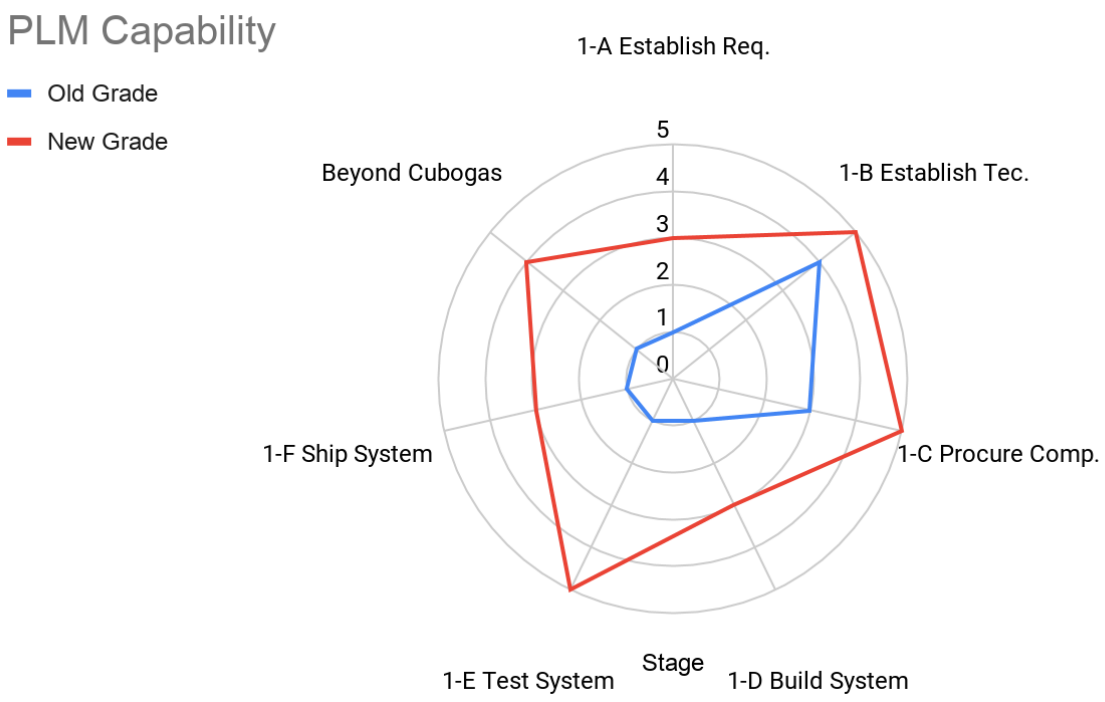


Fig. 59: PLM Capability Maturity Assessment in Production Stages

Even though the one depicted here is an ideal situation, every bit can help improve the company. Therefore, no enhancement should be overlooked if it's worth investing in.

Chapter 6 - KPIs for PLM Benefits Evaluation

To the purpose of creating a tool to measure the effectiveness of proposed improvements this chapter will introduce a set of indicators and the way they can be evaluated.

Furthermore, the implementation of the improvement proposed in chapter 5 for function "*1-C Procure Components"* will be analyzed from the point of view of intangible benefits and possible profits.

KPIs Description

A KPI (Key Performance Indicator) "is a number or value which can be compared against an internal or external target (benchmark) to give an indication of performance". Also, it can be defined as a metric which aims to evaluate the success of an organization engaging in a particular activity.

The performance indicators by which the PLM benefits will be evaluated are divided in 5 macro categories: quality, time, cost, infrastructure and communication. For each of these categories a number of indicators have been identified in order to evaluate the current situation and the would-be scenario and to keep track of the improvements as the PLM enhancement plan is set in motion.

- Quality
    - Product Traceability: the introduction of a configuration management system allows for more accurate product information and traceability
    - Improved Documental Management: archiving, authorizations and versioning
    - Drawing Changes Number: average number of changes in a drawing
    - Part List Changes Number: average number of changes in a bill of materials
    - Engineering Changes Number: average number of changes overall
    - Non-Conforming Elements Number: average number of non-conforming elements

- Time
    - Startup Average Time: average time for an order start-up (kick-off meeting to actual production)
    - Time to Market: complete product development time (kick-off meeting to shipping)
    - Average Time for an Engineering Change Proposal Processing: proposal to implementation
    - Average Time for Document Creation: average time between document (especially technical drawing) need and its release to be accessible by other internal users
    - Average Time for Document Change: average time between document change need and its re-release

- Cost
    - Carry-Over Components Percentage: percentage of previous projects' components that are employed in new projects without changes
    - Change Cost before Preliminary Design Review: average cost due to a change that has to be implemented before the preliminary design review
    - Change Cost before Building Review: average cost due to a change that has to be implemented before the building phase
    - Document Storage Cost: average cost for document storage
    - Document Searching Frequency: average frequency with which the documents are being looked for
    - Document Searching Time: average document searching cost
    - Request for Deviation Processing Cost: average cost due to a request for deviation from original specifications
    - Request for Deviation Number: average number of requests for deviation from original specifications
    - Document Printing: average number of pages printed
    - External Suppliers Printing: average cost of pages printed externally
    - Engineering Change Proposal Number: average number of engineering change proposals

