Universitetet i Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY

MASTER'S THESIS

Study program: Offshore Technology - Industrial Asset Management	Spring Semester 2018 Restricted access
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Title of thesis: Digitalization and enabling technology: A study of a modelling technology and its Applications	
Credits (ECTS): 30	
Keywords: Digitalization Smart Assets Decision Support System Multilevel Flow Modeling	**Number of pages:** 105 Stavanger, June 14, 2018

Acknowledgements

As the final written work of the master program (MSc) Offshore Technology - Industrial Asset Management, this Master thesis is submitted at The Faculty of Science and Technology, at the University of Stavanger in Norway.

I would like to express my gratitude to the academic professor Jayantha Prasanna Liyanage and the industrial professional Bjarne André Asheim, Managing Director of Eldor Technology. I would like to thank them for all their support, time and encouragement to complete my thesis.

Finally, I would like to express my deepest gratitude to all my relatives, in particular my parents and sister, and friends that helped me to go through this challenge.

Abstract

Decision support system is fundamental for any industrial process. In the Oil & Gas industry is essential to have this support, but in the present time it is not usually done effectively. Oil and gas operators that are use to work in the control rooms deal everyday with advanced analysis strategies of the facilities. However, dealing with the data they receive is not always easy or reached in real-time, making difficult the optimization of the operations. This lack of information and experience when treating process data leads companies to fail in performance, efficiency and economy, and it represents a challenge that the Norwegian company, Eldor AS, is facing successfully with the creation of Egolf.

The purpose of the present study is to show the importance of Digitalization and operations of Smart Assets in the industry, enhancing better performance and optimizing the process decisions that will effectively reach the main goals of the companies that apply them. To do so, the study of a solution is shown in the thesis proving that Multilevel Flow Modeling approach for the representation of flow processes, applied to Egolf technological program can provide an advanced alternative through causal analysis application. This new technology enables the real-time access to crucial information providing efficient decision support for continuously increased productivity, overexposure risk, and unnecessary costs.

Engineers can use Egolf as an effortless and user-friendly cloud-based tool to tackle challenges that the process industry is facing nowadays like continuously increased productivity, accelerated product introduction, optimized and more flexible production, and assured product quality, predicting the process behavior when it is expose to abnormal conditions in the Oil & Gas industry and, maybe in the future, in many other sectors.

KEY WORDS: Digitalization; Smart Assets; Engineering Asset Management; Decision Support System; Multilevel Flow Modeling; Industrial Process

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1 Introduction

1.1 Digitalization and Smart Assets for Decision-making support

Digitalization as a trend and operations of Smart Assets have demanded to improve decision-making in the different sectors and markets. Then, digital data is generated so, through innovative technology and machine learning, that can be interpreted after getting more insights through data science. Considering this, operations of smart assets, as Oil and Gas platforms or Health-care facilities, are very useful for the industry and increase value to the companies. According to Liyanage and Langeland this term was born due to the demand for instant steps to improve operational efficiency and to decrease operating risk in offshore exploration and production activities. It is related to the smart use of advanced information and communication technologies and new data management techniques.

Everyday people experience new opportunities and hazards so there is always a chance to make wrong decisions. Furthermore, within a company, two sorts of decision making can be defined up to the type of process requirements that needs to be performed. This decision making can be centralized if the performance allows taking time in order to choose the right actions by the head of the department. On the other hand, it can be decentralized when rapid decisions need to be made to the right workers can take responsibility for it. Criticality, risk and predictive methods help to identify the big problems and opportunities as well (Woodhouse, 2010). In order to reach a suitable decision-making, data and information are essential to take into account all the aspects of cost, risks, and longevity. Therefore, data, information and knowledge management are essential factors that companies must invest in

(Woodhouse, 2010). Using this, the organization can have a worthy decision-making system supported by the use of innovative technologies.

According to Frankel (2008), the environment related to decision-making is changing because of the new technologies. Those are able to monitor, measure, record, analyze and compare making to develop solutions and required actions of it possible. The employees can have access to information at the real-time, they can get the results of analysis of the data and knowledge of the current conditions as well, so it makes possible to deal with changes directly and much more effectively.

1.2 Challenges in the process industry and Scope of the thesis

The process industry is facing a lot of challenges in the present time that are causing severe impacts in their performance. Among these challenges, Siemens states the following ones as the most crucial: continuously increased productivity, accelerated product introduction, optimized and more flexible production, and assured product quality (Lorenz, 2013). Besides, lack of a good decision support system, wasting time and money carrying out repairs at the most inconvenient time, unnecessary predictive and preventive maintenance regimes leading to over downtime, and inefficient monitoring of the physical system increasing risk exposure, are the main problems the industry is coping with. The need for better and more flexible control of the industrial activities seems obvious but, still, a lot of effort needs to be made to elaborate efficient solutions.

The purpose of the present study is to see the way Digitalization as a trend has improved the operational performance in the industries. Also, how 'Smart Assets' like Oil and Gas facilities have demanded more reliable and advanced technologies for efficient decision support. Besides, a study of how industrial companies rely on their Decision Support Systems nowadays and in the future applying innovative technologies. The evaluation of the potential of a new tool has been developed due to the need for new technology for suitable industrial decision support. MFM method is selected for the industrial process representations, and Egolf tool will embrace those layouts and analyze them in abnormal situations. Three digital simulations of industrial processes in different contexts are done proving that, Multilevel Flow Modeling (MFM) approach applied to Egolf technology can provide greater decision support. Thus, the analysis of one of the digital processes is carried out to study if a situational awareness framework is delivered and the effectiveness of its decision support system. The data and information frame expected should optimize the decision process that will effectively reach the main goals of the companies that apply them quickly and safer.

1.3 Methodology

The first step was taken began by analyzing the role that Digitalization and Smart assets are playing in the present reading recent articles and relevant reports to study the revolutionary accessible applications implemented by different companies. The development of the research demanded full-time study due to the learning process of the innovative applications for the completion of the thesis. During this learning process, few interviews were held related to the MFM methodology, and meetings in Eldor office helped for the analysis and modeling of the processes applied. Once, I could join a big meeting where professionals from Denmark could come to the Eldor office to discuss further development and enhancement of the product.

Furthermore, having a close collaboration with Eldor AS company helped through the investigation with the application of their new tool Egolf for the demonstration of the great advantages the new technology can provide. For that, often weekly visits and a desk in Eldor office was provided for the success of the study.

1.4 Limitations of the study

As limitations along the thesis few points can be mentioned. Firstly, entire meaningful knowledge of industrial processes was a disadvantage, so investigations and studies were carried out for the selection of convenient industrial processes to be applied for the research.

Secondly, the lack of comparative studies with other new technologies due to the application of only one innovative tool to show the impact of using modern assets in the industry sector. And thirdly, underdevelopment work was carried out in Egolf and the mfm-test engine by the professional employees of Eldor AS and the Technological University of Denmark (DTU), respectively. Thus, ought to this ongoing advancement, it has been challenging to make a complete analysis of all the characteristics.

1.5 Layout of the Thesis

The topics in the Thesis are divided as follow:

- **Chapter 1 : Introduction** The background of digitalization and implementation of smart assets is presented, and an introduction of the Egolf cloud-based software is described. Besides, some difficulties during the study are also mentioned, and eventually the layout of the Thesis.
- **Chapter 2 : Digitalization and New Technology** A detail survey is presented of how digitalization affects our day-life now and in the future.
- **Chapter 3 : Technologies and Techniques** A detail survey is presented of how the implementation of smart assets has changed the way industrial enterprises work by presenting some examples of the assets regarding processes simulations.
- **Chapter 4 : Multilevel Flow Modeling Technique** MFM approach and other different methods that are used for industrial companies nowadays are described and compared. To narrow the study, a multilevel flow model (MFM) was the method applied for the further developing of this investigation.
- **Chapter 5 : Study of Application of Egolf Technology in different contexts** In this chapter Egolf and its characteristics are described explaining its effortless use providing crucial support to operators in the control rooms for industrial processes. Finally, three different physical systems (gas pipeline, water heating tank, and a power

generator plant) are selected only under the condition of previous acquired general understanding .

- **Chapter 6 : Egolf Technology Analysis and Decision Support** Causal reasoning analysis of the water heating tank is explained, so the implementation and the results of the model are shown verifying the simple use of this innovative tool that helps operators through the analysis of abnormal operations.
- **Chapter 7 : Future Egolf Applications** In this chapter, little brainstorming is made to include Egolf and MFM approach for a broad future application.
- **Chapter 8 : Discussion and Conclusions** The last chapter in this thesis shows the main conclusions for this and future studies, highlighting that Digitalization and smart assets play an important role in the industry. Then, both MFM method focus on objective analysis and Egolf seen as a useful tool for the prediction of abnormal process situations, provide good situational awareness and decision support through abnormal situations.

2 Digitalization and New Technology

This chapter will present and introduce the main concepts on which this thesis is based.

2.1 Digitalization

According to (C. Handscomb & Woxholth, 2016), McKinsey partner, there are three game changers that are modifying the Oil & Gas industry. He defines them as: firstly, the existence of massive resources in the world is forcing the oil companies to focus on cost, efficiency and speed due to the stability of low oil prices, secondly, profound technological advances are including automation in all areas and requiring high human-machine interaction (data analysis), and thirdly, regarding social demands lead to demographic shifts to attract the new generations to work in this sector. Sadly, the oil and gas industry felt in the comfort zone of having experts for a long time that now it is crucial to take into account new generations that will help to drive innovative technologies and connect new ideas for the future. Step by step, innovation is taking heavier leadership, and this could help to engage younger workers (C. Handscomb & Woxholth, 2016).

For that, Handscomb also mentioned five ways of how oil and gas companies can adapt to this near future period. The following list shows the ideas recommended to remain still competitive through adaptation (D. Branson & Morrison, 2017):

1. Organizational agility

2. Digital organization

3. The millennial-managed organization
    a) More flexible employment structures
    b) A new working environment and culture
    c) A positive external footprint
4. The decentralized company
5. A redefinition of what's core

This has become a necessity despite the fact that the Oil and Gas industry was familiarized with big data, technology, and digital innovation from the early 1980s, but for longer than a decade the industry has not taken any advantage of their opportunities in a meaningful manner (Forum, 2017). Thus, experts talk of the 4Th industrial revolution as a new era that is coming thanks to the way digitalization is taking place and gaining more and more importance. But, "There is no digitalization and no digital transformation without digitization (of paper and processes)" as found in (i scoop, 2018).

So, at this point, the access to new technologies is obviously helping but there is still a long way to go in order to transform everything non-digital/ analog/physical into the digital version or format. Once this is done, the utilization of all this information and data would be much simpler and faster by a computing system. Document scanners are the most common tool used in business. These machines create a digital representation/document imaging out of the scanned paper. After this step companies can achieve those documents or what is even more important for them, use the data that those scanned documents contain. To do so, data can be retrieved with capture software and extract it in a digital manner and give it a function to achieve a goal. In the context of processes, its definition is very similar to automation. As far as businesses digitize all physical documents to convert them into digital data, those companies are working on the automation of business processes and work-flows for example, and it will be considered digitization as well.

In conclusion, digitization of information enables, by automation of manual processes, transforming data from an analog to a digital format. According to Larry Boyer, his definition of

Digital Transformation is (Boyer, 2018):

“Digital Transformation is the change of business operations, culture and mindsets from the computer and industrial age to a new mindset and operations that connect humans and machines to create exponential change and tipping points.”

The Figure **2-1** shows in which state towards digitalization companies are (Gartner, 2013).

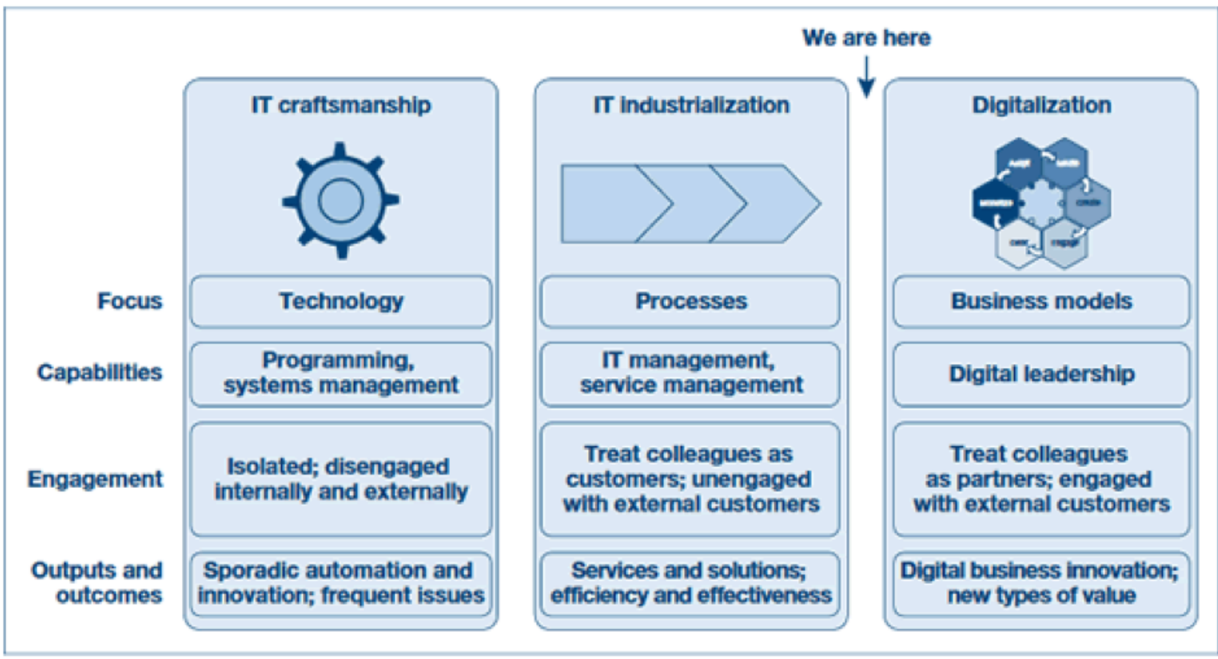


Figure 2-1: Digitalization according to Gartner end 2013 – more or less a synonym of digital transformation (Gartner, 2013)

When speaking about digitalization means actually the utilization of data and all digital technologies to generate profit, enhance business, develop processes and generate a suitable atmosphere for further digital companies wherever the data origin is. According to the i scoop article, in business, digitalization is focused on the improvement and transformation of its operations and functions, processes, and activities by the application of data and digital technologies for further and better performance to reach a certain benefit. In this report, they also refer to digitalization as a different way a business can optimize its functionality. In a digital workplace, digital tools can be used (mobile devices and technologies) which offer them global collaboration and communication platforms, creating new opportunities, involving more than barely digitalized data (i scoop, 2018).

The last definition they include, goes even further and it is related to how digital technologies can affect all possible societal and human activities in the healthcare sector, government, marketing, financial sector, etc. being able to transform and help in all sort of areas. In conclusion, digitization is required to go towards digital transformation and for a business to become a digital business needs digitalization (i scoop, 2018). It is also crucial the use of standardized approaches across geographies that support performance and allows for lessons to be shared more effectively across the organization (Dominik & Handscomb, 2015). In the future, companies in all industries will evolve toward more flexible units with the intelligence communications-enabled network and a more variety and decentralized network of lower capacity building much robust entities, like many US electric power companies are facing now the way toward digital transformation (Smith, Power, & Utilities, 2018).

World Economic Forum, in collaboration with Accenture, states some recommendations to the industry for a successful digital transformation as found in (Forum, 2017):

- Make digital a priority for senior executives.
- Drive a culture of innovation and technology adoption.
- Invest in human capital and development programs that promote new, digital thinking.
- Put in place a methodical approach for developing and/or industrializing new capabilities.
- Reform the company's data architecture.
- Identify opportunities to deepen collaboration and understanding of sharing-economy platforms.

2.2 EAM, Smart Assets and DSS

2.2.1 Engineering Asset Management

The entities' strategies are based on what, when and how to invest, considering the risks among other kinds of decisions so these are gathered all in a framework to see and ensure that the final actions lead to the desired companies' goals. According to Woodhouse, that is Asset Management about found in (Woodhouse, 2010). In addition, another definition needs to be included which says that engineering asset management (EAM) implies to gather human dimensions and decision modeling aspects of EAM with technology through systems integration, considering crucial to have an overview that includes strategy, risk measurement, safety and environment, and human factors. Thus, it is known that an asset manager is involved within several kinds of assets, like for example in chemistry analyzing organization there are asset managers for samples, analysis and control and monitoring within the laboratory asset group. Then, engineers are asked for providing technical knowledge essential to decisions regarded to the organization's assets, including technical knowledge of design and operation, and engineering and data analysis skills in reliability, maintenance, etc. (Hastings, 2010).

The main purpose of EAM is the application of integrated engineering structure with the organization's business. This relationship should be carried out effectively while achieving a particular goal, and it can be done by using smart assets and implementing a more digitalized performance. These requirements are connected and there is a need to understand the data and information management issues seen as a part of a robust asset management system. These are such a great challenge. Among they stand motivation, education, communications, leadership, teamwork, and sense of ownership, so the purpose is to ensure and establish the sustainable approach of AM as it is the need of information technology, integration of data and changes in the human dimension. EAM got an excellent Information Technology system (IT system) so can collect, keep and study all the information related to the asset life-cycle processes. Using this, the organization can have a worthy decision-making system.

2.2.2 Smart Assets

According to Liyanage and Langeland this term was born due to the demand of instant steps to improve operational efficiency and to decrease operating risk in offshore exploration and production activities. It is related to the smart use of advance information and communication technologies and new data management techniques. Smart assets through integrated e-operations go through joint exploitation of advanced technologies, digital information and communications technologies capabilities.

Advancement in information sciences and technologies, and long-term commercial benefits of their successful usage, not only systematically builds strategic digital capabilities, but also provides necessary digital environment for active knowledge and intelligent data management. This organizational setting is capable of (Liyanage & Langeland, 2009):

- Real-time data acquisition, joint data analysis and data interpretation.
- 24/7 network-based connectivity for collaborative decision making and work planning.
- On-line video monitoring and conferencing facilities.
- Smart sensors, intelligent transducers, and equipment with advanced functionalities.

Real-time operational and technical data for decision optimization , and it allows also tighter integration of work processes, decision loops where the division of work to optimize activities is carried out effectively and efficiently (Liyanage & Langeland, 2009). The Figure **2-2** shows the digital transformation pyramid companies should follow through the application of innovative technology (Turchi, 2018).

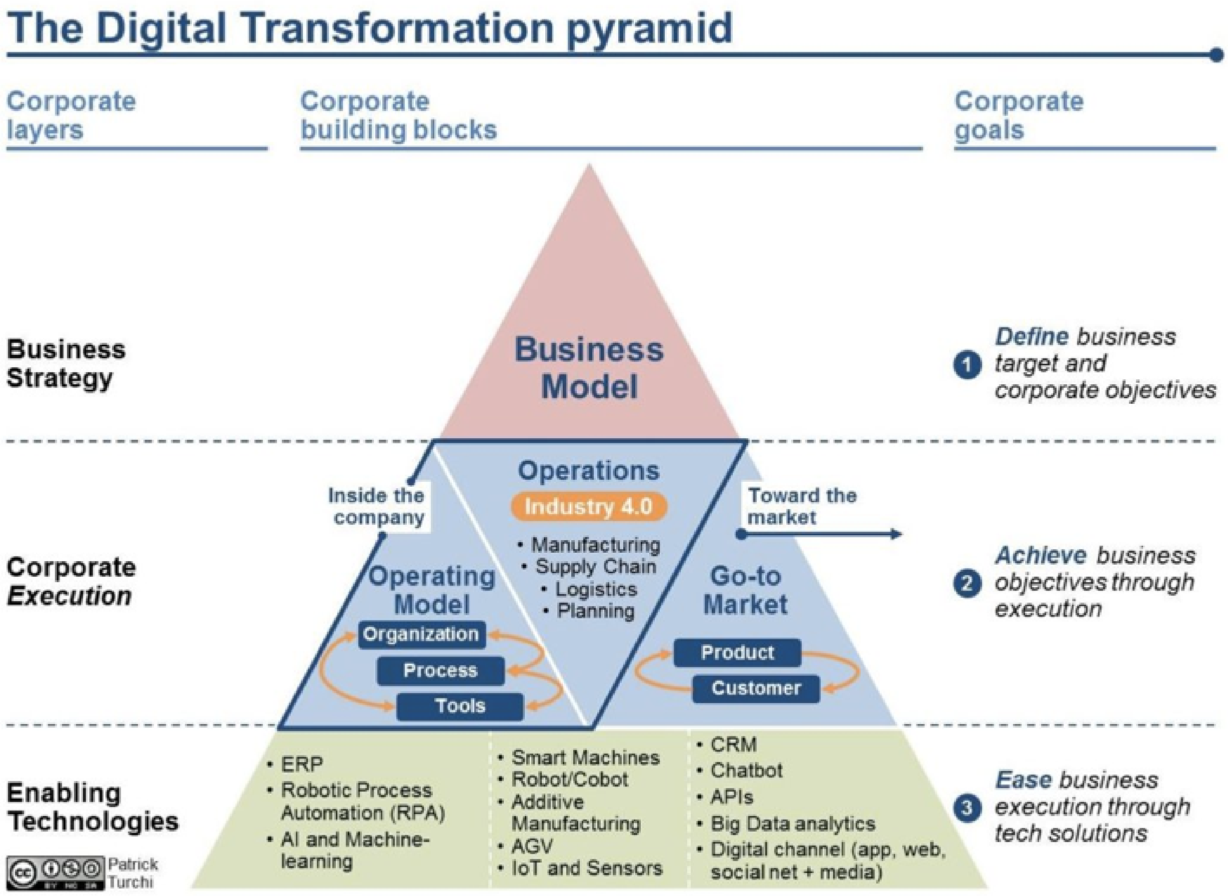


Figure 2-2: Application of technology for digital transformation (Turchi, 2018)

2.2.3 Decision Support System

The system decision process (SDP) is a collaborative, iterative, and value-based decision process that can be applied in any system life cycle stage (G.S. Parnell & Henderson, 2011). It is a process of thinking and of taking actions that maximizes the success of supporting a systems decision. It captures the iterative, cyclical flow of activities that should be performed prior to go through each of the critical decision gates. It is a process of thinking and taking actions that reach the maximum success of supporting decision making in the system. Furthermore, advances on technology is making companies to restructure their decision-making system considering (Frankel, 2008):

- Change drivers: affect environment, technology (time and workers), communication needs, Internet revolution of management, new technological environment, customer relations management and boundary-less organizations.
- These changes require that everybody involved in a business has to be part of the information gathered and can add content. By using this method, the companies can reach their responses quickly and work more effectively.
- The employees can have access to information at the real time, they can get the results of analysis of the data and knowledge of the current conditions as well, so it makes possible to deal with changes directly and much more effectively.

In the Public sector, as a traditional organization, changes have been less noticeable than in the private one due to their different goals. Changes go from product development to process integration and have an impact on the decision environment and structure of the organizations. So the change drivers could be considered as those which affect the environment, technology (time and workers), communication needs (evaluation and filtering), internet revolution of management (effective communication), new technological environment, customer relations management and boundaryless organizations. These changes require that everybody involved in a business has to be part of the information gathered and can add content. By using this method, the companies can reach their responses quickly and work more effectively (Frankel, 2008).

According to Frankel (2008), the environment related to decision-making is changing because of the new technologies. Those are able to monitor, measure, record, analyze and compare making to develop solutions and required actions of it possible. The employees can have access to information at the real-time, they can get the results of analysis of the data and knowledge of the current conditions as well, so it makes possible to deal with changes directly and much more effectively.

For a proper work of the Boundary-less organization, its decision-making system must respect that everyone at any level of the organization can add information to the system flow, must be willing, encourage and able to diffuse their own ideas, give a review and productive criticism of their thoughts and use feedback to convert them into productive and accurate decisions for the good and growth of the company. The organization is really important to assure in time decisions and organizational effectiveness and to make effective use of the new technology. It will be flexible in order to allow people to move among functional departments and groupings. In this organization 'everyone is the director'. Furthermore, it makes possible that cooperation and participation contribute to decision effectiveness. To reach a successful decision, access and sharing of information are needed by the managers and staff, also their ability to use advanced information technology (Frankel, 2008).

2.3 Innovative Tools and Technologies

Nanotechnology, supercomputers, all new technology is a revolution for all industries and sectors. The oil and gas companies have been affected by the era of this new technology, for example in monitoring and maintenance activities by introducing drones and equipment sensors. A new technology, related to well drilling, is the seismic imaging technology which helps to find oil and gas trapped miles away under the seabed and ground. By using this developed and efficient new devices, sub-sea oil fields can be shaped in much more detail creating further advantages in order to reach, from shore, higher reservoir pressures and temperatures at deeper locations and longer distances. Those innovative ways mentioned before show the great impacts of technology at the present time, which can be translated into cost saving and greater production (D. Branson & Morrison, 2017).

The future is heading towards the Digital Oilfield, which means all elements of an oilfield will integrate and communicate at all time and the different companies evolved will control, measure and register all the data that the oilfield reveals. Sensors will constantly read data from pipelines, wellheads and mechanical equipment, and this information will be evaluated by computers connected to real-time operation centers, being the main goal to optimize production and minimize down-times, lowering operating costs and improving productivity. As a consequence, Booz Allen Hamilton's professionals consider that all these improved digital technologies may rise 25% oil and gas assets' profits (D. Branson & Morrison, 2017).

The international oil companies (IOCs) created new technologies and made discoveries that introduced the early evolution of this industry. Recently, national oil companies (NOCs) are trying to develop their own innovations in order not to fall behind their competitors (Saudi Aramco, expertise in enhanced oil recovery, Petrobras, expertise in deep-water knowhow). Besides, international enterprises like Schlumberger or Halliburton provide integrated field management services to operate assets for other companies (Petrofac), and the emerging Chinese and Indian companies, with the desire of having direct control of more complex projects and buy assets, are changing the roles and relationships of the different parties. Thus, new partnership, collaboration, and business models are created ought to the necessity of innovation (D. Branson & Morrison, 2017).

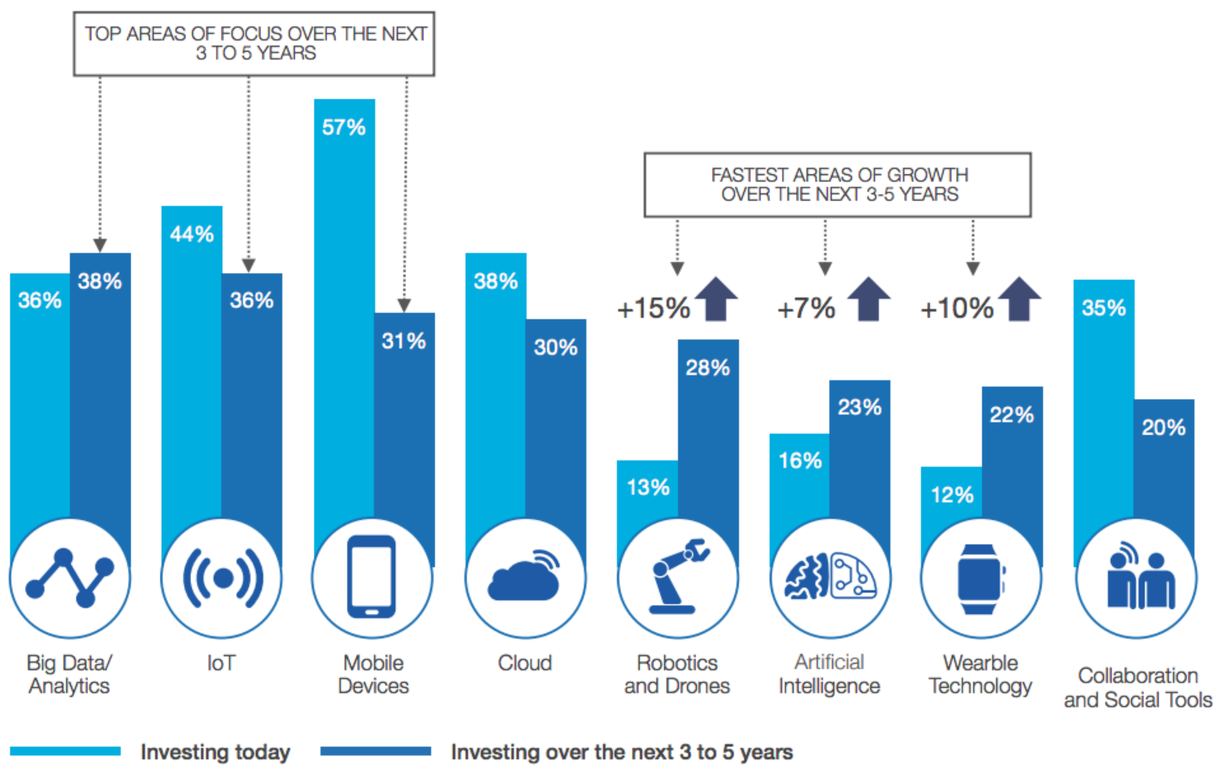


Figure 2-3: Investments in Digital Technologies (Forum, 2017)

Great evolution in technologies is generating immense potential by driving trends in the Petroleum industry. Thus, utilizing these technologies in an innovative way, companies could have greater benefits in all areas by exploring and applying all their capabilities (Forum, 2017). The Figure **2-3** shows the current and future investments in the Digital Technologies (Forum, 2017).

When it comes to upstream enterprises, it is quite challenging to contain expenditure increases in the resource development arenas and supply chain due to all workers layoffs because that meant the eradication of knowledge, experience, and skills. Thus, it is super important that nowadays they take advantage of new technology to monitor all the activities and projects carefully in order not to have a great increase in costs. In consequence, international oil companies need to accomplish innovative digital initiatives for cost and efficiency enhancements and focus on offsetting expense escalation. It is time then for companies to cooperate together to increase value and take advantage of the different abilities of each one of them. For instance, BP and Kosmos generated an alliance to go further and analyze all opportunities available in Mauritania and Senegal, so BP's project will be supported by Kosmos' experience and technical exploration skills. Another example would be GE that has diverse of agreements among different size companies for the implementation of sensors, databases and digital devices to help in the prediction of machine breakdown in deep sea and offshore platforms. Thus, it is essential to develop new collaboration and partnership models (D. Branson & Morrison, 2017).

Time ago, whenever maintenance or physical check of an asset was needed, operators we required to go on the spot facing any kind of risk. Fortunately, all monitoring and checking activities are now automated so physical and manual work on the location are basically applied when extremely required. In the end, smart assets will be managed by themselves and virtually, suggesting if a service or maintenance is required before it is actually crucial which reduces the need for employees and resources, and increases cost benefits. According to Annie Gurton, all those benefits of smart assets are (Gurton, 2000):

- Assets do not get lost (because location is not known)
- Assets are maintained better. Engineers are alerted of maintenance requirements before service is needed
- Assets can order own consumables direct from the suppliers, saving time

- Assets are pre-sold before the lifecycle is reached, enabling best prices to be recouped
- Assets are used more effectively within enterprises, avoiding the need for renting or purchase of unnecessary duplicates
- Helpdesk support is more effective
- Digital assets are logged more accurately and, in more detail
- Illicit flaunting of copyright or patents is minimized
- Charges for use of copyrighted material is made automatically
- Licenses are managed more efficiently
- Can include digitized photographs and other graphics. Systems can search and monitor the Internet for illicit use of copyrighted material

Generation will help companies in the Oil and Gas sector to embrace and develop new technology, creating a variety of smart tools and machines. This kind of equipment will be capable of not only gathering data and information in a numerical way from every single part of the process, which most of the time is not easy to understand but also representing, in a visual manner, for a much better and deeper illustration of the information. Thus, communicating visually enhance the performance of the interpretation along an oil production plant for example, and improve the decision-making system due to a vision of the problem is faster to interpret than words alone or numbers. Eldor AS is on the way to help companies in this sector with its lately released program Egolf offering the composition of industrial flow processes enlightening the cause-consequence analysis.

Summarizing, Technology, applying the use of smart assets, is considered as the driver for changes within a company or a whole industry, and identifying the impact this can make on each level is an essential capability, whereas Digital Transformation is its enabler.

3 Technologies and Techniques

New technology has changed the way companies work nowadays and has opened new greater opportunities in all industries and sectors. Smart Assets are a revolutionary game changer in terms of efficiency and optimization increasing safety, reducing costs and enhancing quality.

Big data is being driven nowadays from everywhere so, in order to capture and analyze it, technology is considered a basic task. Modern companies are using this data at a higher level supported by information technology (IT) systems guiding expertise to take accurate and fast decisions, sometimes, companies can even make decisions in real time thanks to this trend. This means a profound transformation in all industries and sectors like innovation and marketing, being companies as eBay and Google the early leaders taking into account all this major information analyzing the best way to attract people on their business. Due to this new way of capturing and studying data, avoiding instincts and experience decisions, is bringing to enterprises greater business opportunities.

BASF Global is an integrated global chemical company that through the use of digital technologies and data is changing the way four different departments are developing their own activities increasing the effectiveness and the efficiency. These four areas and the way they are being affected are:

- Smart manufacturing: employees at BASF relay on the Augmented Reality application to read the information that sensors and mobile devices have registered from the equipment conditions. Also, a predictive maintenance can be arranged thanks to the modeling of life-data on the operating conditions and the use of sensors to plan the most optimal maintenance measures reducing failures and enhancing the coordination between production and maintenance processes. The power plant 4.0 will be assessed by a precise forecast related to, depending on the time of the year (weather and economic situation), the supply of steam and waste heat by the production plants, steam contribution of the power plants, and the need for electricity plus historical information that the software processes which main goal is finding relationships and establishing connections with energy demand. The new program has been a success improving up to 60% the forecast for stream demand (BASF, 2018c).

- Smart innovations: available networked data structures complexity if simplified using mathematical models and experiments regarding catalyst research, reducing development time and making early hypotheses. Besides, they use life-data obtaining customers' requests of the automotive paints to finally adjust it regarding their needs. The latest approach gathers all information in the core and in one single format, providing faster and better decision-making, for example for a catalyst researcher in a laboratory it is simpler if good from bad samples are separated quickly (BASF, 2018b).

- Smart supply chain: the connection among customers, suppliers, and partners enhance transparency, and with the objective of making deliveries within one hour instead of 24 they created AGB (automated guided vehicle) considered a new kind of vehicle concept. In Ludwigshafen, this type of autonomous and tel-operated mobile will supply production plants at a reduced cost and faster than before. On the other hand, they also provide a platform that gathers global logistics and relevant weather data building a more understandable framework, so departments as logistics and customer service can cooperate together to deliver more accurate and sooner information, affecting and optimizing their supply chain(BASF, 2018d).

- Digital business models: the company provides OASE, it facilitates the connection between a gas production platform and service, and Maglis, suitable for farmers. Easy-to-use and connected tools are supplied supporting decision-making, for example helping farmers to succeed from panting to marketing activities (BASF, 2018a).

Regarding power grid solutions, eSmart Systems company releases Connected Drone coupled with their Intelligent Assistant, which is connected to eSmart Systems Connected Platform and Microsoft Azure for optimizing operation of the power grid. The use of Artificial Intelligence enable Drone Connected to image recognition for further infrastructure inspection improvements. The company present the drone's intelligent features as (eSmart Systems, 2018):

- Automatic detection of masts, insulators, traverses and top hats.
- Automatic detection of objects on power lines.
- Automatic detection of missing top hats.
- Installation analysis of insulators.

Figure 3-1: Drone used for checking of maintenance conditions of wind turbines (Sucasas, 2018)

In addition, a McKinsey research demonstrated that using IT in smart power grids and efficient building, among other areas, could reduce greatly the carbon emissions that the IT industry generates (M. Chui & Roberts, 2010). Meaning that making the right strategies and using the proper smart assets, like reducing servers needed for operations applying visualization software, would mitigate the impacts produced in the environment by reducing the footprint that keeps growing due to the demand for IT capacity and services. The Figure **3-1** shows a drone completing a condition check of a wind turbine (Sucasas, 2018).

According to Agustín Delgado Martín, Manager of the Innovation and Sustainability department in Iberdrola, the company supports the use of drones for the maintenance of the generators to reduce the efficiency loss. In the past years, they used to send an operator to check the blades with the use of a binocular, but now, they are supported by drones for a more exhaustive analysis of the blade conditions. The drone's study not only gives a conventional visual inspection but also, provided with sensors and cameras, insights of failures deep inside the blades. It also is capable of failure decision-making and gives warnings of failure detection, so an operator can go to see the anomaly and confirm the diagnosis, however, the information is downloaded when the drone is back due to its short-term autonomy. It is essential, Agustín says, to not only count on the drone, not only count on the sensors but also and most important to have a software capable of reading and understand the gathered information(Sucasas, 2018).

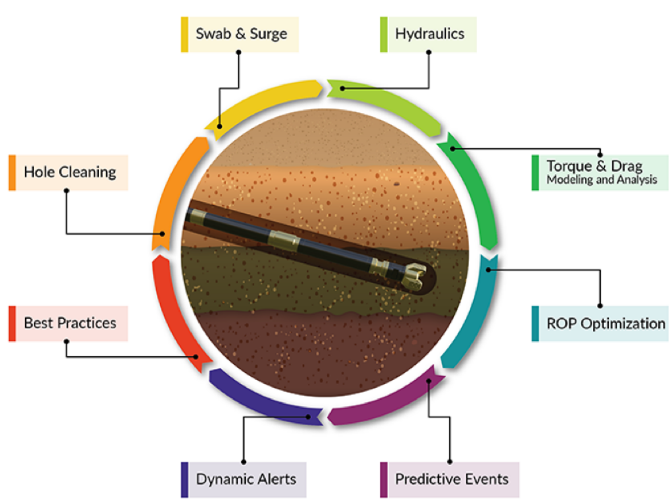


Figure 3-2: Smart Asset in the drilling market (Petrolink, 2018)

In the drilling industry, the complexity of the wells is extreme compared to past times so operators are facing difficult situations to lower well costs to remain competitive in today's market. In Petrolink, they have developed Real-Time Drilling Analytics to keep track of the plan and reducing the time it takes to drill a well maintaining safety and quality and controlling any deviation that could cause big undesirable impact on performance. The Figure **3-2** shows the technology used for Petrolink (Petrolink, 2018).

The previous examples mentioned above are some general applications of the technologies and techniques that mean a big advantage for different activities in the grid and drilling sectors.

3.1 Applications for simulation

Regarding the design of industrial processes, like production of Oil & Gas plants, innovatory software and programs have been also developed and transformed the physical process analysis. This Chapter is focused on these innovative tools used by those enterprises involved in the visual representation of physical systems helping people to deliver a better and deeper understanding of the processes that are applied. The Table **3-1** shows six different types of emerging applications from IT divided into two broad categories: information and analysis, and automation and control (M. Chui & Roberts, 2010).

Table 3-1: Six different types of emerging applications (M. Chui & Roberts, 2010)

Information and analysis			Automation and control		
1 **Tracking behavior**	2 **Enhanced situational awareness**	3 **Sensor-driven decision analytics**	1 **Process optimization**	2 **Optimized resource consumption**	3 **Complex autonomous systems**
Monitoring the behavior of persons, things, or data through space and time.	Achieving real-time awareness of physical environment.	Assisting human decision making through deep analysis and data visualization	Automated control of closed (self-contained) systems	Control of consumption to optimize resource use across network	Automated control in open environments with great uncertainty
Examples: Presence-based advertising and payments based on locations of consumers Inventory and supply chain monitoring and management	*Example:* Sniper detection using direction of sound to locate shooters	*Examples:* Oil field site planning with 3D visualization and simulation Continuous monitoring of chronic diseases to help doctors determine best treatments	*Examples:* Maximization of lime kiln throughput via wireless sensors Continuous, precise adjustments in manufacturing lines	*Examples:* Smart meters and energy grids that match loads and generation capacity in order to lower costs Data-center management to optimize energy, storage, and processor utilization	*Examples:* Collision avoidance systems to sense objects and automatically apply brake Clean up of hazardous materials through the use of swarms of robots

Assets are becoming crucial elements in the information system enabling information and data by capturing, computing, communicating and collaborating that coupled with radio-frequency identification and linked technologies, it is known as "The Internet of Things". Thus, equipment like sensors, actuators will be essential to acquire data, to enable changes automatically, and deliver information transforming business models and enhancing efficient processes. Therefore, all information related to industrial process conditions can be gathered also through sensors and analyzed to make automatic adjustments minimizing downtime, risk, expensive human intervention and increasing productivity.

Chemical, physical, electrical or mechanical activities are involved in industrial processes. Besides, in engineering processes there are a wide variety of interrelated tasks, by nature, machines or people, developing the transformation of inputs into outputs. Also, large quantities production of a material implies series of unit operations for the chemical engineering, so engineers use a different type of diagrams that will be explained in more detail in 4.1, presenting the layout of the process chosen for the simulation in Egolf in this kind of visual representation. In addition, when referring to processes there are three main types: job, batch and flow production. The last one will be the reference of this thesis due to it can be applied to Egolf program, but MFM method can be used for both batch and flow production (BBC, n.d.).

Whereas batch production refers to an intermittent and irregular production, flow production stands for the same kind of operations but without the resting period for a machine to recharge. Therefore, a flow production is described as a continuous process of linked parts from the starting point until completion of the process (LLP, n.d.).

The election of the appropriate flowchart software is essential for those people related to business and industry-specific applications to build easy and fast professional-quality diagrams. Furthermore, tools like Lucidchart and SmartDraw, help the user to create their visuals of a great variety of systems adding collaboration, connection, and presentation features. The Table **3-2** shows the options for impact and good-looking professional visuals that nowadays can be used in the market (L. Fairbanks, 2018).

Table 3-2: Flowchart Software and Features (L. Fairbanks, 2018)

Flowchart Software	**Features**
Edraw	Contains a variety of examples for a lot of kind of visual representations, considered as a visually rich program.
Lucidchart	Browser-based program used for intuitive non-complex drawings but with a diversity of symbols and diagrams.
Adobe Illustrator	Production of complex visuals.
Visio	Production of complex visuals supported with professionally designed templates, and interface and technical functionality (e.g. Ability to set and check rules) for Mac users with ability to export files from another flowchart software in Visio format.
Creately	Real-time interaction characteristics and low cost.
SmartDraw	more complete and powerful than Office or Lucidchart, and easier and more comprehensive than Visio. It is a user-friendly chart to draw all kind of diagrams in all sectors. From simple to complex drawings using automation to create diverse visuals quickly and effortless getting excellent results. The designer can add text to the elements and these interact with each other logically, and a lot of templates are provided so neither training or artistic skills are needed.

The user can have access to all of them using their free trials, having the chance to test the software and check if it fulfills the user's specific requirements before purchasing.

3.2 Process simulators

Engineers can generate optimal process designs for chemical plant analysis in order to manage enhancement strategies, control and optimize operations with steady-state and dynamic plan simulation tool. The Table **3-3** shows process simulator packages applied by different industries, scales and objectives (Simulatelive, 2017).

Table 3-3: Process Simulators and Features (Simulatelive, 2017)

Begin of Table	
Process Simulators	**Features**
Aspen Plus	Design, operation and optimization calculation capabilities. It is applied by petrochemical, chemical and pharmaceutical companies simulating nondeal, electrolytic and solid systems. Scalability and mixing of solution methodologies characterized this tool adding flexibility to the processes and very expensive.
CADsim Plus	BPerformance of chemical mass and energy balances and simulation of dynamic conditions. developing of complex dynamic simulations with the use of batch operations and control logic.
Chemcad	Its libraries enable steady-state and dynamic simulation of continuous chemical processes with endless capabilities.

Continuation of Table **3-3**	
Process Simulators	**Features**
ChromWorks	User-friendly simulation tool for chemical and biochemical process simulations based on technical characteristics and including a cost evaluation module with enabling the use of experimental data.
Aspen HYSYS	Process simulator for upstream production, gas treating and processing, refining and safety analyses(aspentech).
Design II for Windows	Heat and material balance calculations design for engineering processes with database and crude library facilitating process engineers with such designs instead of computer operations.
DWSim	Open source for Windows and Linux systems for chemical process simulations.
DynoChem	Focused on the pharmaceutical industry, capable of template models generation and incorporation of multi-site equipment databases.
EMSO	For simulation, optimization, and process control of general processes using a modeling language in C++ for Windows and Linus systems and compilable to others if needed. It offers static and dynamic simulations with a graphical user interface for model development, simulation execution, and visual results.

Continuation of Table **3-3**

Process Simulators	**Features**
Eq-comp	Complex chemical engineering simulator for vapor-liquid properties regarding hydrocarbons leading to pressure vessel, pipeline design and similar equipment, predicting phase equilibrium properties.
gPROMS	For products and their manufacturing operations with integrated design and optimization. Export formulations, define risk factors and develop formulation and manufacturing chain effectively.
Hydroflo	Identify steady-state flows and pressures in a single source and pumped flow systems. It is a drag-and-drop workspace providing a vertical view of the process with PDF reports of system elements and instant feedback of the system elements.
Hysys	Similar to Aspen Plus but focused on oil, gas and refining processes for optimization of operating parameters for feedstock changes. Better planning and optimization decisions are made using calibrated models and tools for import and export of petroleum assays are available.
HSC Chemestry	For easier and quicker thermodynamic and mineral operating calculations. Specific for process research, development, design, and digitalization, compounded by 24 modules connected to 12 integrated databases.

Continuation of Table **3-3**	
Process Simulators	**Features**
IndissPlus	For chemical engineering processes in normal operating conditions with a rich library within Thermodynamic and Unit Operation Modules. New models can be incorporated from another platform (multi-layer component architecture).
ITHACA	For chemical, mining and mineral processes with graphical interface to build flow diagrams, real-time information, results exporting, specific library and communication with data logging and operating systems at low-cost.
LIBPF	For industrial continuous systems using building blocks for process engineers in C++allowing the split up of structure and configuration from operating conditions facilitating the reuse of work-flow by generating flow-sheets as objects.
PROSIM	Chemical process simulation software or energy, oil, gas, chemical, petroleum, pharmaceutical and food industry to improve plant efficiency and process design and decrease the impact on environment.
CHEMCAD	For chemical process model designs enhancing productivity, connecting day-to-day tasks for chemical engineering work-flow and engineer's efficiency.

Continuation of Table **3-3**	
Process Simulators	**Features**
Egolf	User-friendly web-based tool used for building models according to Multilevel Flow Modeling (MFM) methodology to represent goals and functions of complex engineering systems.
End of Table	

The Norwegian company Eldor Holding AS has produced a cloud-based MFM model creator and editor coupled with Danish DTU cooperation. The company released their version accessible to anyone by creating a user account logging in to start creating personalized MFM projects and models. The program is capable of the representation of chemical processes and plants from any location in the world. Thus, by implementing the use of this cloud-based program with the reasoning software, operators will be able to discuss operation conditions and safety parameters of abnormal situations through industrial flow physical systems providing them proper situational awareness and decision support.

Eldor company defines EGolf as a “web-based tool used for building models according to Multilevel Flow Modeling (MFM) methodology to represent goals, functions, and relations of complex engineering systems” (Eldor, 2018). MFM methodology and its goal work domain are described in more detail in 4.3 and its main characteristics are confirmed by a standard language that can model functional relations of industrial plants and it is well suited with human cognition and problem-solving. It is important to understand this methodology due to its capability of modeling flow processes improving safety and plant availability through its objective domain (Burns & Vicente, 2001).

4 Multilevel Flow Modeling Technique

Digitalization is changing the way companies can work compared to the traditional ways, and operations of smart assets are being implemented to help in the daily routine, so work can be more efficiently done reducing time and unnecessary risks. The main objective of this thesis is to look at Egolf, developed by the cooperation between the Norwegian company Eldor AS and the Technical University of Denmark, DTU, as an alternative tool which can be used for visual representation and analysis in those industrial flow processes applying a multilevel flow model (MFM) approach. Egolf can be used as a new cloud-based program in the oil and gas industry and seen as a pretty advanced new technology capable to analyze qualitatively industrial processes to enhance safety, productivity and reduce costs by leading to the most optimal performance and decisions in advance. Then, the Technical University of Denmark, DTU, is providing the causal reasoning engine.

Besides, after the representation of three different industrial processes based on MFM approach, and supported by qualitative analysis, abnormal situations were defined, and a cause-consequence reasoning study could be made. In this study, some limitations were found related to the process of engineering understanding and the utilization of the software. When trying to represent the different processes shown on this thesis, like the power generation plan, there was a need of proper knowledge in order to properly connect the equipment and to understand the trajectory of the different substances. Furthermore, there were some critical paths that needed to be considered as long as some of the functions were not available due to underdevelopment working. That is why learning MFM language was essential and key in this procedure focused on its objective work domain.

For the design of any industrial process, the modern industry is using different flow diagrams providing information for the displacement of the physical system reaching a more complex layout as it goes forward in the industrial design. It helps the engineers to reach a better understanding of the processes by providing detail information for better and faster-needed changes in the system. Thus, several techniques as causal methods are being used after for the application of those designs in the technologies available by the companies. Those techniques are useful due to their different approaches facilitating the futures actions required to perform a safe maintenance and major replacements when abnormal situations occur.

As mentioned before, multilevel flow model is the technique developed based on objective trees and Eldor AS is applying it to its tool, Egolf. In this chapter, the different flow process representations, using different examples, are discussed and presented due to the need of a first layout of the physical systems for the industry and the list of the main objectives of the same before designing it in the applied technology Egolf, using the MFM approach. Therefore, MFM technique is compared to other methods and explained in detail in this chapter due to its application when simulating in the program.

4.1 Flow Diagrams

At the start-up procedures for a plant design it is recommended the use of the different flow diagrams available before including the installed process control systems. These plant representations provide support to the operator about for example what, how specific valve should be changed and where is needed to pay more attention in order to be aware of the effects of this change.

The purpose of these diagrams does not end with the set-up of the plant, but they also represent the present values measure when working under normal operating conditions considered as a “base case” and helping to compare operational activities along the life-cycle of the plant. The following diagrams can be considered for the first steps of a plant design:

- Block Flow Diagram (BFD)

- Process Flow Diagram (PFD)

- Piping and Instrumentation

BFD provides a series of blocks which characterize different unit operators connected by up-streams and down-streams, representing either single processes (block flow process diagram) or complex ones (block plant flow diagram). It gives an overview picture of the plant design ignoring too many details. However, as much information is not shown, it just contributes to have a first idea of the process contributing as a starting point for developing PFD.