- Infrastructure
    - Drawing Average Access Time from Storage: considering all different storage methodologies employed
    - Information Technology Platform Ownership Cost: average cost to maintain the infrastructure
    - PLM Users Number: how many users organize their work through the PLM system

- Communication
    - Average Document Approval Time by the Customer: average time in which a customer approves a document and approval is communicated back to all interested parties
    - Average Drawing Searching and Transferring Time: average time needed to search for a drawing and transfer it
    - Average Documents Number: average number of documents per order
    - Average Drawings Number: average number of documents per order

The most relevant indicators from each category will be selected in order to evaluate them in the current scenario and how they could change over time.

Each one of these indicators will be also ranked to measure its weight relatively to the overall evaluation. A grade will be given out based on the following characteristics an indicator can have:

- Significance (S): how much the indicator is correlated with the PDM introduction
- Measurability (M): how much the information can be accurately measured
- Reliability (R): how much the measure can be deemed correct and reliable
- Feedback rate (F): how quickly analysis and data acquisition can be developed
- Visibility (V): how much visible could the indicator be when tracking it through the PLM system

All of these characteristics will be graded on a scale from 1 to 5 where 1 means very low and 5 means very high. This ranking process allows to verify that data will be consistent throughout future gatherings and that proposed improvements are actually feasible, but most importantly, that the effort is taken in the right direction.

Reference KPIs AS-IS

For exemplary purposes the top ten relevant aforementioned indicators will be graded based on their significance, measurability, reliability, feedback rate and visibility relatively to the overall flow of an order within the company as described in chapter 3 (with the additions of the current usage of PLM in chapter 4).

Most Relevant KPIs

Indicator	S	M	R	F	V
Product Traceability	5	5	4	3	3
Improved Documental Management	5	3	1	1	1
Engineering Changes Number	3	5	5	3	3
Startup Average Time	4	5	5	4	5
Time to Market	4	5	5	4	5
Carry-Over Components Percentage	4	5	5	5	5
Document Printing Cost	5	4	2	3	1
External Suppliers Printing Cost	5	4	4	4	1
PLM Users Number	5	4	4	5	5
Average Drawing Searching and Transferring Time	5	3	3	4	3

The following table represents the ranking of the indicators. The top 5 will be selected to be quantified:

Most Relevant KPIs per Category

Indicator	Total Grade
Product Traceability	20/25
Time to Market	23/25
Carry-Over Components Percentage	24/25
PLM Users Number	23/25
Average Drawing Searching and Transferring Time	18/25

The benefit of the improvement of the PLM system will now be presented through the resulting top 5 indicators through historical data gathered inside the company and forecasts based on how much the upgrade could impact the analyzed meter.

Most Relevant KPIs, PLM Improvement Analysis

Indicator	As-Is	Would-Be	Gain/Loss
Product Traceability	Low: merely the bill of materials and some documents related to components	High: not only the product's manufacturing but also the successive life of the product could reveal very detailed information hitherto untracked	Much more detailed information on the product, components, suppliers, cost, profitability...
Time to Market	12-16 weeks	<10 weeks: the more data the system gathers, the more scheduling, planning and production will move quickly	Cubogas products are already very high quality. Beating competitors on delivery times would be a strong advantage for the company
Carry-Over Components Percentage	90%: improvements would be very effective since even 5% means 40 less components to worry about	>95%: data analysis could find patterns which would allow for a very high carry-over percentage starting from many basic configurations	More streamlined and standardized production, decreases time to market
PLM Users Number	15 users: engineering and procurement departments only	• 50+ users: soft implementation, most employees use the PLM system • 500+ users: full implementation, external users join the PLM system	A PLM system is as effective as the amount of data in it. Many users mean a massive amount of data. If even the external actors used it, information would be even more accurate and detailed
Average Drawing Searching and Transferring Time	~20 seconds per component: searching time ~10 seconds per component: download time ~30 seconds per component: email time	Null: every drawing is instantly available on the same platform to all users who have been granted access to it	Save time on tasks that can be easily automated, more details in the next paragraph

1-C Procure Components: PLM Benefits Estimation

After experiencing first-hand how work in the procurement department of Cubogas is performed, here's an estimation of the benefits the improvements proposed in chapter 5 could bring.

As-Is	Would-Be	Estimated Benefit
Check that the technical drawing is released and final	Automatic system check	Avoided loss of about: $0,5\ h/day *$ $3\ resources *$ $5\ days/week =$ $7,5\ man * hours/week$
Download technical drawing	-	Avoided loss of about: $0,3\ h/day *$ $2\ resources *$ $5\ days/week =$ $3\ man * hours/week$
Identify related supplier	-	Avoided loss of about: $0,1\ h/day *$ $3\ resources *$ $5\ days/week =$ $1,5\ man * hours/week$
Send files manually to the supplier	Send email notification to the supplier of new technical drawings available	Avoided loss of about: $0,7\ h/day *$ $2\ resources *$ $5\ days/week =$ $7\ man * hours/week$
Input offer in the ERP system	-	Avoided loss of about: $(1\ h/day *$ $1\ resource +$ $3\ h/day *$ $1\ resource) *$ $5\ days/week =$ $20\ man * hours/week$

The total estimated savings amount to about 1.000 hours per year in FTE (Full Time Equivalent) resources time, combined for the whole procurement department. This kind of effort, which can be easily automated, could be redirected towards other, more creative, kinds of tasks such as looking for new strategic suppliers or refining already existing contracts to obtain better deals.

Chapter 7 - Conclusions

All in all, the thesis shows how a thorough use of a PLM system in a company can help improve it and save time on processes, which in turn helps in reducing time to market, increasing product and documentation quality and reliability and maximizing cooperation among internal or external actors involved in the whole supply chain.

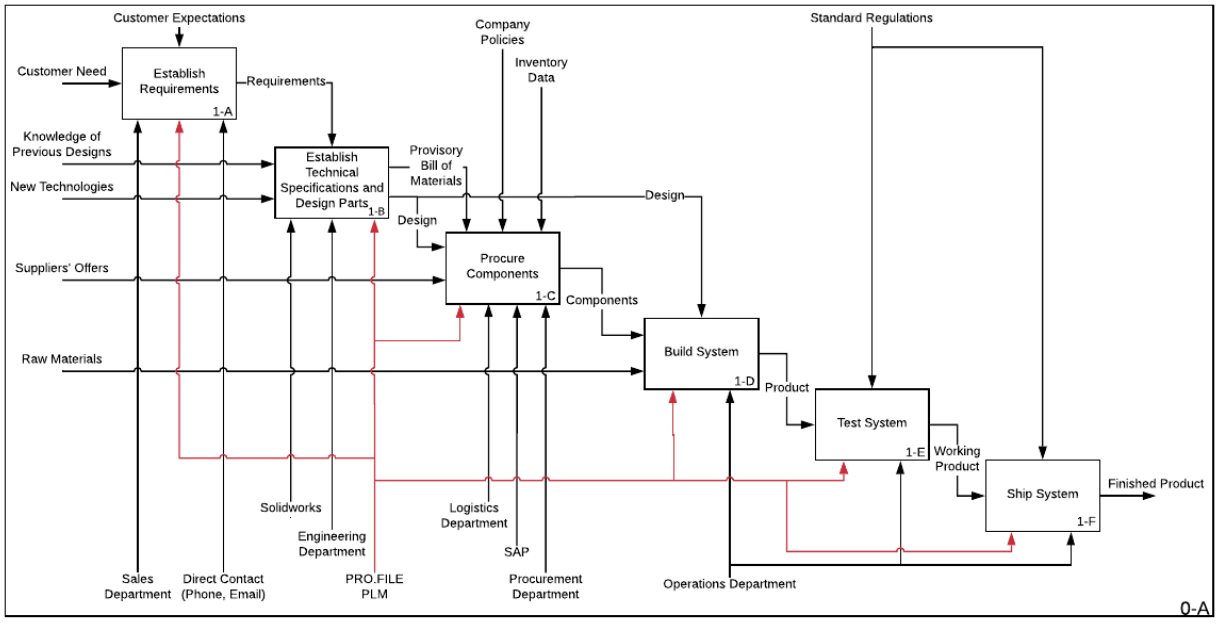


Fig. 60: Inside Cubogas Level 0: PLM revision

As shown in the figure above, the PLM system can penetrate every branch of the company and improve it sensibly. The possibilities are virtually unlimited, even more because the more data is created, the more data is used and the more data becomes useful.

Instant availability of information, elimination of the use of paper, reduction of human mistakes in communication, improved communication among different departments are only some of the big benefits that the PLM system can help develop.

The most important resources become data and insights about the product and its whole lifecycle. Especially in these times, where big data is a fundamental strategic advantage on competitors, it is important to possess an instrument which allows to quickly transform raw data into useful information for the company. A good PLM system, if well established in the whole company, can do it autonomously.

The whole point is to fully achieve the PLM benefits and ultimately to obtain higher margins on the products sold or stronger competitiveness given by a plethora of small improvements in the whole process flow.

Future Works

This thesis aims to be a guideline for process improvements in a medium enterprise. The next step is to analyze the estimated costs of the described improvements and to organize a team to carry them all out, one by one, prioritizing the most effective one (through a benefit over cost ratio).

The process would be very long and slow but a certain investment in the growth of the company and its scalability.

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