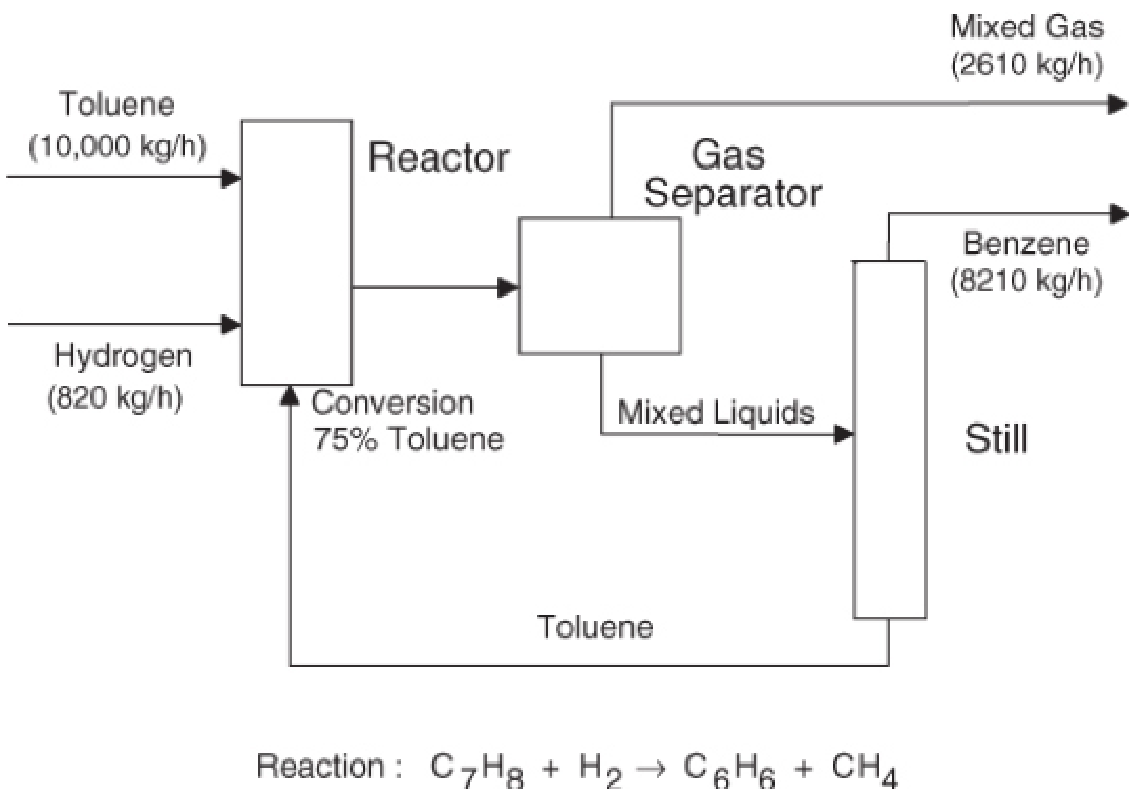


Figure 4-1: Block Flow Process Diagram for the Production of Benzene (D. Bhattacharyya & Whiting, 2012)

Both, block flow process diagram and block plant process diagram are useful delivering in-formation of the overall operation of chemical plants that will orient operators through the different products and operational stages. Another advantage is that this type of diagrams give flexibility to any changes without costly expenses so not too much process detail is involved (D. Bhattacharyya & Whiting, 2012). The Figure **4-1** shows the visual representation of a BFD.

PFD represent a step up from the BFD containing more information of the process. Process flow diagrams (PFDs) are used in chemical and process engineering. These diagrams show the flow of chemicals and the equipment involved in the process. Generally, a Process Flow Diagram shows only the major equipment and doesn't show details. PFDs are used for visitor information and new employee training. The representation of the equipment can differ from company to company and the following information is deliver as basics (D. Bhattacharyya & Whiting, 2012):

1. Process topology
2. Stream information
3. Equipment information

The Figure **4-2** shows the visual representation of a PFD as an example (D. Bhattacharyya & Whiting, 2012).

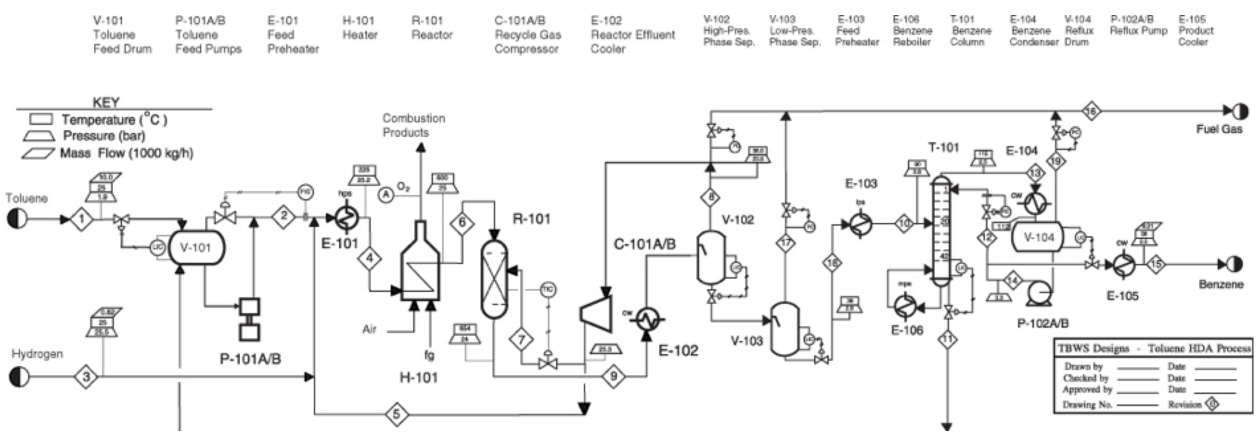


Figure 4-2: Benzene Process Flow Diagram (PFD) for the Production of Benzene via the Hydroxylation of Toluene (D. Bhattacharyya & Whiting, 2012)

Replacement of the equipment is usually done replacing an old piece for a new one so detail on the diagram can remain needing only few modifications. This kind of diagram is considered the first comprehensive one for a new plant or process, enough information is delivered related to the equipment, material balances and energy in order to add control systems and calculate economic statement of the process.

Furthermore, its value remains after the construction of the plant like the previous diagram, used as the document that represent on the best way the operational activities of the plant, and for operators training providing support for operating problems diagnosis and being aware of the effects that changes on the process can made. Among all software, there is a web-based program providing this kind of design, RFFlow5 (D. Bhattacharyya & Whiting, 2012).

The Figure **4-3** shows the visual representation of a P&ID as an example (D. Bhattacharyya & Whiting, 2012).

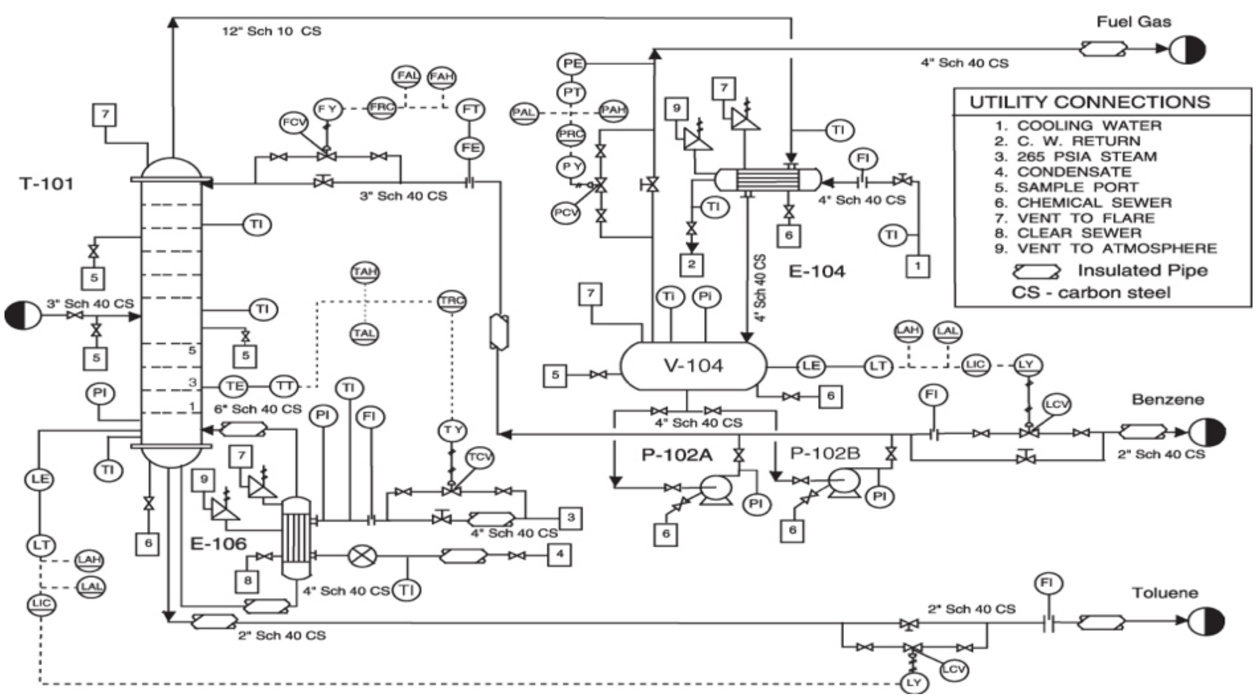


Figure 4-3: Piping and Instrumentation Diagram for Benzene Distillation (D. Bhattacharyya & Whiting, 2012)

P&ID, known as mechanical flow diagram (MFD) as well, present useful information for engineers to start the planning for building the plant. It specifies all mechanical requirements of a physical process flow except for few information like pipe lengths or equipment locations.

One PFD is supported by many P&IDs in order to include all the information. This sort of diagram is the last stages of the design and is the one that operators responsible for further design and construction use.

A Process and Instrument Drawing (P&ID) includes more details than a PFD, including major and minor flows, control loops and instrumentation. P&ID is sometimes referred to as a Piping and Instrumentation Drawing, and these diagrams are also called flow sheets, for maintenance and modification of the plant. P&IDs are used by process technicians and instrument and electrical, mechanical, safety, and engineering personnel (D. Bhattacharyya & Whiting, 2012).

The following activities based on this diagram will be (D. Bhattacharyya & Whiting, 2012):

1. Mechanical engineers and civil engineers will design and install pieces of equipment.

2. Instrument engineers will specify, install, and check control systems.

3. Piping engineers will develop plant layout and elevation drawings.

4. Project engineers will develop plant and construction schedules.

This type of layout is used to replace a piece of equipment, stream an existing process, and guide the design and application of a new facility, so changes controlled by Management of Change (MOC) can be made optimally and safely. The meaning of this diagram is essential also during plant operation to compare the process activities along the life-cycle plant. In addition, plant simulators coupled with this diagram will show how quickly changes can be made and the propagation of their effects, monitoring and presenting real-time process operations (D. Bhattacharyya & Whiting, 2012).

There are many on-line flowchart makers available and the software mostly used is Lucidchart. For further development in this Thesis, Lucidchart and Draw.io were used as support tools for the visual representation of the processes applied for the demonstration of Egolf capacities.

4.2 Model-based Methodologies

Model-based approaches are very accurate in order to present a more exhaustive detail in design based on abstracting from the problem domain instead of a description of task performance. The Figure **4-4** shows the visual representation of a DL method for a boiler (Burns & Vicente, 2001).

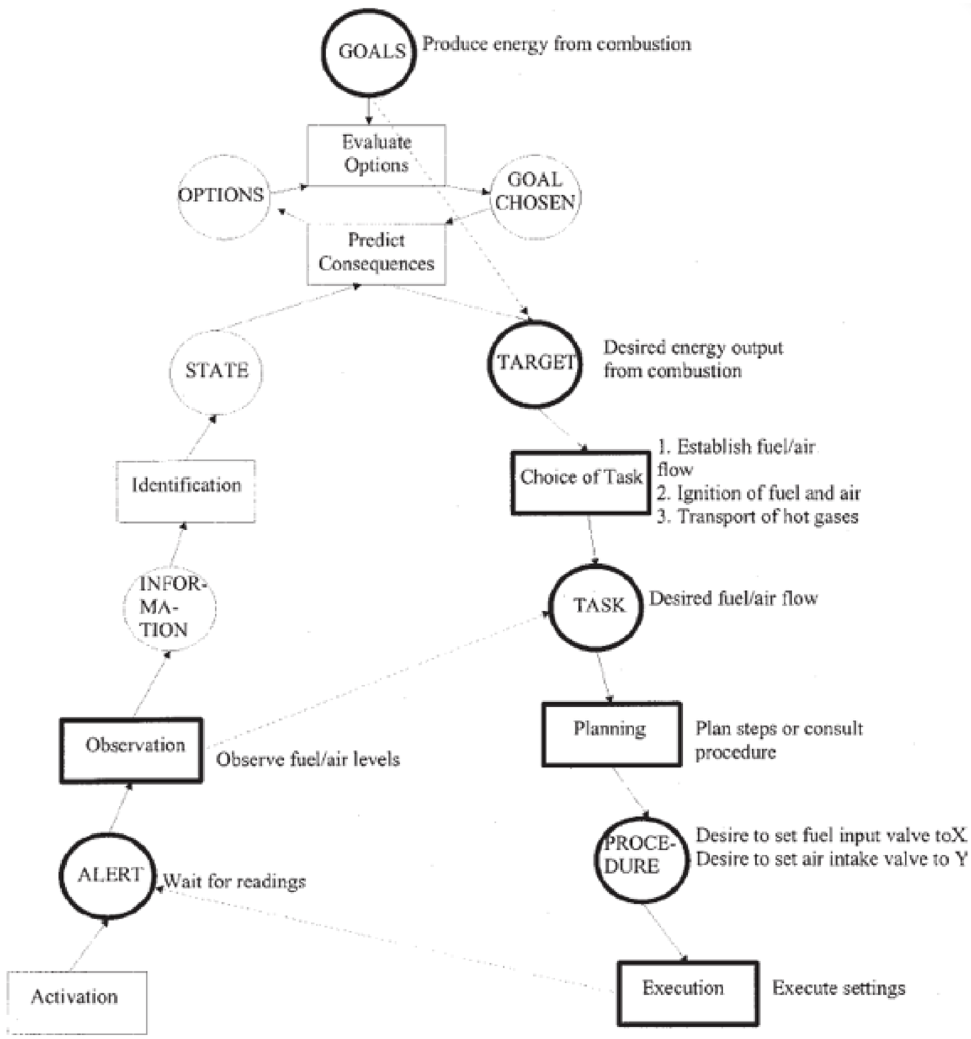


Figure 4-4: DL for the boiler (Burns & Vicente, 2001)

These analysis techniques for analyzing cognitive work are classified in different categories relying on task models like Decision Ladder (DL), work domain structure models using Abstraction Hierarchy approach (AH), and work domain goal models supported by Multilevel

Flow Modeling (MFM). The main focus of the last two techniques is the understanding of how people deal with complex systems compounded by several interacting components which must be controlled to reach particular goals of the system. To see the differences an example of each technique is shown based on the same process, boiler operation.

The DL approach present the activities and task that someone can do to reach an objective. It is commonly suggested as a following analysis after the AH method modeling cognitive activities, states and actions on one branch, and decision-making states and actions on the other branch. Then, the analyst pay attention to the essential phases regarding the required task. The Figure **4-5** shows the visual representation of a AH method for a boiler (Burns & Vicente, 2001).

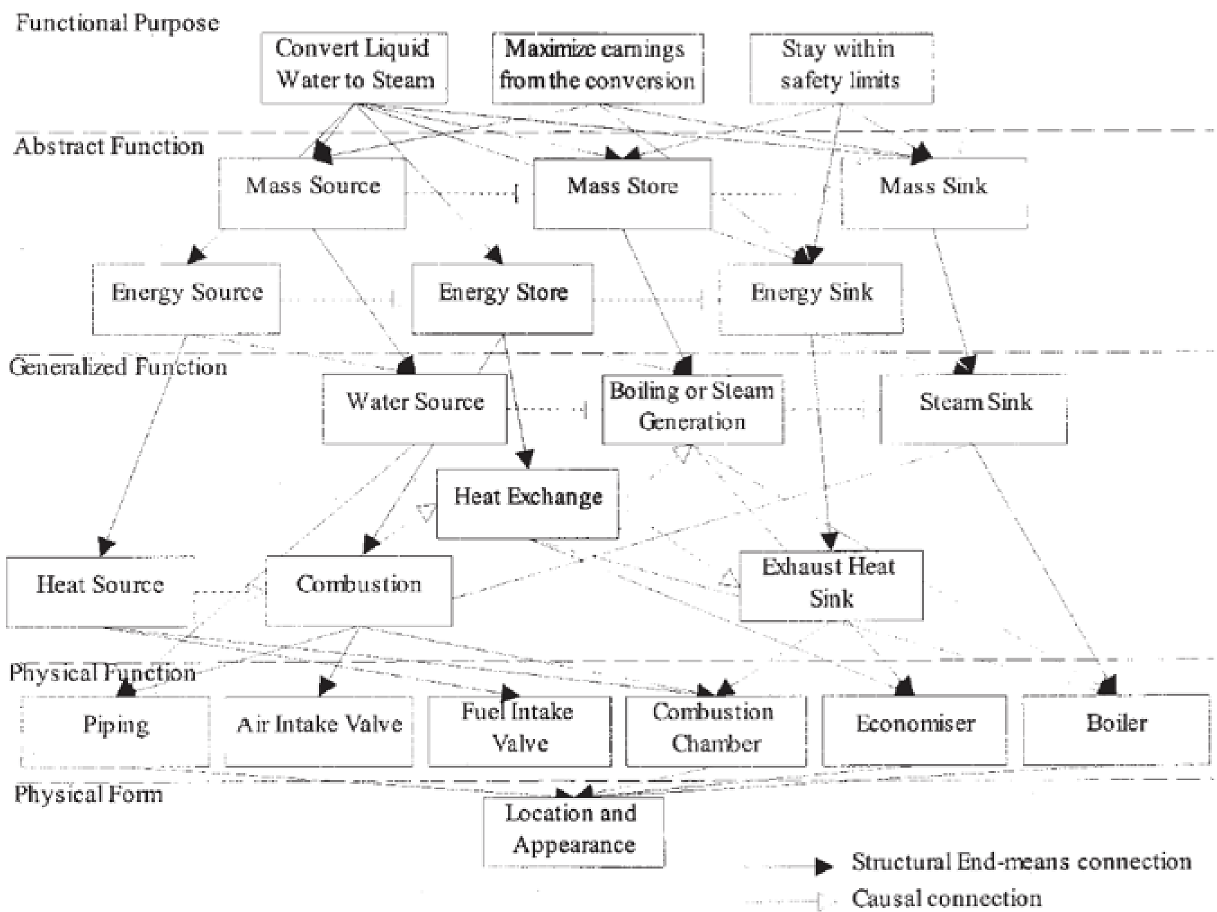


Figure 4-5: AH for the boiler (Burns & Vicente, 2001)

The AH approach describes the structure of the process that needs to be controlled regardless task, goal, worker or interface. It is considered under the condition unanticipated events may occur due to the system complexity and a person cannot have complete control of how the process works in its totality. Thus, its main goal is to define how operators see and understand problems and complications that can happen in the system.

The Figure **4-6** shows the visual representation of a MFM method for a boiler (Burns & Vicente, 2001).

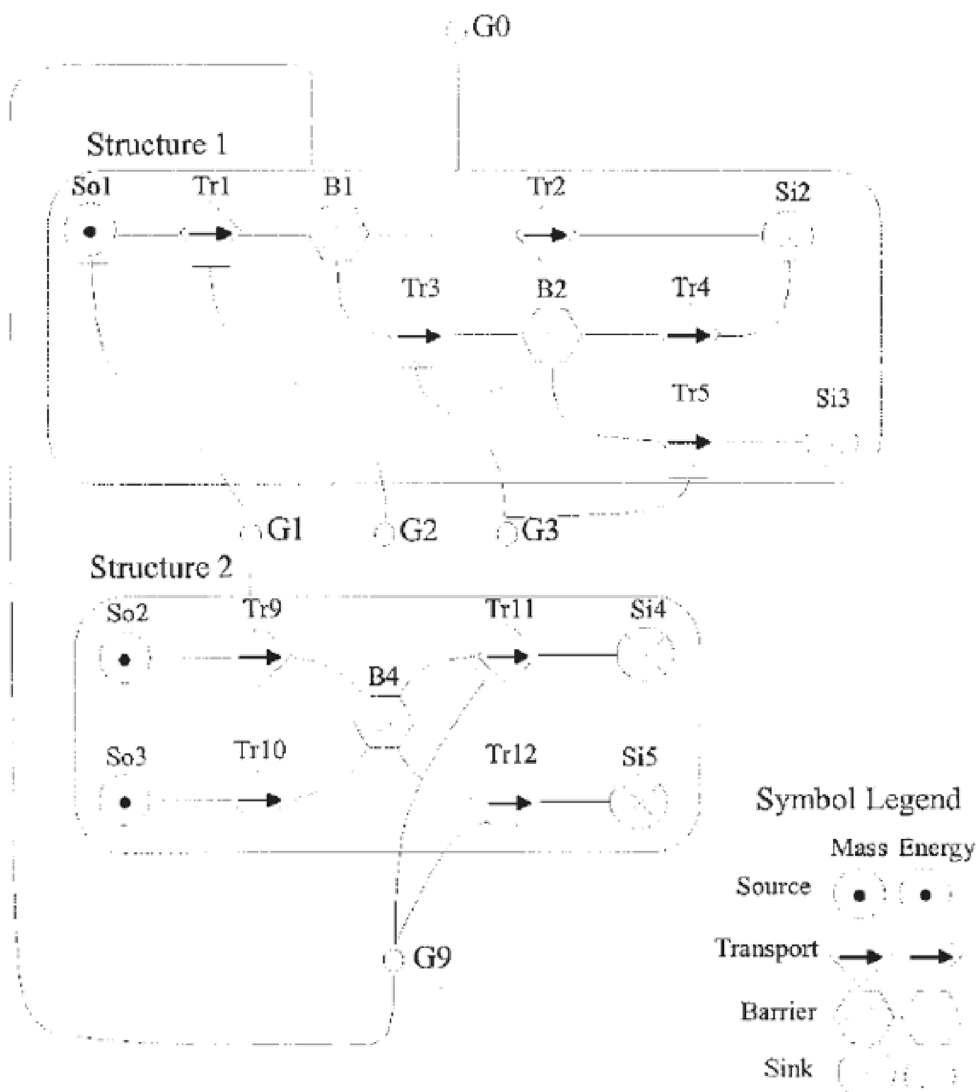


Figure 4-6: MFM for the boiler (Burns & Vicente, 2001)

It divides the system into levels placing the functional purpose defining what it is designed to do at the top, and the lower levels represent the states in the work to get to the objective or purpose, and it uses means-end relations to connect levels. So, the main difference compared with MFM is that it is focused on purpose and not on goals and AH is an event-independent model.

The MFM method represent the phases of the process being controlled regardless any particular task, goal, worker or interface. It was developed as an extension of the previous approach to translate AR into a grammatical model and lately as an alternative to it. Therefore, it shows the roles that particular equipment plays in order to achieve specific operational states supporting the operator to understand and use the equipment. Thus, objectives in this approach are event-dependent so those might be not convenient any longer in case of an unexpected occasion.

Goals and functions can be modeled by the method called Multilevel Flow Modeling (MFM). It is able to represent complex industrial systems, from gas and oil facilities to power production plants. This model has its own language by using graphical symbols and syntax to describe goals and functions and all means-end and causal relations between functional levels. Both knowledge, about the complex system (operation and plant design) and about the MFM method to represent it in Egolf, are required. This modelling methodology is used for causal reasoning. Several means-end relations are usually connected in complex systems and their interrelations (from physical structure to goals) need to be considered. Thus, one means-end relation can link to one of the elements in another means-end relation through its goal or end.

MFM methodology distinguishes between two groups of modelling concepts: one is the system goals and functions, and the other is physical components. Flow functions are the basic elements in a MFM model. They are defined in relation to the processing of flows of mass and energy. MFM is based on a set of six generic flow functions representing different primitive operations performed on either mass or energy flow. Each flow function is represented by a unique symbol in the graphic model and the functions are specified by their upstream / downstream flow ports and condition ports. The flow ports indicate how a flow function connects with other functions within a flow structure and the condition ports indicate how a flow function connects with other functions across flow structures (Burns & Vicente, 2001).

So far, MFM is the modeling language used in Egolf for the visual representation and analysis of the physical systems and it is based on a goal work domain being reasonable to use and describe this type of modeling symbols and how they are used for future application.

4.3 MFM Process

To represent the goals and functions of complex industrial systems there is a useful method for modeling called Multilevel Flow Modeling (MFM). It provides graphical symbols and syntax describing casual and means-end relations between functional abstraction levels, and previous knowledge about the complex system is essential for the layout of the process and operations. Thus, functions can be defined on many levels of abstraction reaching great detail of the operation, and these are considered dependent on context. Furthermore, there are different concepts of the means-end relation which connect specific state (means) with those opportunities presented for further actions and the targets that are necessary to reach. MFM method provides the capability of casual reasoning of functional concepts (Lind & Zhang, 2017).

The functional structure of a complex system can be presented considering the interrelation of mass or energy flow structures in different abstraction levels in MFM, showing how the process plants should work but not how they actually behave like quantitative thermodynamic models do. That is the difference between normative models (MFM) and descriptive ones. Then, MFM can represent the system goals and functions, and physical components, and it is very important to have the opportunity to represent process plants in such a way due to the interchange of energy and mass that affect the components and systems, and it helps to have control on safety, costs, and production (Lind & Zhang, 2017).

The Multiflow Level Modeling method is based on the goals domain defined for the specific processes design, then a description of the objective tree for the process is mandatory to model physical systems. For the different process models used in this study, this step is not applied due to the lack of support for this technique regarding technology and knowledge-based. However, it is essential for the utilization of this type of graphs in order to reach a complete well-defined process model.

The Figure **4-7** shows an example of an objective tree that can be used in the present time to build the model in Egolf (Hohmann, 2014).

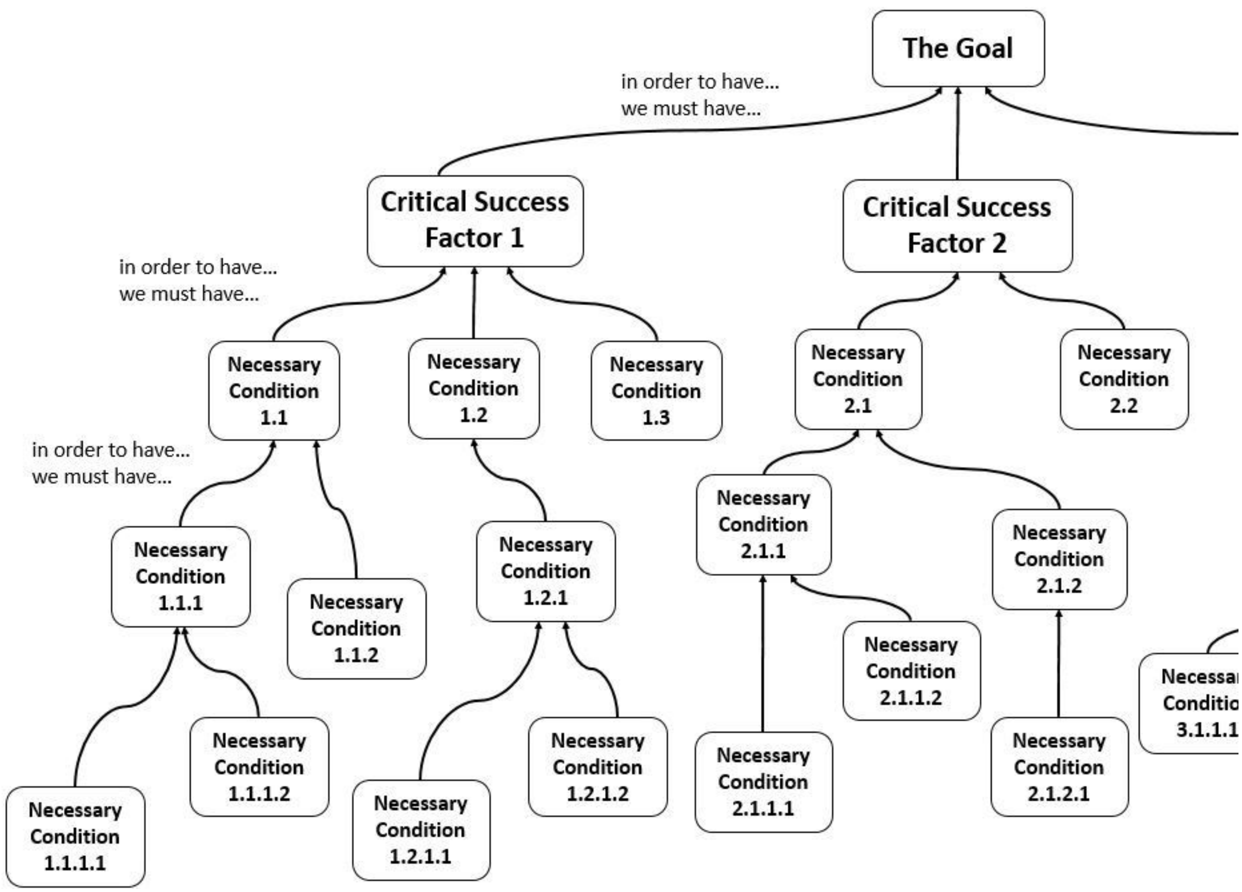


Figure 4-7: Objective tree example (Hohmann, 2014)

Helping with the definition of the process goals makes easier to the operators in the control rooms to understand the objectives that need to be reached for a much better performance. Then, this kind of technique is essential to build a proper process model in Egolf and it supports engineers in the industry to follow paths that will accomplish those goals faster and easier.

Basic elements, as flow functions, are representing primal operations with six different symbols in the graphic model, defined by the connection to upstream / downstream flow ports between flow functions inside a flow structure and across flow structures. The following illustrations show the different MFM symbols and their definitions, and below are described several rules that need to be considered.

4.3.1 Flow Functions, Flow Structures and Causal Relations

The flow functions in MFM are represented as source, sink, transport, barrier, storage and balance, and mass and energy flow functions are representing the flow structures.

The Figure **4-8** shows all the flow functions and structures, and they are represented with three initials and combined with integer numbers (Lind & Zhang, 2017).

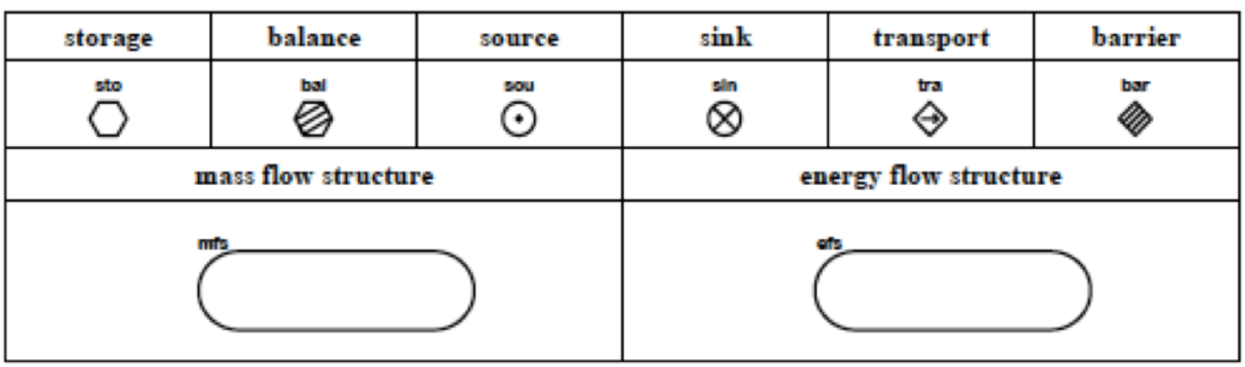


Figure 4-8: Flow functions and Flow structures (Lind & Zhang, 2017)

The Figure **4-9** shows how the flow ports look like (Lind & Zhang, 2017).

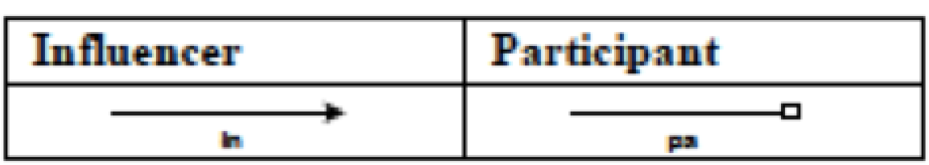


Figure 4-9: Flow Ports (Lind & Zhang, 2017)

All the flow functions included in a flow structure are connected and they affect each other meaning that if the status of one varies, the ones next to it will be influenced depending on their flow port connection. Those are defined as MFM causal relations, considering those as links that influence the relations between functions. They are described with symbols namely influencer and participant with unique IDs as well. There is a need to highlight that causal relations do not define or show the flow direction of the process.

4.3.2 Syntax Rules for Flow functions

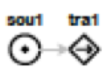
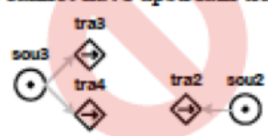
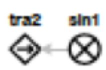
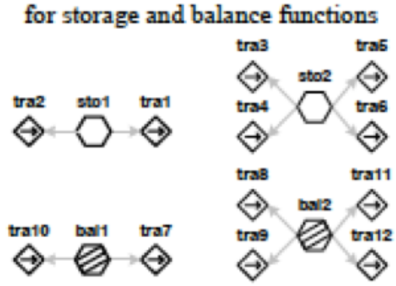
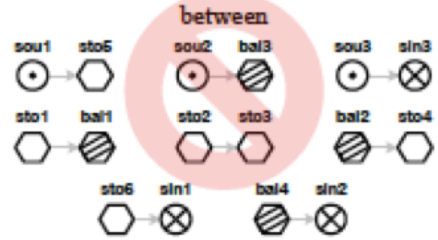
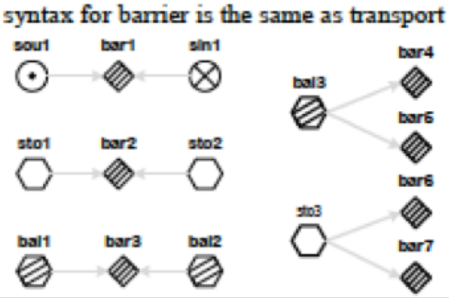
There are several rules that should be taken into account when building MFM models in Egolf, so depending on the function a proper connection must be applied and the model will be assigned as valid without any errors. The syntax rules for flow functions are defined (Lind & Zhang, 2017):

- Rule 1: each transport or barrier function has two connections, one upstream, and one downstream.
- Rule 2: barrier functions shall only be connected with either balance or storage functions.
- Rule 3: transport functions shall only be connected with source, sink, balance, or storage functions.
- Rule 4: storage and balance functions can have any number of connections.
- Rule 5: storage and balance functions should only be connected with transport or barrier functions.
- Rule 6: each source or sink function has only one connection, one downstream connection for source function, one upstream connection for sink function.
- Rule 7: source functions shall only be connected with transport functions and only if the direction of flow is away from the source.

- Rule 8: sink functions should only be linked with transport functions and only if the direction of flow is towards from the sink.

The Table **4-1** shows the illustrate and the allowed and non-proper connections when using MFM models (Lind & Zhang, 2017).

Table 4-1: Allowed and Illegal connections (Lind & Zhang, 2017)

Allowed Connections	Illegal Connections
for source function 	source function cannot link to more than one transports and it cannot have upstream transport 
for sink function 	sink function cannot link to more than one transports and it cannot have downstream transport 
for storage and balance functions 	source, storage, balance and sink functions are not allowed to be connected without a transport function in between 
syntax for barrier is the same as transport 	two transports or two barriers cannot be connected together, transport and barrier function cannot be connected together 

According to Lind and Zhang, the transport function is connecting other functions and is linked to a definite flow direction, and a barrier should be implemented between two systems to prevent the flow between them if applied.

The Table **4-2** shows the flow functions syntax rules referred to in-flow and out-flow ports when using MFM models (Lind & Zhang, 2017).

Table 4-2: Inflow and Outflow Ports for the functions (Lind & Zhang, 2017)

Flow functions	Num. of In-flow port (type)	Num. of out-flow port (type)
source	0 (-)	1 (transport)
sink	1 (transport)	0 (-)
transport/barrier	1 (source, sink, storage, balance)	1 (source, sink, storage, balance)
storage/balance	n (transport)	n (transport)
		***Where n > 0**

Depending on the physical configuration of the system, a non-transport function can affect the upstream or downstream at which it is connected, but a transport function will always vary the state of substances in its adjacent functions directly within mass or energy structures. MFM method refers to it as direct influence, and indirect influences make reference to how non-transport functions impact on flow ports, upstream and downstream transports.

4.3.3 Syntax Rules for Causal relations

To use MFM causal relations some rules need to be considered (Lind & Zhang, 2017):

- Rule 1: both influencer and participant must have one start function and one end function.
- Rule 2: the start function for influencer or participant can only be a source, sink, storage, or balance.
- Rule 3: the end function for influencer or participant can only be a transport or barrier.
- Rule 4: there must be at least one influencer relation attached to a balance function.

4.3.4 Targets, Threats and Means-end Relations between mass and energy

Several conditions are assigned to MFM functions representing conditions for availability of the function, and for function performance. The first ones refer to a function as enabled or disabled, and the second type represent when a function is working at a normal or an abnormal state. These models not only represent the relations between physical systems and systems objectives using means-end connections, but also their functions and objectives.

The Table **4-3** shows the symbols define in the MFM methodology as the four types of function-objective means-end relations and targets and threats (Lind & Zhang, 2017).

Table 4-3: Function-objective Means-end relations and Objectives (Lind & Zhang, 2017)

produce	maintain	suppress	destroy
pr	ma	su	de
target		threat	
tar		thr	

The Table **4-4** shows the symbols used for function connection between mass and energy flow structures (Lind & Zhang, 2017).

Table 4-4: Connection between mass and energy flow structures (Lind & Zhang, 2017)

Mediate	Producer-product
ma	pp

4.3.5 Syntax Rules for Means-end Relations

Syntax rules for means-end relations are presented (Lind & Zhang, 2017):

- Rule 1: every means-end relation must start from a flow structure and have a main function in this flow structure that must be labeled.
- Rule 2: producer-production and mediate relations end at a function which serves as their target.
- Rule 3: produce and maintain relations end at a target.
- Rule 4: suppress and destroy relations end at threat.

Other relations are designed so the achievement of an objective affects the availability of a function, connecting flow functions to a threat, through a disable relation, or target, through an enable relation.

The Table **4-5** shows the symbols used for such representation (Lind & Zhang, 2017).

Table 4-5: Connection between flow functions and objectives (Lind & Zhang, 2017)

enable	disable
	

4.3.6 Syntax Rules for Condition Relations

Here are the syntax rules for condition relations (Lind & Zhang, 2017):

- Rule 1: enable relations start from a target and end at its enabled function.
- Rule 2: disable relations start from a threat and end at its disabled function.

After getting familiar with the Multilevel Flow Modeling approach, its language and rules, a short guide will lead to the use of Egolf tool as an alternative for the cause and consequence analysis of the physical systems applying abnormal situations and discussing all the information received from the engine.

5 Study of Application of Egolf Technology in different contexts

Once MFM methodology and language has been explained, Egolf tool is introduced to show how simple flow processes can be implemented in the tool by operators effortlessly. This innovative program can show industrial processes visually, helping and offering the engineer a clear display of the physical system providing faster support when operating decisions are needed. Three different processes have been chosen to be represented and analyzed for the program.

The reason to implement three cases is due to the need of showing how Egolf is able to design different sized physical systems no matter the level of difficulty and the scale of the project. Besides, Egolf models are designed based on the objective tree analysis of the physical systems. However, the examples selected are considered quite basic so their process flow diagrams represent enough information to build the models in the web-based program. Eventually, when the visual representation is finished, the cause-consequence analysis is carried out utilizing the mfm-test engine 6.

5.1 Introduction to Eldor Company and Egolf Technology

The oil capital of Norway, Stavanger, and the oil capital of the UK, Aberdeen host the engineering company Eldor. This company is one of the leaders in alarm management, and gives support for modifications and improved operations to oil, service and engineering companies. Eldor provides world class expertise to the O&G Industries for the following areas (*Eldor AS*, 2010):

- Control Room and Remote Operations
- Control and Safety Systems & Alarm Management
- Telecommunication and Industrial IT

Eldor is using innovative technology and domain knowledge to reinforce safety, enhance production and improve regularity in the petroleum industry. Thus, professionals in Eldor are building a state of the art technology software in order to enable replacement of devices without stopping production reducing up to 30% of upgrade project expenses carried out by the Oil & Gas sector (*Eldor AS*, 2010).

This company understands that Digitalization has become important in this industry, and it embraces it and develops it is more advantage and innovative technology software namely Alarmtracker. Thus, this product came out due to the necessity of situational awareness support of unplanned upsets and abnormal events that low production profit. Furthermore, the Alarmtracker elaborates counter-action plant to the operator for all these possible incidents and displays the root cause and possible consequences of the situation reducing the time of action. So far, it applies mathematical models and in the future, the fusion of Alarmtracker and Egolf will make easier the interpretation of those situations and actions (*Eldor AS*, 2010).

On the other hand, Egolf web-based tool is developed by the Norwegian company Eldor and it is free to use nowadays, so anyone can create a user account and enjoy what Egolf can offer. The user is able, not only to generate a personalized library in order to use his/her self-design illustrations but also to build as many models as necessary. Egolf reinforces its friendliness with the user by providing a direct physical and distinctively a number of options, utilizing figures, and it has separate categories for the different functionality and representations, making an effortless experience (Jensen, 2018).

To continue, a technical evaluation of the program itself is done clarifying its utility and limits. Finally, a technical assessment is given highlighting the positive use of its features and their limits. To start with, the user goes to 'My documents' and adds a folder, he/she has to add a project, and the step forward would be adding his/her own models. Therefore, the user is free to add as many projects and models as wanted, keeping all models required within the same project, and this one within 'My Model' category.

The Figure **5-1** shows Egolf tool when the user creates an account and log in it, showing in the left panel the specific projects and models, and the personalized library (Eldor, 2018). The tool facilitates a well-organized structure of several projects and cases within a project providing easy and quick access to them by the operators who define the models.

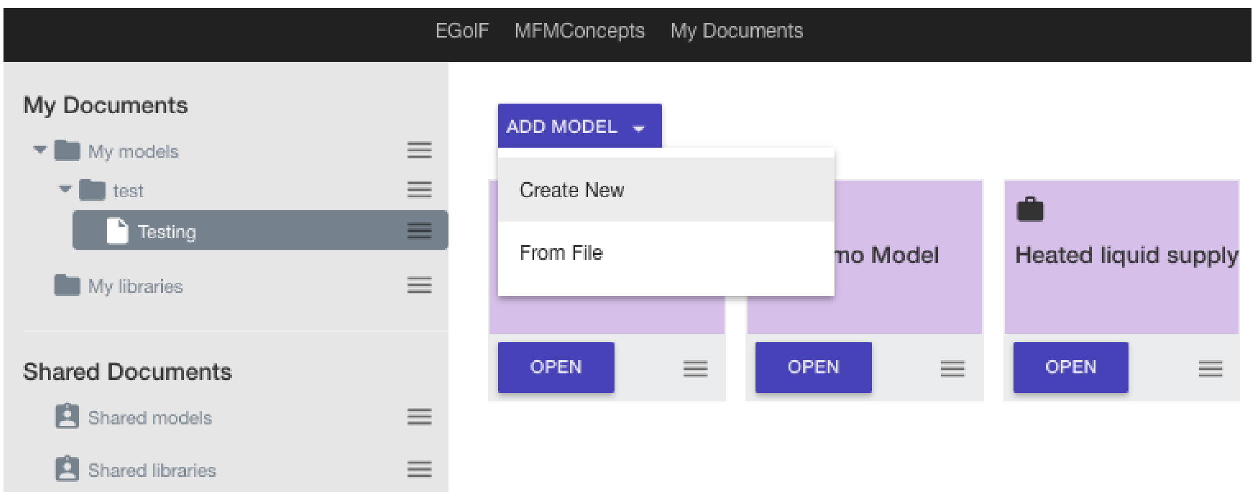


Figure 5-1: First step to create a model in Egolf (Eldor, 2018)

Due to its connectivity, projects, models and library can also be share and common for other users to have the option of supervising and modifying them, and it will be reflected in the 'Shared Documents'.

As mentioned before, after logging in Egolf, the user can add a model of the process desired by clicking on "ADD MODEL" so a title is given and some description can be defined as well. The Figure **5-2** shows the screen that appears when the user adds a model in order to defined the title and some description if needed (Eldor, 2018). Engineers can find this kind of tool useful and effortless when describing the processes they are interested in before start modeling.

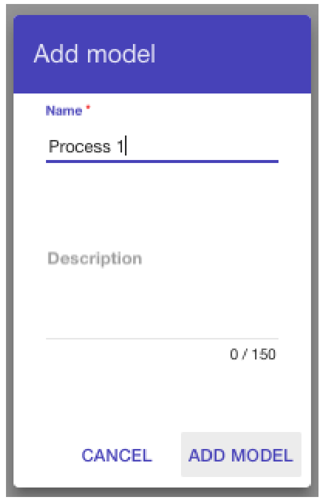


Figure 5-2: Add model screen (Eldor, 2018)

Once the model is defined, the user clicks 'Open' and the Egolf flow-sheet appears. It has specific symbols considered as a handy shortcut and well-structure set that represent the parts of the process, the relations among them and the different objectives, offering right away all the possibilities the user can use. The clear choices are located on the left column and the design of the figures also help the people to understand and choose the right ones in an easy way.

The Figure **5-3** shows the the flow-sheet that Egolf generates so the flow process can be built using MFM method (Eldor, 2018). In these flow-sheet is where the process models will be generated with the capacity of modeling very complex systems due to its large extension layout.

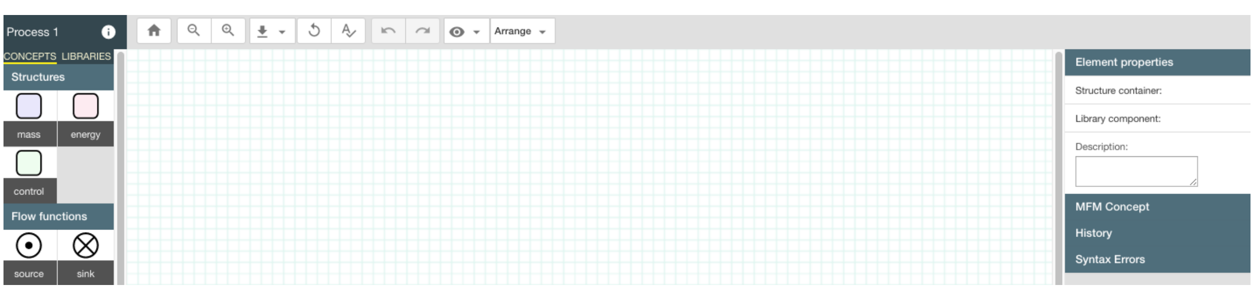


Figure 5-3: Egolf Flowsheet (Eldor, 2018)

The panel to the left shows the symbols of the features that the user have access to based on the MFM method to build the model. And also some specific parameters and information related to the functions can be defined and found on the right panel. There is also a bar at the top of the flow-sheet that the operators can find useful when the model is finish to check and confirm that there are no syntax errors, and in case there are any, he/she can find them in the panel to the right and correct them. In addition, the model can be downloaded in different formats, among other options. All these features and characteristics can be used in an intuitive way by the engineers in charge.

Eventually, all characteristics related to the Multilevel Flow Modeling and Egolf cloud-based tool are shown and described. Thus, in Chapter 5, some process examples in different context are presented in order to show how to model them in Egolf using MFM approach and in Chapter 6, mfm-test will be carried out selecting different abnormal conditions. The Tables **5-1**, **5-2**, and **5-3** shows Eldor's design for its functions on the modeling tool Egolf and the description given to each of them (Eldor, 2018). The following concepts are:

Table 5-1: Structures and Flow Functions in Egolf (Eldor, 2018)

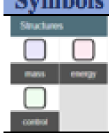
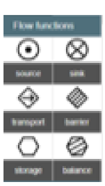
Symbols	Concepts		Definition
	Structures	Mass	Includes a mass flow functions connected by influence relations.
		Energy	Includes a set of energy flow functions connected by influence relations.
		Control	Includes a set of control functions and targets connected by influence relations.
	Flow functions	Source	The function of a system serving as an infinite reservoir of mass or energy. No physically realizable has in principle unlimited capability to deliver mass or energy. However, the source function is used to provide an adequate abstraction of the physical phenomena considered.
		Sink	The function of a system serving as an infinite drain of mass or energy. As for the source function, this function can be used in many cases as an adequate abstraction.
		Transport	The function of a system transferring mass or energy between two systems or locations. A transport function has one upstream and one downstream connection to an influence relation. The downstream connection point is indicated by the arrow head representing the direction of flow. Note that the flow direction is not identical to the directions defined by the influence relations.
		Barrier	The function of a system that prevents the transfer of mass or energy between two systems. Typical examples of systems which implement barrier functions are the cladding on nuclear fuel rods, heat isolating material and a trap in water systems.
		Storage	The function of a system which serves as an accumulator of mass or energy. A storage function can have any number of connections and any number of enablement conditions. An example could be the function of a tank when used as a device for accumulation of a fluid, in this example we are dealing with a mass storage. Another example could be the storage of energy in a boiler by heating the water.
		Balance	The function of a system which provides a balance between the total rates of incoming and outgoing flows. Each balance function can have any number of connections and any number of conditions.

Table 5-2: Control Functions, Targets, Influence Relations and Control Relations in Egolf (Eldor, 2018)

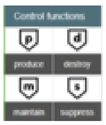
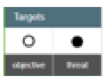
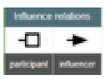
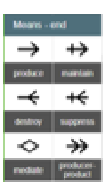
Symbols	Concepts		Definition
	Control functions	Produce	The function of a control system S1 which is producing (p) a new state in the controlled system S2
		Destroy	Relate a threat (the "non- end") with a function structure if one or several functions F (means) in the structure contribute to destroy the threat. F is indicated by a label on the relation.
		Maintain	The function of a control system S1 which maintain (m) the actual state of the controlled system S2.
		Suppress	Relate a threat (the "non-end") with a function structure if one or several functions F (the means) in the structure contribute to suppress the threat. F is indicated by a label on the relation.
	Targets	Objective	A state which should be produced or maintained. Objectives are related to function structures by means-end relations.
		Threat	A state which should be destroyed or suppressed. Threats are related to function structures by means-end relations.
	Influence relations	Participant	A flow function F (source, sink, storage or balance) is connected with a transport T upstream or downstream with a participant relation if the system realizing F passively provide or receive substance for the transport T.
		Influencer	A flow function F (source, sink, storage or balance) is connected with a transport T upstream or downstream with an influencer relation if changes of its state influences the amount of substance transported by T.
	Control relations	Actuate	Relate a control function F1 with a function structure containing a function F2 which is the direct object of control. F is indicated by a label on the relation.

Table 5-3: Condition Relations and Means-end in Egolf (Eldor, 2018)

Symbols	Concepts		Definition
	Condition relations	Enable	Relate a function with a target (objective or threat). It is used when the function is enabled when the target is achieved. All functions can be enabled.
		Disable	Relate a function with a target (objective or threat). It is used when the function is disabled when the target is achieved. All functions can be disabled.
	Means-end	Produce	Relate an objective (end) with a function structure if one or several functions F (means) in the structure contribute to produce the objective. F is indicated by a label on the relation.
		Maintain	Relate an objective (end) with a function structure if one or several functions F (means) in the structure contribute to maintain the objective. F is indicated by a label on the relation.
		Destroy	Relate a threat (the "non- end") with a function structure if one or several functions F (means) in the structure contribute to destroy the threat. F is indicated by a label on the relation.
		Suppress	Relate a threat (the "non-end") with a function structure if one or several functions F (the means) in the structure contribute to suppress the threat. F is indicated by a label on the relation.
		Mediate	Relate a function F1 (the end) with a function structure if one or several functions F2 (the means) in the structure contribute to mediate the function. F is indicated by a label on the relation. This relation is used when a system has the role of being an intermediate between an agent and another system that serve as an object of action.
		Producer-product	Relate a function F1 (the end) in a function structure S1 with one or several functions F2 (the means) in another structure S2. F2 is indicated by a label on the relation. This relation is used when the interactions between functions in structure S1 result in a transformation that serves a function in the context of the objective related to S2.

By showing the technical features of the tool, some of them like the representation of the symbols used to build the models can be considered of effortless use and intuitive application. However, there is a basic need to have great knowledge of the language model (MFM) that needs to be implemented. Other features, like some tabs in the upper bar of the screen, may not be that easy to understand what is their functionality and their final meaning. Besides, when starting building the model, the features are different from the ones that appear when analyzing it. This can be seen in Figure **5-3** and **6-7**.

On the other side, it facilitates the visual appearance of the models by selecting grid and labels, and it saves the changes automatically providing the chance of going backward when required. It also shows the definition of the symbols used eliminating the effort of useless assumptions. Furthermore, the verification tab is found crucial due to its useful function. It valid the resulting model if all the connections are correct otherwise, the tool clearly provides the possible errors found facilitating the modeling corrections.

5.2 Application of Technical Features of Egolf

In this section, some industrial processes examples are applied to show the flexibility of the tool simulator in a different context. The level of process complexity is shown up-down within the examples in this document, is the first one "the simplest" and the third one "the most complex". Firstly, there is a process that describes the flow of a gas pipeline with pressure control applying a hydraulic supply which regulates the pressure in the pipe which will be used to describe MFM method and Egolf characteristics based on the process diagram of the system. Secondly, a system for heating a liquid is found with the flow, level, and temperature control, so the Egolf model will be designed using its flow diagram and this case will be selected for the reasoning analysis implementing the mfm-test cause-consequence program by DTU. And finally, the third and last physical system example represents a power production plant using steam, where a more compounded system is defined in complete detail through the whole process based on the objective tree analysis.

5.2.1 Gas pipeline

The Oil and Gas industry is making use of several complex operations and facilities. Then, the technical features of gas transportation are described as follow presenting the general concepts in this context in the Tables **5-4**, **5-5**, **5-6** and **5-7**. Its operational purpose is to drive the gas flow through a pipe under safe and controlled operations.

Table 5-4: Hydraulic supply system

Hydraulic supply system	Hydraulic mfs	Hydraulic supply circuit in a mass flow structure
	Hydraulic supply	Entry for Hydraulic supply
	PT1	Pressure Transmitor placed in the hydraulic supply line
	Pipe	Connextion between the control valve an the transmitor
	PCV	Pressure control valve for the circulation of the hydraulic supply
	Solenoid	Device that will control the hydraulic flow route
	HydrauTra1	Hydraulic supply transport selected by the Solenoid
	Actuator	Cilindered device activated by pressure that will control the valve function in the gas pipeline
	HydrauTra2	Transportation line that will drive the hydraulic supply back
	Hydraulic return	Final destination of the hydraulic supply

Table 5-5: Gas system

Gas system	Gas mfs	Gas circuit in a mass flow structure
	Gas sou	Entry for the Gas
	Shut down valve	Divece controlled by the Actuator cilinder
	PT2	Pressure transmitor placed in the Gas pipeline
	Gas Trans	Transportation of the gas
	Gas outlet	Final unkown destination for the gas

Table 5-6: Control for the shut down valve

Control for the shut down valve	on/off valve	Main objective of the shut down valve
	SP2	Set Point Cilinder pressure signal
	Produce	Let the Actuator influence on the valve

Table 5-7: Control for the Solenoid

Control for the Solenoid	Solenoid control	Main objective of the Solenoid
	SP1	Set Point gas pressure signal
	Maintain	Depending on the pressure the Solenoid will maintain its function or it will change

The physical system represent a gas pipeline with an ESD valve (Emergency Shut Down), and this valve is regulated with an actuator displayed by the hydraulic supply. Furthermore, the pipe has a pressure sensor placed after the valve, which will either activates or not the circulation of hydraulic supply through the solenoid. Depending on the pipe pressure rating and other aspects the pressure sensor will inform of the gas transportation pressure thus, when an over-pressure situation occurs this will continue to drop lower due to the solenoid controlling the hydraulic flow route. So, by generating the enough high force (hydraulic pressure) on the actuator cylinder to overcome all resistance needed to press piston, the valve will be moved to stabilize the pressure in the gas pipeline. Thus, firstly, a diagram of the flow representation is necessary to understand the kind of process and follow its layout.

The Figure **5-4** shows the diagram and visual description of the system for the flow of gas through a pipeline controlled by pressure detection (P. Zhu & Jeeves, 2018).

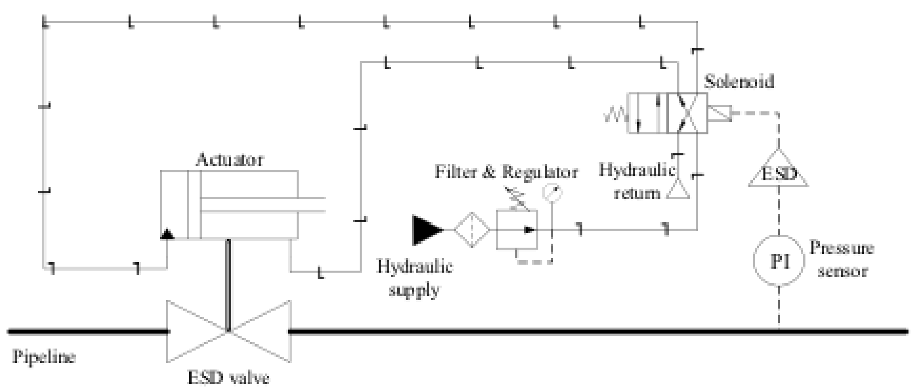


Figure 5-4: PFD of the Gas Pipeline (P. Zhu & Jeeves, 2018)

In order to build the MFM model for the system, the objectives and mass and energy flow relations need to be identified realizing a means-end analysis. By looking at the system, the next list show the objectives for the physical system:

- To Ensure that solenoid control - objective 1: Maintain hydraulic supply flow
- To Ensure that valve can work - objective 2: Produce the valve opens and closes

The next step, after understanding each part that forms the whole process and what are the main objectives are essential to be reached, the user can apply MFM method in Egolf to start building the model for this case.

The Figure **5-5** shows the application of MFM method in Egolf to this example based on the diagram of the system for the flow of gas through a pipeline controlled by pressure detection.

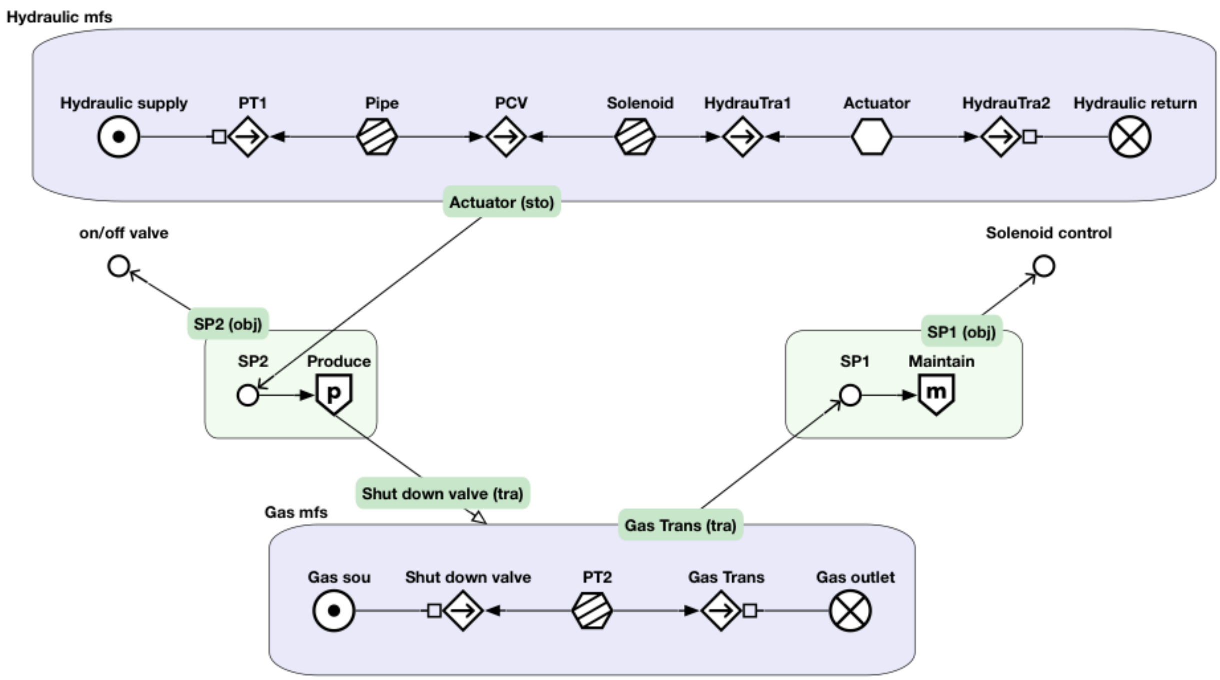


Figure 5-5: Egolf model of the gas pipeline with an ESD valve

In an MFM mass flow structure the gas flow is represented by connecting the material (gas) source Gas sou, to a material storage function PT2 through a transport function Shut down valve, and then the storage is linked to a material sink Gas outlet through another transport function Tra3. All functions within the same flow structure affect each other using the right work flows, these would be the causal relations. Hence, the accumulation of gas in the pipeline will vary in the physical system if the gas flow rate varies at the inlet, assuming the rest of the system work the same.

Translating this into the MFM model, the state of PT2 will change if the state of Shut down valve changes, taking into account that the other functions perform the same. In the MFM model for gas flow there are four MFM patterns having participant between Gas sou and Shut down valve, influencer between Shut down valve and PT2, influencer between PT2 and Tra3, and participant between Tra3 and Gas outlet. In this case, not only the transport functions influence their adjacent flow functions, but also the storage function will affect the transporting of gas from its source to the sink due to the influencer relations.

The Figure **5-6** shows the connection of symbols for the gas and hydraulic supply circulation in the MFM mass flow structure that will be presented graphically using a "bubble" which will gather all functions within the same drawing.

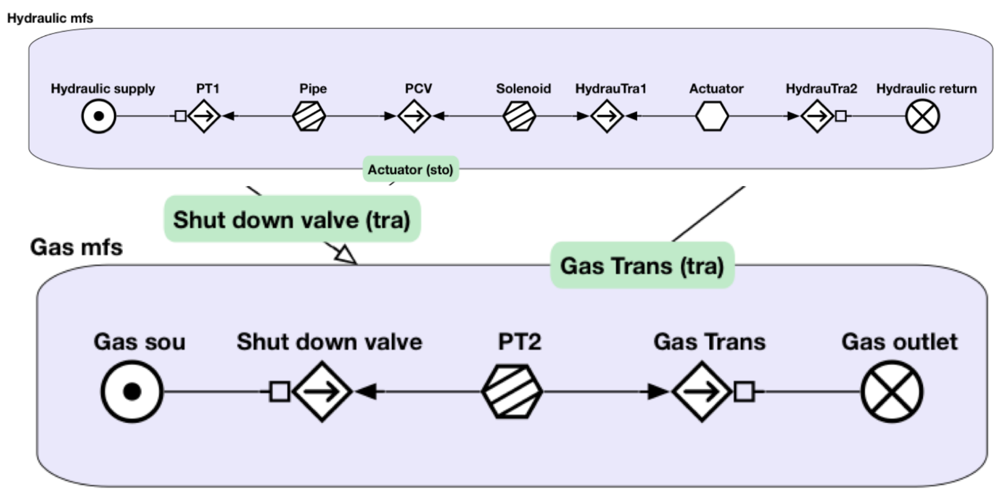


Figure 5-6: Mass Flow Structure of the driven gas and hydraulic supply

The hydraulic supply flow is represented, in an MFM mass flow structure, by connecting the material (hydraulic supply) source Hydraulic supply, to a material storage function Solenoid through two transport functions PT1 and PCV creating the necessary balance function between them Pipe. Then, the storage is connected to another material storage Actuator through another transport symbol Tra1, leading to the final material sink Hydraulic return through Tra2. Eventually, as in the previous case, all functions will be represented inside a mass flow structure.

In the MFM models, structures are connected to goals that will achieve the necessarily desired states of the system to continue operating under the right conditions. In this case, the goal-achievement relation is a flow control established by pressure detection. This kind of control will regulate the inlet flow manipulating the emergency shut down valve installed in the gas pipe, which function is to transport gas from the source to another location.

The pressure sensor Tra3 is receiving gas pressure signal continuously and it is read by SP1 having an influencer relation to Maintain so Solenoid control is actuating according to the pressure signal produced for the sensor to control the solenoid functions. The same behavior is found for the valve in the gas pipeline being either open or closes the states of the valve, so depending on the pressure signal, the solenoid will circulate hydraulic supply to keep the valve open or to close it in a case on a high-pressure occasion.

This example of the process shows how Egolf is able to represent simple cases by using MFM method and helps to get familiar with the tool. In conclusion, it is a user-friendly tool with the requirement of understanding the MFM symbols and rules.

The Figure **5-7** shows the connection of symbols for the valve controlling the gas flow, and the solenoid control in the MFM control flow structure.

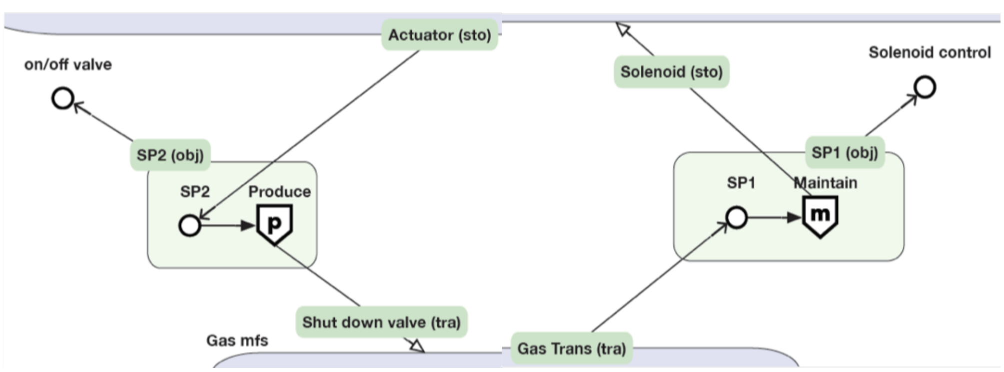


Figure 5-7: Control Flow Structure of the valve allocated in the gas pipeline and the Solenoid allocated in the hydraulic supply circuit

In conclusion, the model in Egolf in this context is represented by a simple layout after acquiring deep knowledge of the MFM methodology. This is the first step before analyzing the system behavior under abnormal conditions. Then, its visual projection is found clear and descriptive with the labels information. The model disposition supports the interpretation of the diverse flow patterns by differentiating between the control flow structures (Solenoid and Valve) of the mass flow structures (Gas and Hydraulic) and within themselves. Furthermore, it keeps all flow functions together within the same structure and it clearly shows that the objectives are the Solenoid Control and the Valve functions with such a representation. Despite the fact that this visualization of the gas pipeline is clear, the interpretation and functionality of all MFM features is crucial and it needs of greater expertise for its correct model in Egolf.

5.2.2 Water Heating Tank

Hot water has plenty of industrial and domestic uses like cleaning, bathing and space heating. Domestically, the heat transfer process takes place in water heaters. Then, the technical features of water heating are described as follow presenting the general concepts in this context in the Tables **5-8**, **5-9**, **5-10**, **5-11** and **5-12**. Its operational purpose is to drive the hot water through a pipe for space heating or bath purposes maintaining the water level and temperature in the tank.

Table 5-8: Heat efs

Heat energy flow structure	Heatfs	Water Heat system contained in the liquid
	Water sou	Heat the water contains
	WaterTra1	Transport for the water
	Water Temp TT	Water temperature transmitter
	Water Tra2	Transport for the water
	HeatBal	Heat balance between the two water outlet
	Out flow	Transport of water heat
	Sin3	Final destination for the water heat
	Drain Valve	Normaly closed, only available in specific cases
	Sin4	Final destination of the water heat in special cases

Table 5-9: Electric efs

Electric energy flow structure	Electfs	Electric system for heating the water
	Power sou	Conecction to the power
	Power trans	Transport for the electricity
	ElecBal	Electric balance between the electricity used and losses
	ConvEltoHeat	Device that converts electricity into heat
	Sin5	Final destination of the electricity system
	ElLoss	Electricity losses due to disipation
	Sin6	Final destination of electricity losses

Table 5-10: Flow cfs

Flow Maintain Control	Flow Maintain	Objective target is to maintain the water flow in the system
	SP1	Set point signal of water flow from the flow transmitter
	Maintain1	It controls the valve functions, open/close

Table 5-11: Level cfs

Water Level Maintain Control	TankLevel Maintain	The target is to maintain the water level inside the tank
	SP2	Set point signal received from the transmitter in the tank
	Maintain2	It will mediate the valve position depending on the water level signal

Table 5-12: Temperature cfs

Temperature Maintain Control	Temp Maintain	The target is to maintain the temperature of the water in the tank
	SP3	Set point signal that gives information gathered from the transmitter in the tank about the water temperature
	TIC	Temperature indicator controller which will mediate on the power production for heating generation

Previously, a simple process is modeled to show the lecturer the basic steps to getting started in Egolf, the next example will show more structures that can be added and new relations among flow functions and structures are represented. The following physical system presents an open tank connected to a heating unit that will rise the temperature of the water contained inside the tank.

The process is compounded by three control systems where the one connected to the outflow is dependent on the water level in the tank to release flow when needed, and another is connected to the water temperature in the tank to generate heat if needed. The third flow control system represented in the inlet flow is not essential but its representation will be reflected in Egolf model facilitating a more complex layout for this kind of processes. Again, having a full understanding of the physical system selected, the model in Egolf can be visually presented.

The Figure **5-8** shows the diagram and visual description of the system for the water heating tank, there is an inlet water flow indirectly connected to the tank and two outlet flow pipes. The main outflow pipe is controlling the outflow and the secondary will be only used in case of waste/drain needed (van Paassen & Wieringa, 1999).

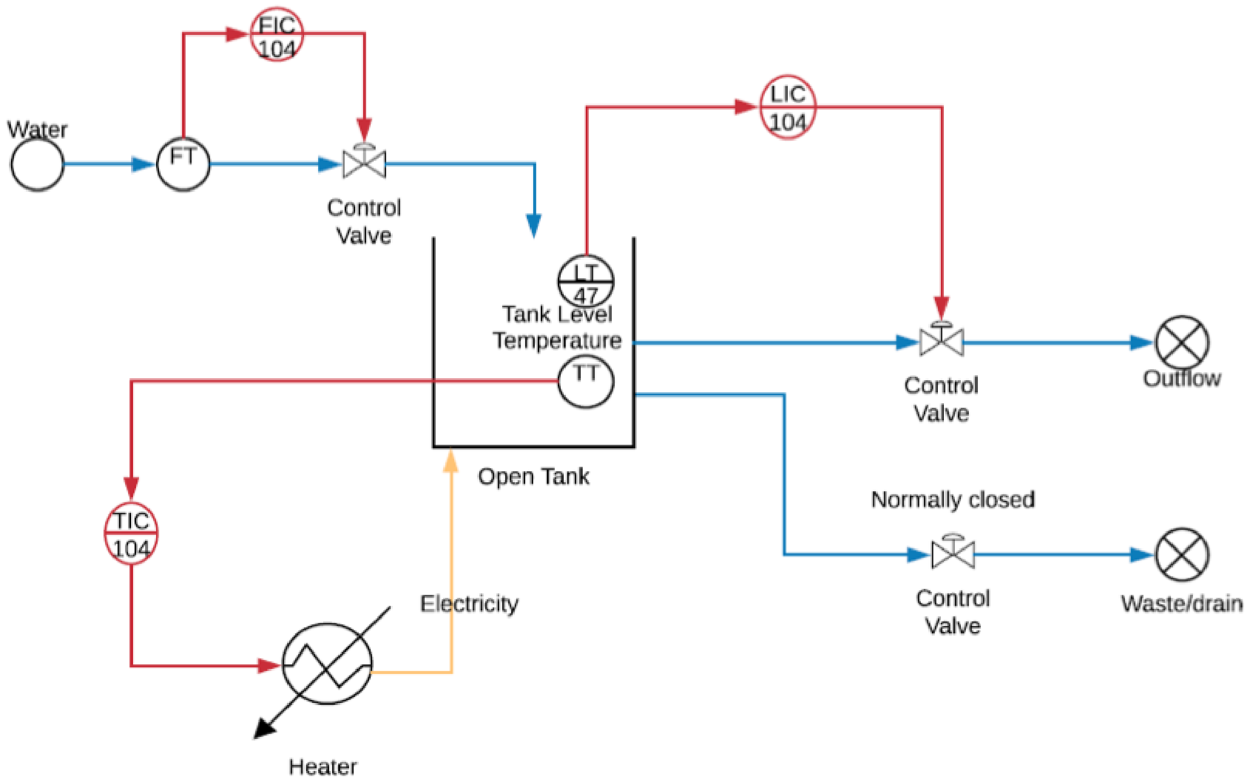


Figure 5-8: PFD of the Water Heating Tank (van Paassen & Wieringa, 1999)

By looking at the system, the next list show the objectives for the physical system:

- To Ensure that water can move - objective 1: Maintain water flow ratio within tank conditions
- To Ensure that water level limit in the tank - objective 2: Maintain water level above limit in the tank
- To Ensure that water temperature limit in the tank - objective 3: Maintain water temperature above limit in the tank

The Figure **5-9** shows the Egolf model of the water heating tank system applying MDM method.

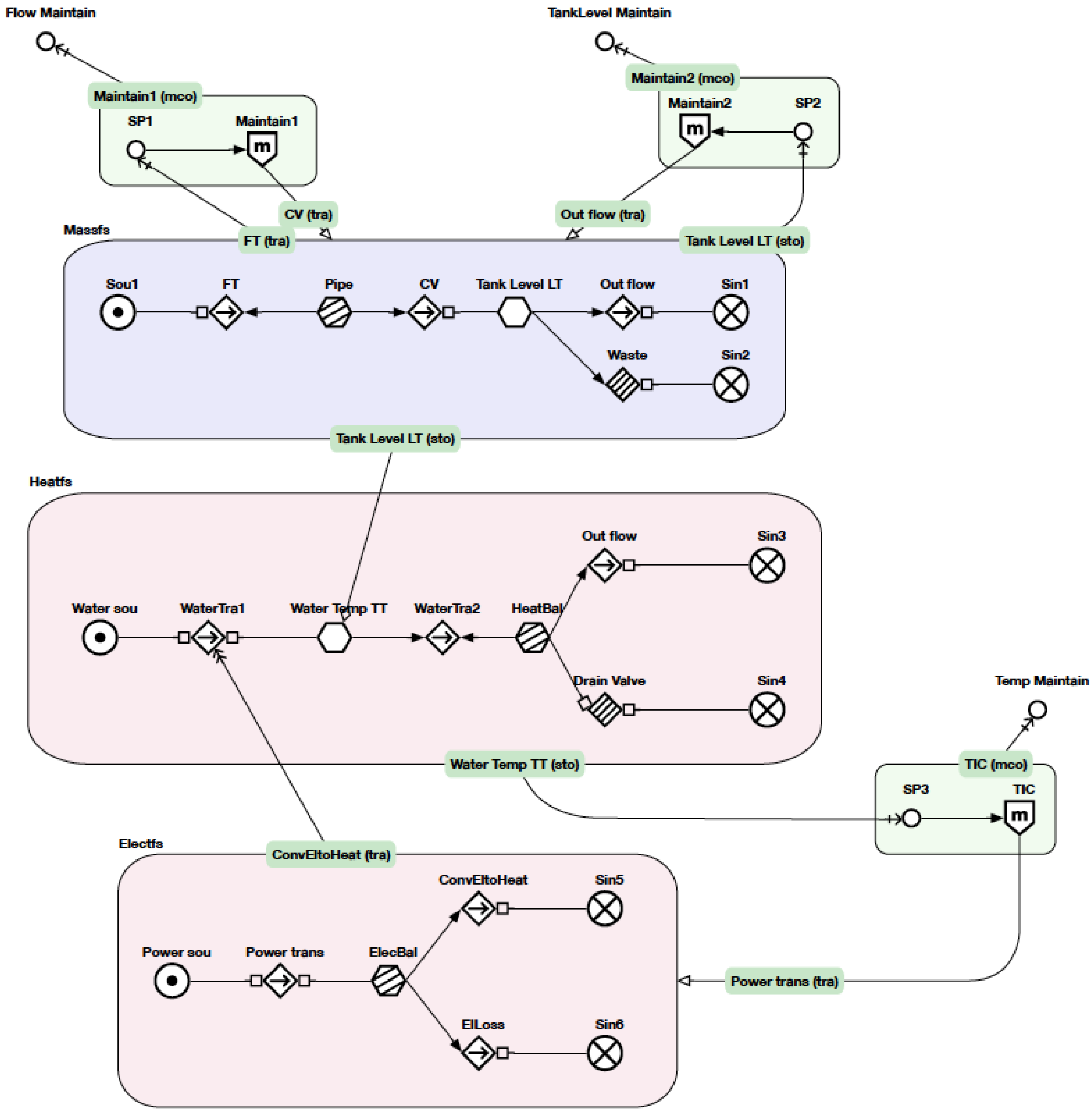


Figure 5-9: Egolf model of the Water Heating Tank

Here, only the energy flow structures for this case are represented due to the need of modeling this type of structures for this case and mass flow structures where described in the previous section 5.2.1.

The Figure **5-10** shows the connection of symbols for energy flow as heat and electricity in the MFM energy flow structure that will be presented graphically using a "bubble" which will gather all functions within the same drawing.

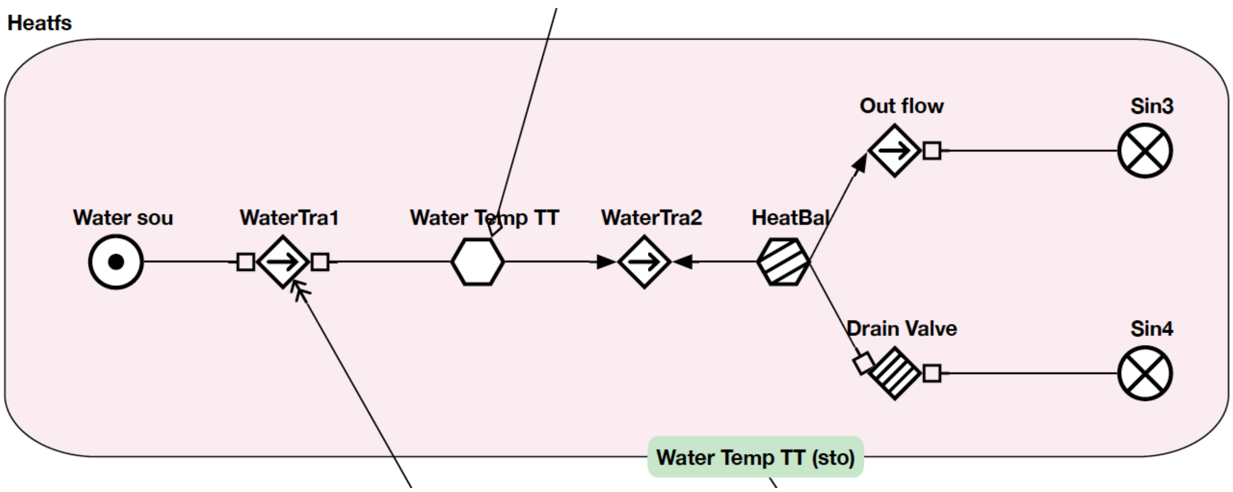


Figure 5-10: Energy Flow Structure of the driven water flow and electricity

The Figure **5-11** shows the connection of symbols for the solenoid control in the MFM control flow structure.

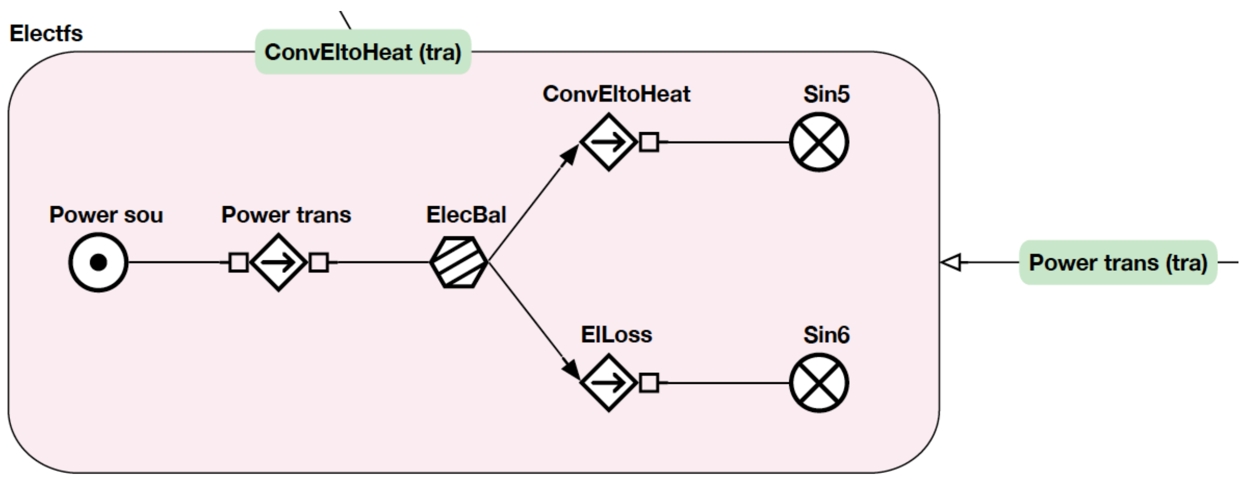


Figure 5-11: Control Flow Structure of the Solenoid allocated in the hydraulic supply circuit

A level and a temperature control are added to the system to regulate the water level and temperature, so the tank will be used as a storage function regulating the outlet flow. The control configuration presented in the diagram informs that the controller will operate the control valve of the outflow pipe, which function is to drive water from the tank to another location.

The Figure **5-12** shows the connection of symbols for the Flow, Temperature, and Level control of the process in Egolf in the MFM control flow structure.

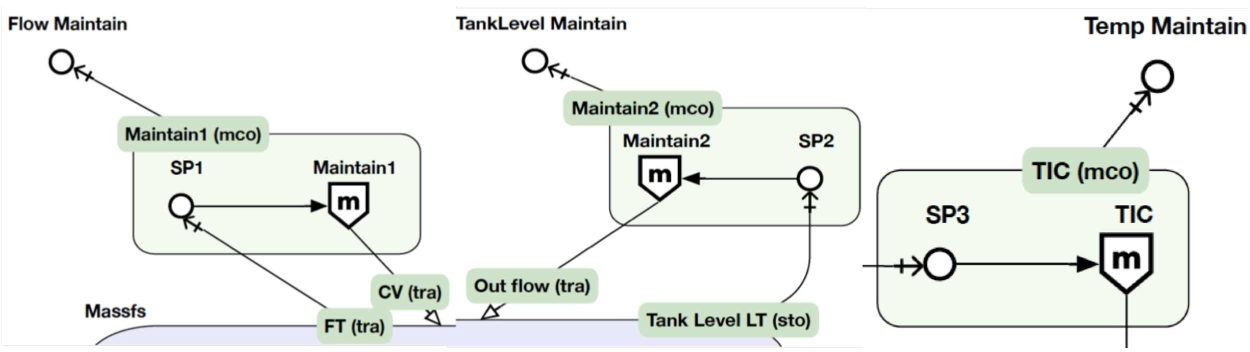


Figure 5-12: Control Flow Structure of the Flow, Level, and Temperature of the Power Plant

For this case, two means-end relations were applied representing "producer-product" arrow meaning the use of electricity for the production con heat, and a "mediate" arrow representing the influence of the water level in the tank to the water temperature in the same.

The Figure **5-13** shows the connection of symbols by means-end relations in the water heating system.

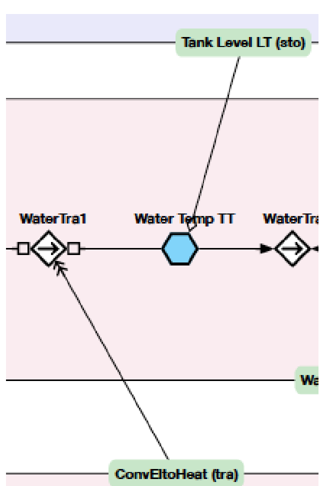


Figure 5-13: Means-end relations for the water heating tank

In conclusion, the model in Egolf in this context is represented with a more complex layout than the previous one and shows the use of more of the Egolf features. This is the first step before analyzing the system behaviour under abnormal conditions that will be hold in Chapter 6. Then, its visual projection is found clear and descriptive with the labels information proving that bigger systems can be applied in the tool. The model disposition supports the interpretation of the diverse flow patterns by differentiating among the control flow structures (Flow, Temperature and Level) of the mass flow structures (Water) and energy flow structures (Heat and Electricity) and withing themselves. Furthermore, it keeps all flow functions together withing the same structure and it clearly shows that the objectives are the Water Flow, Temperature and Level maintenance with such a representation. Despite the fact that this visualization of the water heating is clear, the interpretation and functionality of all MFM features is crucial and it needs of greater expertise for its correct model in Egolf tool.

In Chapter 6, the reasoning analysis is shown using this example due to its structure in order to introduce the type of cause-consequence study that is applied. Thus, mfm-test cause-consequence engine provided by DTU is necessary for this part of the analysis.

5.2.3 Power generatior plant

Steam is generated in the industry for different purposes. Then, the technical features of power production are described as follow presenting the general concepts in this context in the Tables **5-13**, **5-14**, **5-15**, **5-16**, **5-17**, **5-18**, **5-19**, **5-20** and **5-21**. Its operational purpose is generate power by driving steam through the turbine using fossil fuels in the heating system and a generator for the conversion of mechanical into electric energy.

For the last model, a more complex example is selected under knowledge of this type of systems conditions. It consists of a power plant generator driving the steam generated in the boiler through the turbine converting that kinetic energy into electricity. In the third physical system the following components are represented: the boiler, the heat exchanger, the combustion chamber, air and fuel intake valves, the turbine for conversion of energy, the condenser and the associated piping.

Table 5-13: Mfs of the Physical System

Mass flow structure of the physical system	Massfs	Mass flow structure
	Emissions	Transport for emmissions flow
	Air Preheater	Heat exchanger between the emissions and the air entrance flow
	Heater Barrier	Barrier that avoids the mass exchange between the sustances
	Air sou	Entry of air to the system
	Air FT	Air flow tranmitter
	Pipe	Balance between the transmitter and the fan
	Fan	Device that will increase the air velocity
	Preheated Air	Air flow at higher temperature
	Fuel sou	Entry of fuel to the system
	Fuel FT	Fuel flow tranmitter
	Fuel CV	Fuel control valve will regulate the flow entrance of fuel
	Comb Chamber	Combustion Chamber where the chemical reaction takes place
	Boiler Tube	Barrier that avoids the mass exchange between the sustances from the C.C. And the B.
	Boiler	Equipment where the generation of steam occurs
	Steam HP	Steam flow at high pressure
	Turbine	Equipment used to extract the energy from the steam flow
	Steam LP	Steam at low pressure
	W heat exchanger	Heat exchanger between the cooling water and the steam flow
	Cooling W barrier	Barrier that avoids the mass exchange between the sustances
	Cooling water in	Entrance of cooling water to the heat exchanger system
	Cooling water out	Final unknown destination of the cooling water
	Condens Pump	Device that will increase the condense pressure
	Condens bal	Balance between the transmitter and the pump
	Cond FT	Condense flow trasmitter
	Water sou	Entrance for the water flow to the system
	Water	Tmasport for the water
	Feed cool W bal	Balance between the cooling water and the water entry flow
	Feed water pump	Device that will increase the feed water pressure
	Feed W bal	Balance between the pump and the trasmitter
	Feed Water FT	Flow trasmitter
	FCV	Flow control valve for the water flow to the boiler

Table 5-14: Electric efs of the Fan

Electric energy flow structure for the fan	Elect Fan efs	Electric Fan energy flow structure
	Fansou	Power connection of the fan
	Current	Electric current
	Fan	Electric Device
	Elec to Veloc	Conversion of the electrivity into velocity
	Elec fan sin	Electricity final destination
	Elec Loss	Electricity losses
	Loss fan sin	Electric losses final destination

Table 5-15: Heat efs of the Physical System

Heat energy flow structure of the physical system	Heat efs	Heat energy flow structure
	Air Preheater TT	Heat contained in the heat exchanger
	Emissions cv	Heat contained in the emissions
	Air	Heat contained in the air
	Fuel	Heat contained in the fuel
	Preheated air TT	Heat contained in the preheated air
	C.chamberTT	Heat generated in the C.C. Due to the reaction
	Heat	Heat exchanged between the C.C. And the B.
	Boiler TT	Heat contained in the steam generated
	Steam HP	Heat contained in the steam at high pressure
	Steam LP	Heat contained in the steam at low pressure
	heatextrans	Transport of heat from between steam and cooling water flow
	CondTemp	Heat contained in the condensate flow
	Condensate	Heat contained in the condensate flow
	Fresh cond bal	Heat balance between fresh water and condensate

Table 5-16: Pressure efs of the Physical System

Pressure energy flow structure of the physical system	Pressure efs	Pressure energy flow structure
	Pfuel	Transport of fuel pressure
	Pair	Transport of the air pressure
	CombustionChamber	Pressure of the C.C.
	Pbarrier	Barrier that avoids mixing the sustances
	Boiler PT	Pressure of the B.
	Steam HP	Steam at high pressure
	Steam LP	Steam at low pressure
	ConvMech	Conversion of steam pressure into mechanic energy
	PcondBal	Pressure of the condensate
	Pfresh cond Bal	Pressure balance between the condensate and fresh water
	Pfeed w Bal	Pressure of the water entry to the B.

Table 5-17: Generator efs

Generator energy flow structure for the generator	Generator efs	Generatore energy flow structure
	Heat to mecha	Conversion of heat into mechanic energy
	Generator	Device for electricity generation
	mechaniconvertelectrici	Conversion of mechanic to electric energy
	Mech elect sin	Final destination for the electricity
	Loss	Losses in the Generator
	Loss sin	Final destination of the losses

Table 5-18: Fuel Flow cfs

Control of the fuel flow	Flow maint	Fuel flow maintainance
	SP1	Set point for the fuel flow
	Fuel Flow	It will control the fuel valve function

Table 5-19: Air Flow cfs

Control of the air flow	Air Flow	Air flow maintenance
	SP2	Set point for the air flow
	Air Flow	It will control the air velocity through power conecction

Table 5-20: Feed Water cfs

Control of the Feed water	Flow maintain	Water flow maintenance
	SP3	Set point for the water flow
	Feed Water	It will control the water valve function

Table 5-21: Cooling Water cfs

Control of the cooling water	Flow cooling water	Cooling flow maintenance
	SP4	Set point for the steam temperature
	m	It will control the cooling water flow

The process diagram represents four inlet flows, air and fuel are the substances driven to the Combustion Chamber where the reaction takes place generating enough heat providing the boiler with the energy necessary for the production of steam flow, and emissions which energy is used to preheat the incoming air before entering the chamber, then the emissions are driven through a heat exchanger. Another source of water mixed with the condensate generated in the condenser is providing enough flow for the production of steam when it is led into the boiler. Thus, this steam generation has certain pressure conditions utilized and converted into kinetic energy when passing through the turbine connected to the generator producing electricity for other uses. Eventually, the steam is treated in a condenser to decrease its temperature, by the utilization of an external cooling water current, for its reuse as condensate in the boiler previously mixed with the fresh water inlet.

The Figure **5-14** shows the process diagram built to illustrate the power production plant (Burns & Vicente, 2001).

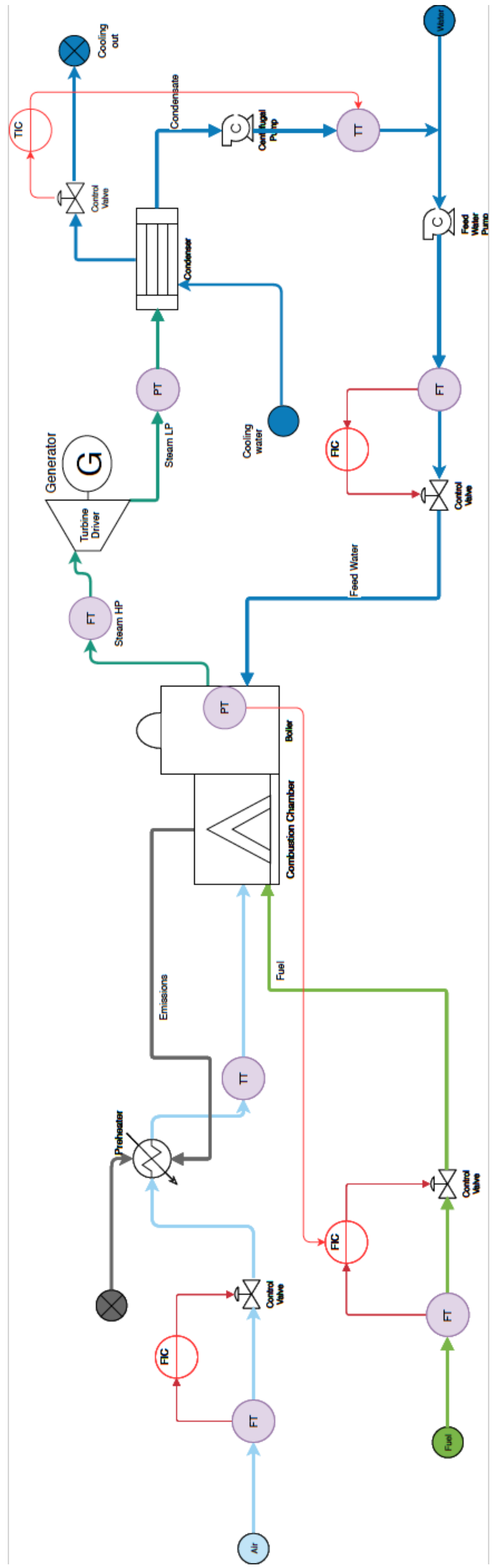


Figure 5-14: PFD of the Power Plant Generator (Burns & Vicente, 2001)

By looking at the system, the next list show the objectives for the physical system:

- To Ensure that fuel can burn - objective 1: Maintain fuel flow ratio within conditions for combustion
- To Ensure that air can burn - objective 2: Maintain air flow ratio within conditions for combustion
- To Ensure that water can move - objective 3: Maintain water flow ratio within conditions for boiling
- To Ensure that cooling water can move - objective 4: Maintain cooling water flow ratio within conditions for condensation

For the construction of the Egolf model and after gathering the information related to the system discussed, by defining the main objectives for this physical system, it will be easier to build the model in Egolf.

The Figure **5-15** shows the Egolf model of the power plant generator system applying MDM method.

Applying all these three cases it is shown the way Egolf tool can be used for different scalable process no matter the level of complexity and the diversity of the equipment required, MFM and Egolf program can make a successful visual representation of physical systems.

In conclusion, the model in Egolf in this context is represented by a very complex layout compared with the ones above and proves the flexibility of the tool. This is the first step before analyzing the system behavior under abnormal conditions. Then, its visual projection is found clear and descriptive with the labels information proving that very complex systems can be applied to the tool despite the scalability. The model disposition supports the interpretation of the diverse flow patterns by differentiating among the control flow structures (Fuel, Air, Feed and Cooling water flow) of the mass flow structures and energy flow structures (Heat, Electricity, Pressure, and Generator) and within themselves. Furthermore, it keeps all flow functions together within the same structure and it clearly shows that the objectives are the Feed Water Flow, Fuel Flow, Cooling Water Flow and Air Flow maintenance

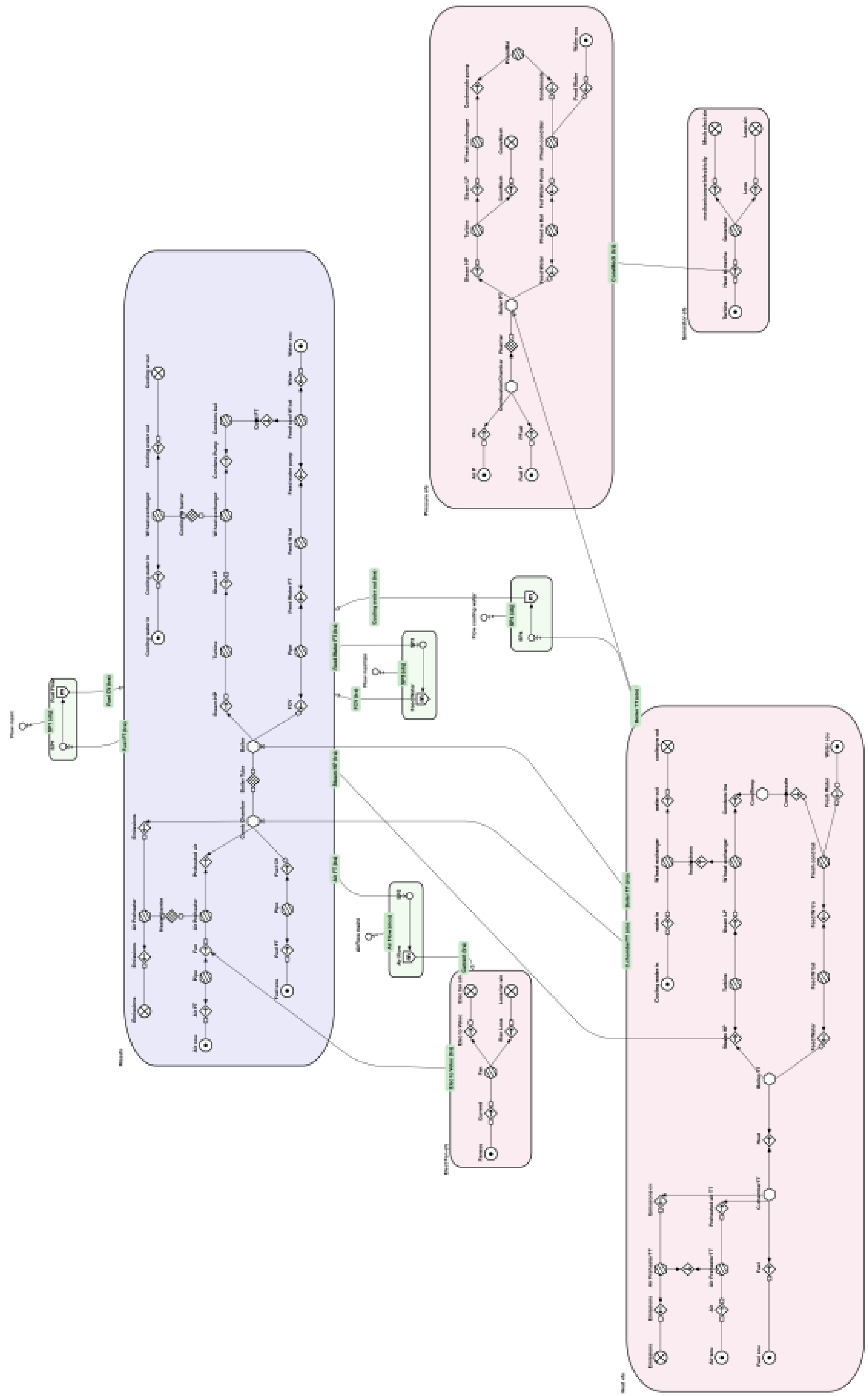


Figure 5-15: Egolf model of the Power Plant Generator

with such a representation. However, flow structures look quite complex but the tool is flexible enough to fit all features in the flow-sheet. Despite the fact that this visualization of the power generation plant is clear, the interpretation and functionality of all MFM features is crucial and it needs of greater expertise for its correct model in Egolf tool.

Eventually, Egolf tool application is found really useful for the representation of industrial processes in different context and scalability. Furthermore, it can be seen as an effortless and flexible program for visual industrial physical systems using MFM methodology. However, more intuitive representations could be developed for easier functionality understanding, for example, barrier functions and a clearer differentiation between storage and balance. I will also apply all tap features within the same flow-sheet screen in the program for more accessible and neat display. Also alarms while building the model would help for a proper representation instead of waiting for the final layout of the process.

6 Egolf Technology Analysis and Decision Support

Process industries cope with challenges that are very important for a reliable performance and more stable activities. Some of the challenges are continuously increased productivity, accelerated product introduction, optimized and more flexible production, and assured product quality. Here, Digitalization as a trend and innovative tools play a major role to beat those challenges and provide more decision support along processing operations. As a solution, Egolf tool is found to be a useful innovative technology to deal with this problems utilizing its causal reasoning engine.

In this chapter, Egolf Technology is used to analyze how the process model behave under abnormal situations. A cause-consequence test is applied using the water heating tank case defined previously in order to show what are the capabilities and advantages of such study. It will demonstrate the characteristics of this type of application illustrating visually the paths of the possible causes that are generating such an abnormal situation and its consequences. For that, the second model example was chosen for the analysis due to its level of complexity and structure so a better explanation can be found and presented applied to the whole process.

The multilevel flow modeling builds entire blocks that represents functions and objectives defining mass and energy flow structures of the physical system and delivers an abstract representation regardless specific equipments of the process. Nevertheless, the model is capable of representing the whole functionality of the physical system so the causal reasoning will provide the information necessary to show the relationship between a cause and its effect. Sections 6.1 and 6.2 describe the theory in which the practice is based.

The two following sections make reference to the theoretical methodology of the engine that DTU developed and showing its application in further subsections.

6.1 Reasoning Propagation

So far, all system functions and objectives are connected by either means-end or causal relations linking and combining the MFM patterns, thus the propagation makes its sense. Besides, the propagation of the abnormal state can be towards its downstream or upstream adjacent function so the reasoning path is generated from the function that has been assigned the hypothesis of its abnormal condition (Lind & Zhang, 2017). Furthermore, if that MFM function is neither a source or sink function, the reasoning path will branch out generating both a root cause and a consequence reasoning path, forming multiple results that will conform a tree structure.

6.2 Rule Based System for MFM Causal Reasoning

The reasoning analysis is generated automatically due to the rule-based software tool that uses reasoning algorithms based on the MFM workbench defined above. Once information of the starting point and the abnormal states is notified, the inference engine starts creating all prepositions based on the model design of the encoded patterns and formulas in the software. Thus, the test can start showing all the results from the conditions and statements defined after validation, generating several paths that are visually presented in a tree structure (Lind & Zhang, 2017). Eventually, the interpretation of the reasoning results can be supported with the assumptions and the model structure of the physical system. The Figure **6-1** shows the rule-based system for MFM causal reasoning (Lind & Zhang, 2017).

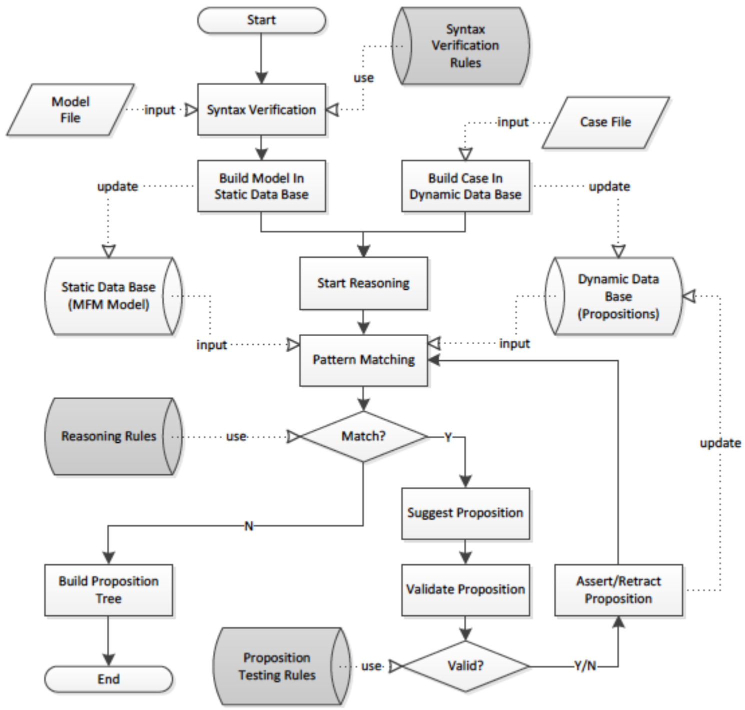


Figure 6-1: Rule-based implementation of the reasoning procedure (Lind & Zhang, 2017)

6.3 Functionalities and Cause-consequence analysis in Egolf

In order to start the causal reasoning analysis, firstly, one hypothesis of a function performance state must be made, and a chain of hypothesis will begin to appear ought to causal relations and means-end relations of the MFM patterns (Lind & Zhang, 2017). The Figure **6-2** shows the possible function states of the MFM patterns.

Function	States
Source	high-high, high, normal, low, low-low
Sink	high-high, high, normal, low, low-low
Transport	high-high, high, normal, low, low-low
Barrier	normal, leak
Storage	high-high, high, normal, low, low-low
Balance	sourcing, normal, leak

Figure 6-2: Possible function states (Lind & Zhang, 2017)

To do so, the Figure **6-3** shows the the specific case that will show the causal analysis supported by Egolf and carried out with mfm-test program, showing the functions in blue color as the process variables for such a case.

The first step in Egolf, before heading to the analysis, is to confirm that the model is valid by checking that syntax is correct. The Figure **6-4** shows the way the user can confirm in the web-based tool if there are any errors in the model and check that is correct before continuing for the analysis (Eldor, 2018).

If the result shows that the model is not valid, it will present the errors found in the right-hand side of the window where the user can find a clear description of the issue and correct it for the final validation and following reasoning.

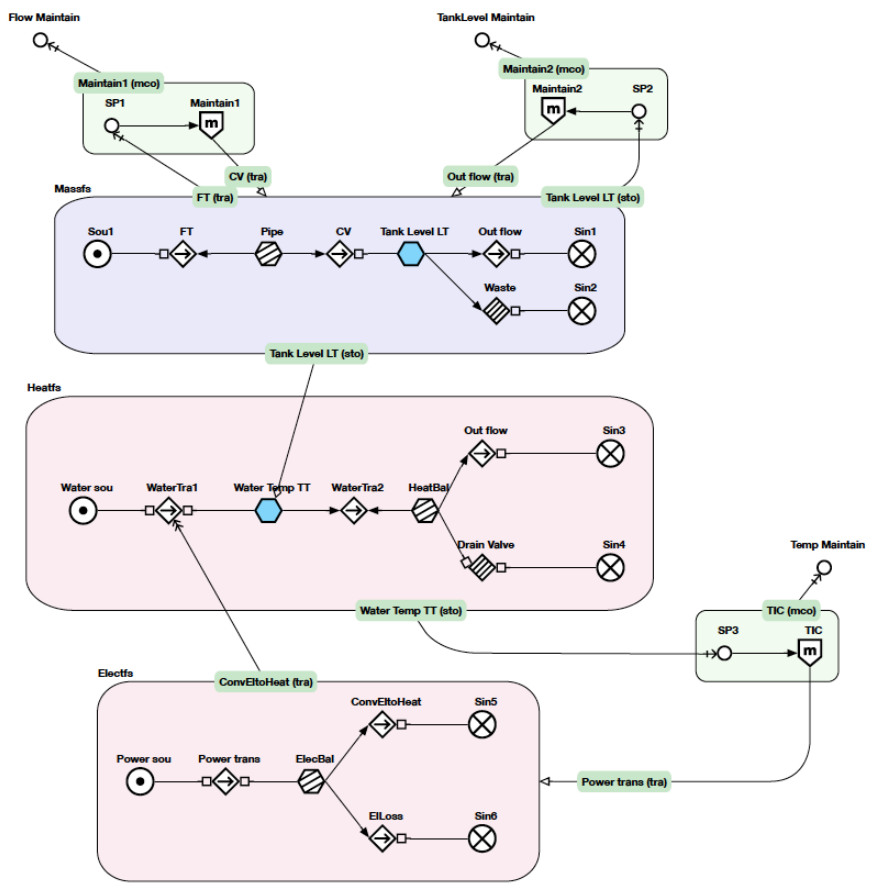


Figure 6-3: PFD of the Gas Pipeline

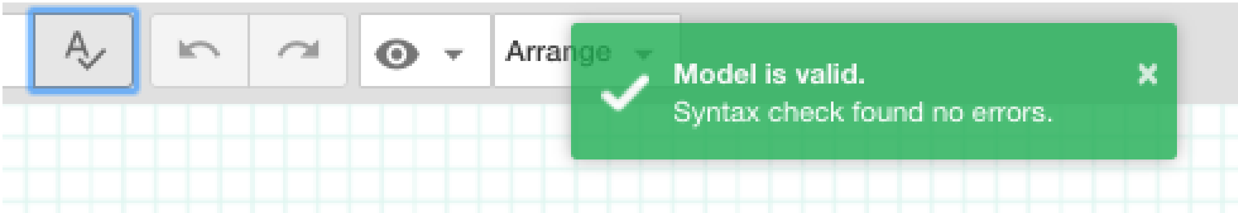


Figure 6-4: Check Syntax feature (Eldor, 2018)

At the present time, the engine tool that carried out all the algorithm for the causal reasoning is not integrated yet in Egolf so several steps are needed in order to full-fill the collaboration. The Figure **6-5** shows the feature the user have access to so different formats of the process can be downloaded and implemented in the mfm-test engine.

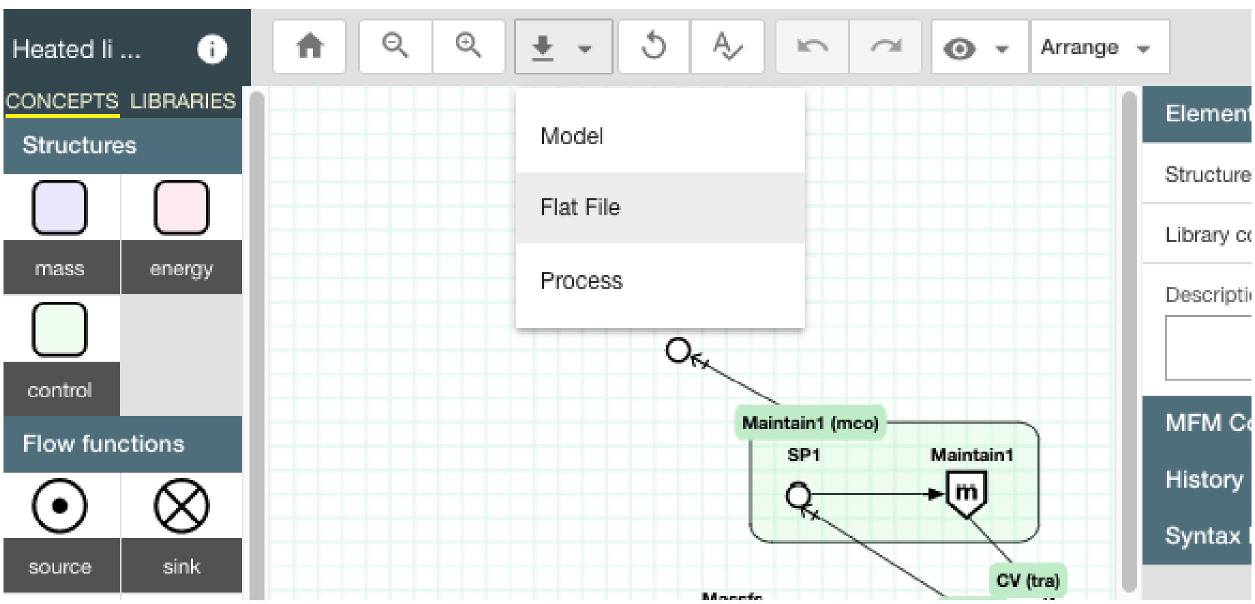


Figure 6-5: Flat file of the model

Once the Egolf model is included in the mfm-test software as a txt. format, the software shows all the functions that are implemented in the process and their possible function states. That way, the behavior of the model can be tested delivering a visual analysis through Egolf tool of the causes and consequences of that hypothetical function state of a particular function. Furthermore, some hypothesis are selected to show the reflexion of the causes and consequences paths that Egolf is able to present helping the decision support system involved in that process.

6.3.1 'High' Water Level in the Tank

The first hypothesis defined for a function state is 'high' water level in the tank specifying high as a working state. Besides, in order to make these following cause-consequences paths to appear, the highlight functions have to be clicked and yellow, for cause-path, and orange, for consequence-path, arrows will define the functions that are affected by the hypothesis. Thus, two features in Egolf show separately in two different flow-sheets the causes and consequences of any statement defined. The Figure **6-6** shows the cause and consequence features on Egolf (Eldor, 2018).

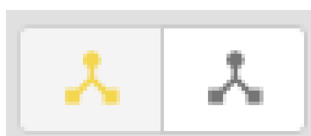


Figure 6-6: Cause and Consequence features (Eldor, 2018)

The symbol assigned on the left-hand side will show the possible causes with their related paths in yellow arrows, and the one on the right-hand side will show the possible consequences and their paths in orange arrows.

The Figure **6-7** shows the possible causes that might generate such a state on the upstream functions, showing the cause-path defined by the yellow arrow and the function states influenced defined as 'high' as well. The understanding of the rule-logic based may be unclear due to the direction of the yellow arrow is pointing at, but it says that the states of the functions in yellow are causing the state of the function in greenish. Having such a statement explained now is easier to analyze the case.

In a cause-effect relation, two different influences can be found. When there is a relation between a transport and other flow functions, it is considered as a direct influence, and other flow functions relations are considered as indirect influences where it is necessary to identify the influencer and participant relation effect. Due to this four cause-paths can be found having 'high' state in the FT function as the root cause, 'sourcing' state in the Pipe function as the root cause, 'low' state in the Out flow function as the root cause, and 'breach-us' in the barrier as the root cause, being the functions in between those paths described as intermediate function.

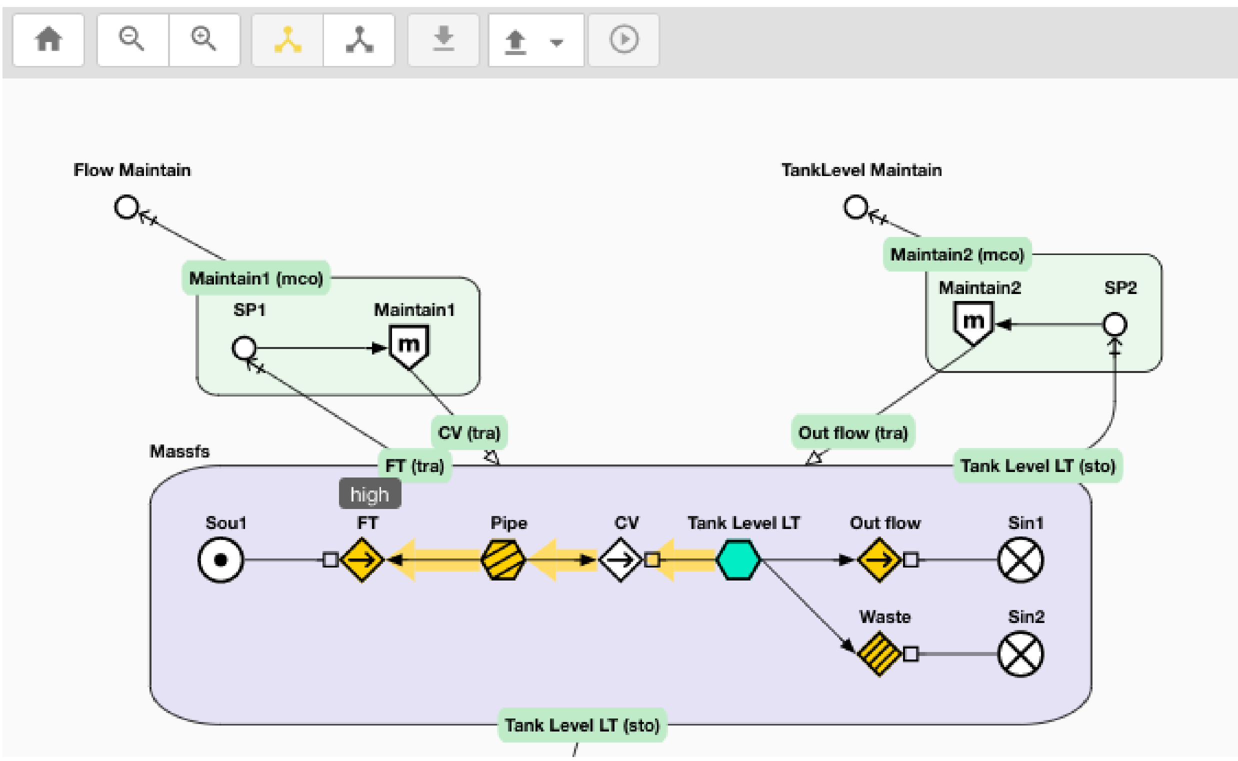


Figure 6-7: Backward Cause-Path

The term used for root cause is not clearly defined either because the rule-based analysis does not clarify that as the truly cause having several more possible causes to consider, but it is a way it is shown in the visual representation for the end of the path.

The following Tables **6-1** and **6-2** show on cause-path of the possible causes that will lead to have a high water level in the tank as an abnormal situation in the upstream path.

Table 6-1: Indirect influence pattern set 1

IF CV state	**THEN** Tank Level LT state
High	High

Table 6-2: Direct influence pattern set 2

IF Pipe state	**THEN** CV state
Sourcing	High

The table **6-3** shows another cause-path that leads to a 'high' water level in the tank. The rule-based engine says that when there is a balance, the propagation goes directly through the balance showing white the intermediate transport function.

Table 6-3: Indirect influence pattern set 3

IF FT state	**THEN** Pipe state
High	Sourcing

On the other hand, the Figure **6-8** shows the possible causes of having such a state on the functions allocated downstream from that situation, showing other cause-paths and the function states influenced defined as 'low' in the transport function and 'breach-us' in the barrier function for this case.

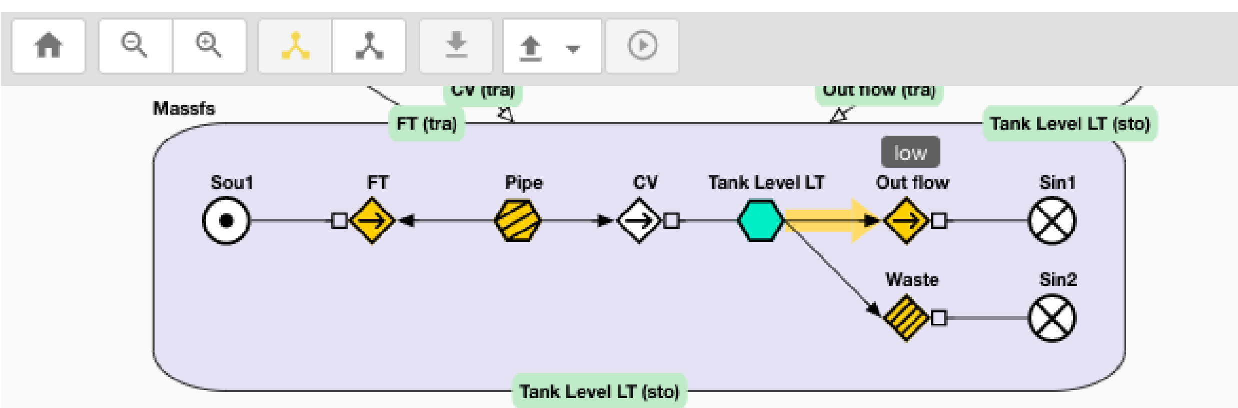


Figure 6-8: Forward Cause-Path

Again the yellow arrow is only showing the propagation in the way the engine leads to the possible causes that are creating that situation, and it could be clearer for the analyst to switch the direction in the visual representation of that arrow in the cases for a straight understanding of the cause-path influences.

The following Tables **6-4** and **6-5** show the possible causes that lead to a 'high' water level in the tank as an abnormal situation in the downstream path.

Table 6-4: Indirect influence pattern set 4

IF Out flow state	**THEN** Tank Level LT state
Low	High

Table 6-5: Indirect influence pattern set 5

IF Waste state	**THEN** Tank Level LT state
Breach-us	High

Other two cause-paths can be interpreted from this reasoning and the state of the functions can be seen with the mouse feature by only placing the mouse tool on the function. As it is shown, this abnormal situation selected only influences the functions within the mass flow structure in a sensible manner presenting 'high' function states on the upstream functions, and 'low' on those downstream functions. Egolf results for the 'high' water level in the tank seem logic, and they confirm that it can be due to massive source or few water flow release.

In the consequence analysis, four consequence-paths are also found, highlighting the 'final consequences' in orange color. The Figure **6-9** shows the possible consequences of having such an abnormal state on the functions affected by that situation, showing the consequence-path and the function influenced states defined as 'high' as well. That make sense when analyzing the abnormal condition having an impact in the energy structure, more water storage in the tank would activate the heating system making it work irregularly, raising the water temperature abnormally in the system. However, Egolf does not show that the electric flow structure is affected as a consequence. So far, if the water flow increases in the tank and the heating system works within the same range, the temperature of the released water would be low.

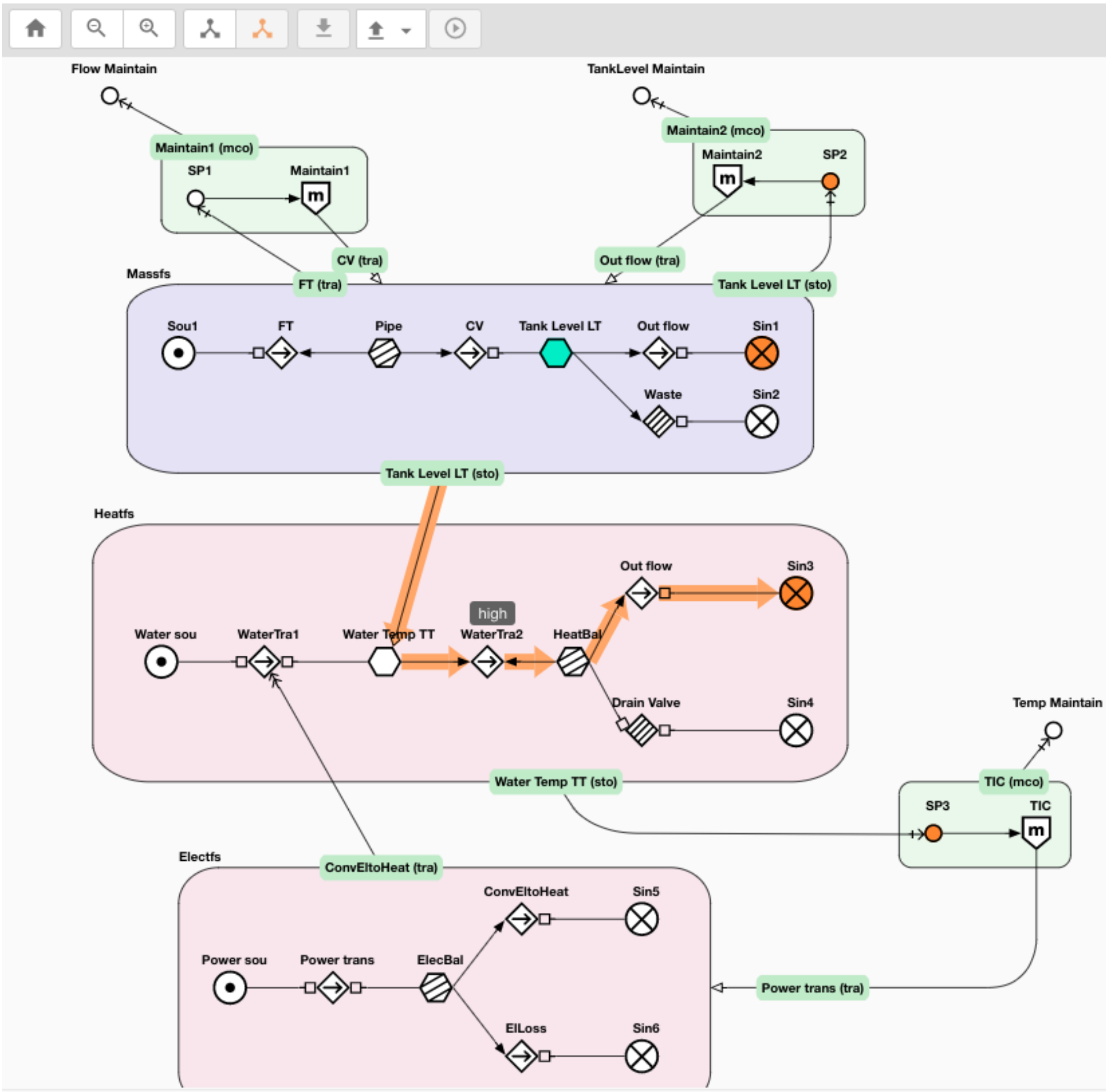


Figure 6-9: Consequence-Path

The following Tables **6-6**, **6-7**, **6-8**, **6-9** and **6-10** show the possible consequences of having a 'high' water level in the tank as an abnormal situation in the downstream path.

Table 6-6: Influence with mediate relation

THEN Water Temp TT state	**IF** Tank Level LT state
High	High

Table 6-7: Indirect influence pattern set 6

THEN Water Tra2 state	**IF** Water Temp TT state
High	High

Table 6-8: Direct influence pattern set 7

THEN HeatBal state	**IF** Water Tra2 state
Not defined	High

Table 6-9: Indirect influence pattern set 8

THEN Out flow state	**IF** HeatBal state
High	Not defined

Table 6-10: Direct influence pattern set 9

THEN Sin3 state	**IF** Out flow state
High	High

Same way as previously, all orange functions are those affected by having high water level in the tanks and, depending on the highlight function selected, it will show one path or another. Those highlight functions are defined as the 'final consequences' from the observer (abnormal situation),again not clearly defined due to multiple possible consequences but is a way the engine closes the consequence-path in the visual representation. Another issue that is important to mention is related to the targets and it is that it has not been defined definitely yet what is its influence in the cases, thus more development needs to be done.

6.3.2 'Low-Low' Water Temperature in the Tank

A second scenario was defined as 'low-low' water temperature inside the tank in the mfm-test engine and it will be reflected in the Egolf cloud-based tool.

The Figure **6-10** shows the causes of having such a state, 'low-low' water temperature in the tank, on the functions affected by that situation, showing the cause-path and the function states influenced defined a 'low-low' state as well.

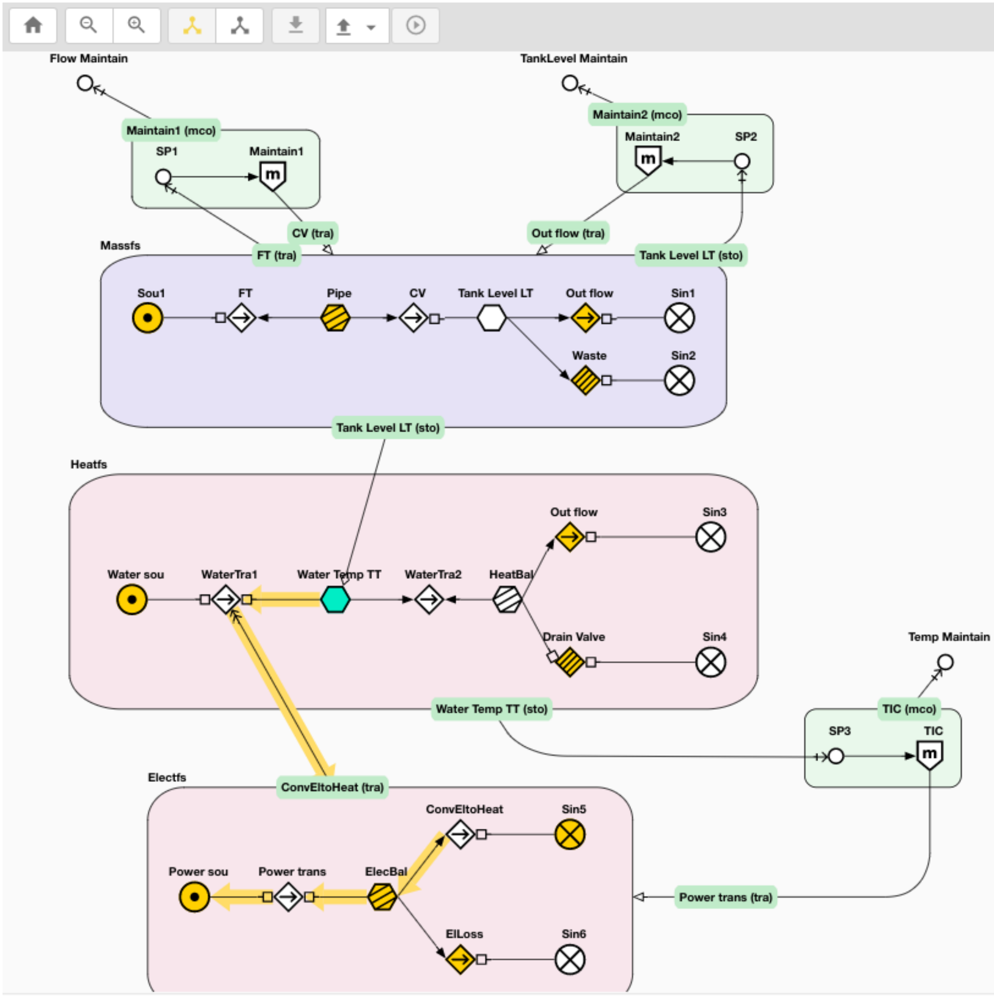


Figure 6-10: Cause-Path

For this situation, having a 'low-low' water temperature in the tank is caused by 'low-low' water temperature in the transport, and that is affected by the conversion of electricity into heat reached through a 'low-low' state, thus the power transport influences having a 'low-low' function state. If the ElLoss function is chosen, the cause-path ends there causing 'low-low' state in the conversion of electricity into heat and these will be all caused by 'high-high' state in losses due to all energy wasted because is not needed. Egolf technology is capable of represent all possible predictive causes for such case.

For this case, eleven cause-paths can be found as the root causes that will create that situation, defined by the functions in yellow, and the functions in the path are described as intermediate functions checking their status by positioning the mouse on them. The following Tables **6-11** and **6-12** show the possible causes of having a 'low-low' water temperature in the tank as an abnormal situation in the upstream path.

Table 6-11: Influence through the producer-product relation

IF ConvEltoHeat state	**THEN** Water Tra1 state
Low-low	Low-low

Table 6-12: Indirect influence pattern set 10

IF ElecBal state	**THEN** HeatBal state
Leak	Low-low

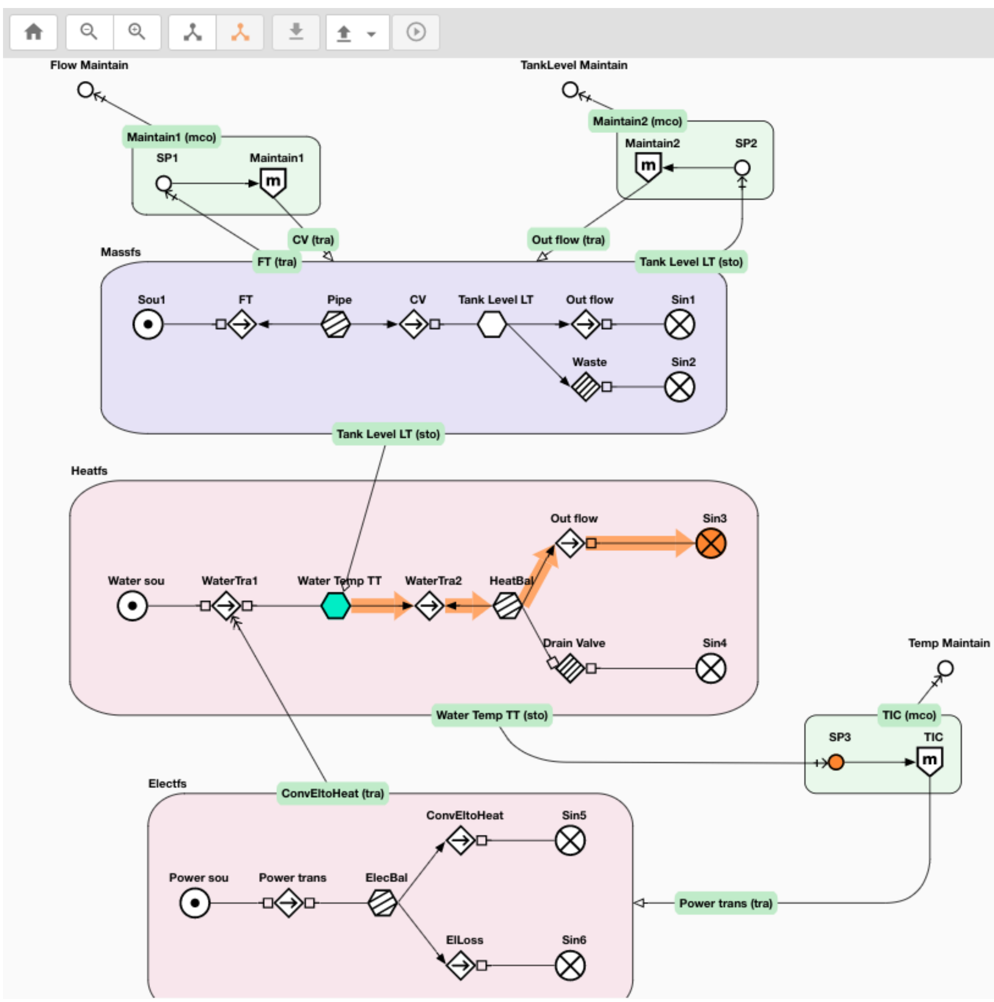


Figure 6-11: Consequence-Path

For the consequence analysis, the Figure **6-11** shows the possible consequences of having such a 'low-low' state on the functions affected by that situation, showing the consequence-path and the function states influenced defined as 'low-low' as well. One more consequence-path can be found by selecting SP3 as one of the possible consequences in this case led due to the hypothetical statement. When analyzing the consequence reasoning, it can be said that is more intuitive ought to the direction of the orange arrows when selecting one consequence created by the abnormal situation.

When following the path above in Egolf, the states of the functions appear and they are also defined as 'low-low' function states as a consequence of the low water temperature in the tank. It make sense that the variation in the water temperature only has consequences related to the energy structure. Thus, it has no influence in the mass flow or in the heater system.

The Figure **6-12** shows the consequences of having a 'low-low' state on the target by that situation, showing the consequence-path and the function states influenced defined as 'low-low' as well.

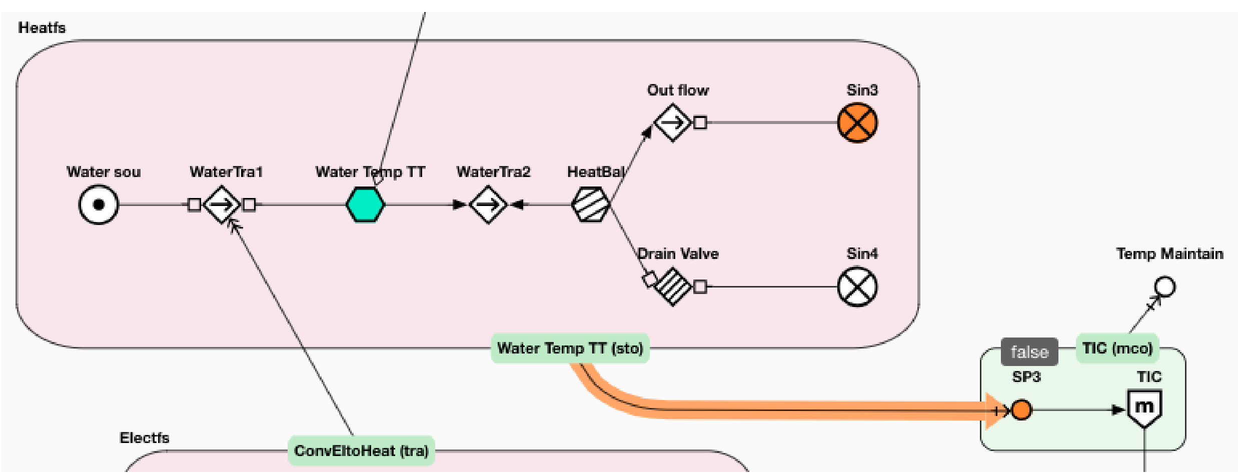


Figure 6-12: Consequence-Path for a Target

Where the consequence path shows the way to the objective, it is rare that the final and most important objective is not highlighted as the previous one does. That generates doubts of the extent of the 'Low-Low' water temperature condition. The following Tables **6-13** shows the possible consequence of having low-low water temperature in the tank as an abnormal situation in the upstream path towards a target.

Table 6-13: Influence from function to a target or a threat

THEN SP3 state	**IF** Water Temp TT state
False	Low-low

Egolf technology has a unique way to reflect the results under abnormal conditions of one of the parameters in the process. It represent the cause and consequences paths visually indicating as many paths as functions are affected by those conditions. Furthermore, the arrows represent an intuitive guide to follow the cause and consequence paths until the final function selected. And, by placing the mouse on the different flow functions, it will show their operating conditions. However, it only shows function states and not the variables of those flow functions so the operator has to remember if pressure, temperature, etc. is defined in that point. It could increase their value if for example there is a feature that could able a range of values as inputs and display them as outputs visually after the analysis. That would give greater support to the operator for faster actions and more flexibility to the tool. It could also present the results in a column to the side instead of using the mouse.

Summarizing, Egolf can display cause paths and consequences paths of a defined abnormal situation, and those cases can be chosen by the user and the analysis engine support showing that the functions connected to a transport function using participant are not influenced by the abnormal situation, like the final objectives of the process model.

6.3.3 Customizing based on local conditions

These two software together, Egolf and mfm-test, provide an effortless and user-friendly chance of causal analysis not only by selecting one hypothetical function state, but also by defining a specific and personalized case.

The Figure **6-13** shows the possibility of defining several function states of the different MFM functions in the Egolf model flow-sheet. Those function states described will highlight the function related in green and on the right-hand side column of the screen all these states will appear. This way, the user is able to set a certain number of variables and states in order to narrow the analysis and define the case situation.

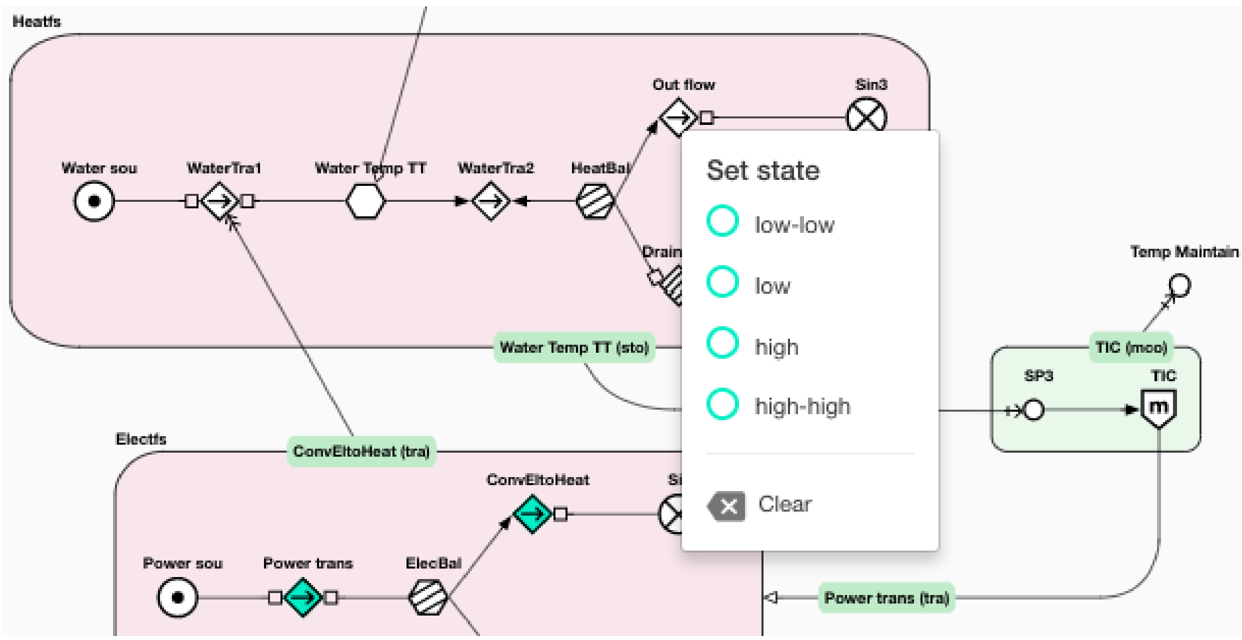


Figure 6-13: Personalized case in the reasoning flow-sheet

The Figure **6-14** shows the series of set states that define the case and 'ElLoss (tra)=high' represent the hypothetical function state (Eldor, 2018).

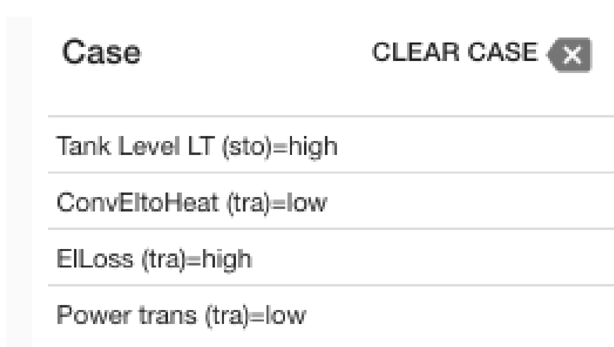


Figure 6-14: Set states and hypothetical function state (Eldor, 2018)

By doing so, the study is more precise and this characteristic makes a more flexible and truthful analysis. Furthermore, in order to check the cause and consequence paths only one step is required. The selection of one of the function states will determine the starting point and the causal and consequential reason of the model, showing and delivering similar scenarios to the previous illustrations.

6.4 Representation of the Information

Eventually, once all function states have been defined, the final information of the reasoning can be reflected and presented in real-time some how the way nowadays Eldor AS is doing it with its other product, Alarm Tracker. Through state-of-the-art visualisation, modeling, and algorithms provides the operator greater decision-support for rapid counteractions on abnormal conditions (*Eldor AS*, 2010). The Figure **6-15** shows one way the information from the analysis can be projected after running the causal analysis in Egolf. It shows the information results of having a function state such as 'Fouling of Contactor Inlet Cooler low' and the suggested preventing actions presented in the example for the Alarm Tracker software (Eldor, 2018).

Figure 6-15: Real-time data information from the analysis (Eldor, 2018)

information refexions

For the cases chosen in the previous sections, 'high' water level in the tank and 'low-low' water temperature in the tank, the information would reflect its possible causes, consequences, and preventive actions. For example, a possible cause of having 'high' water level in the tank would be huge source of water flow and it would be represented outside the circle. On the other hand, low water temperature as a possible consequence in the energy flow structure would be represented inside the circle. In the right column some actions would appear, some could be check the downstream pipe in case it is blocked or the upstream valve that may be not responding to the commands.

The final presentation of the results shows a great advantage for the user understanding of causes, consequences and preventive actions in advance to abnormal situations of flow processes involved in the Oil & Gas industry. The ultimate step for Eldor, in cooperation with DTU, would be the integration of these three technologies: AlarmTracker system, Egolf technology, and mfm-test engine. The application of these innovative assets can mean a revolution in the industry delivering support in (*Eldor AS*, 2010):

- Understanding all situations with reduced time to action (Situational awareness).
- Dealing with the cause(s)of the abnormal situation. Not only the alarms/symptoms (Root Cause).
- Developing scenarios from the abnormal situation shown directly (Consequences).
- Taking the recommended action to get back to the normal situation (Counter Action Planning).
- Dealing with the upsets up-front before they lead to shutdown or an incident (Decision Support).

7 Future Egolf Applications

In this Chapter, future projection of Egolf is presented so this cloud-based program could only not focus on the processes for production of Oil & Gas, but also in many other industries and areas. The following list shows several industries where Egolf and the MFM approach could be used in the future:

- Fishing farms

  For the modeling of this example, the Figure **7-1** shows a process layout of a fish farm for the production of Salmon, stated in (Davidson et al., 2018). The structure of the process diagram could be easily represented in Egolf, providing real-time information of the flow functions states for a much more reliable preventive maintenance, as an example.

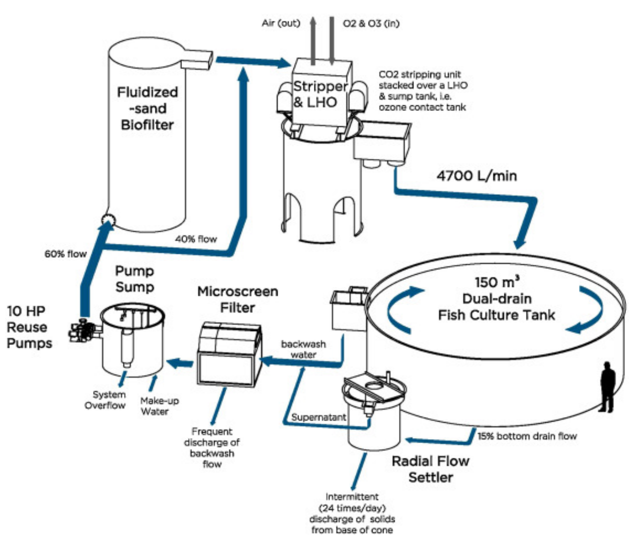


Figure 7-1: Process layout of a fish farm (Davidson et al., 2018)

- Hydro power

  Besides, the Figure **7-2** shows a process layout of a hydroelectric power plant for the production of electricity, stated in (Hydro, n.d.). Again, the proper model could be represented in Egolf, providing real-time status information of the physical system enabling engineers take the right preventive actions in case is needed.

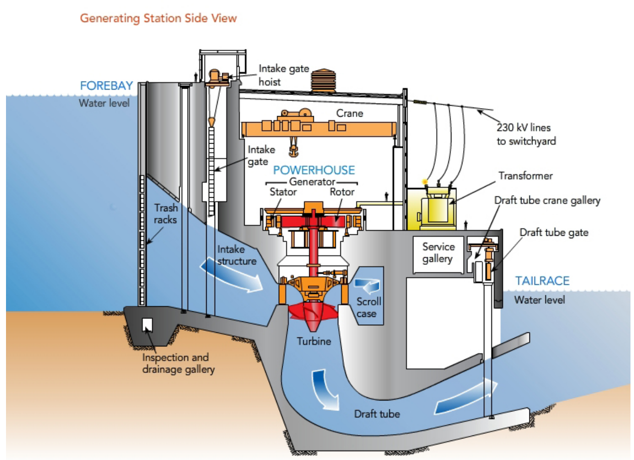


Figure 7-2: Process layout of Hydroelectric Power Plant (Hydro, n.d.)

- Wind power

  In here, another proposal model is suggested involving only electrical flow representations for the production of electricity.

- Solar power

  In this case, the representation would be quite similar to the one that would model the hydroelectric power plant if the purpose is to supply with hot water, and it would be similar to the wind power model if the purpose is only to provide electricity.

- Manufacturing industry (Supply chain): Materials and Process Industries, Fabrication and Assembly Industries

- Energy Management

- Discrete and Continuous Product production

  It has being found that MFM method can be applied to batch production systems as it states in (Zhao, Yang, & Wang, 2011), then Egolf could provide reliable support to this processes.

- Energy analysis

  Nowadays diverse of tools, like Homer, are being used for energy analysis and Eldor could also provide similar services. Then, Egolf could be developed to such extent that its characteristics would help in both off-grid and grid-connected design to evaluate different alternatives. Besides, it could also analyze the system flexibility for the optimization of the energy systems in communities and buildings applying demand response to reach performance goals, safety and cost savings (NREL, n.d.).

So far, the examples used in this thesis are non-related to physical systems of Oil & Gas production due to the complexity and the lack of knowledge and information about them thus, these cases are a proof of the wide use and help Egolf and the MFM test engine can provide. However, those physical systems that have been designed applying the MFM approach confirm that no matter the study field what matters, but the information and knowledge acquisition related to the flow processes. Then, water treatment processes could also be represented, wind, fishing farms and solar power generator plants can also be included in the future as a potential market for further exploration.

Continuous production, safer operations among other challenges are common for any industry and the application of this type of innovative technology as a solution to cope this problems can provide great benefits for all sectors based on the visual representation of the physical systems and their analysis when facing abnormal situations.

8 Discussion and Conclusions

In this research, the common industrial problem in the Oil & Gas sector in decision making is the lack of real-time information support while running operating process activities. The main conclusions are:

- Digitalization has changed all industrial and non-industrial processes and activities in all senses by the application of smart assets enhancing performance, safety and costs compared to the past actions.

- In the present time, Digitalization can be considered as the enabler, and smart assets as the drivers. Both applied can beat actual challenges like continuously increased productivity, accelerated product introduction, optimized and more flexible production, and assured product quality.

- MFM approach is the method that represents the solution for a deeper comprehension of the physical systems helping operators for their interpretation. MFM method is based on the objective analysis of a physical system and is the approach selected to represent the flow processes due to its utility in the innovative technology, Egolf.

- Egolf technology is described as one solution to provide effective decision support and situational awareness when abnormal situations happen. It is an effortless and user-friendly web-based tool able to model flow processes of different scale.

- Three different cases non-Oil & Gas oriented are implemented in the technology chosen due to the straightforward understanding of such processes from the background expertise, showing that any kind of physical flow system can be simulated.

- There is a clear limitation for the MFM and Egolf related only to flow processes that can be designed but, there is also a chance to open for more industries than Oil & Gas, as shown with the examples described.
- Visual representations of industrial processes offer great benefits and facilitate the evaluation of their analysis optimizing the understanding of the actions required to handle abnormal situations.
- When analyzing the possible cause-consequences paths in Egolf, the study turns out to be more intuitive while analyzing the consequences than the causes, due to the arrows orientation towards the final consequences that will finish the path. The yellow arrows point on the contrary direction to the actual understanding, it only refers to the propagation in the cause study and it is not considering the direction the arrows point at.
- Some features of the technology used are not yet available so a complete causal analysis cannot be entirely reached ought to ongoing work.
- In the near future, the results will be easy to understand by operators as the information frame extracted from the innovative software will reflect the results in a very effective visual manner, illustrating effectively the possible causes and consequences and suggesting some preventive activities.
- The integration of AlarmTracker system, Egolf technology, and mfm-test engine will present a greater advantage as a solution to face all challenges for the industry providing immense support in situational awareness, root cause and consequences, counteraction planning, and decision support.

As an extension of this work, the following points are recommended for the future work. Comparison of innovative technological solutions should be made, more case studies should be applied for a deeper understanding of the function concepts and their relations depending on the process. Also, reasoning analysis when software development is done in Egolf, and application of new processes from new working industries supporting more customers.

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