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Proactive Project Control of EPC Projects
A Lean Project Control System

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"*Having no problems is the biggest problem of all. Progress cannot be generated when we are satisfied with existing situations*"

Taiichi Ohno
Japanese Industrial Engineer & Father of the Lean Production System

Keywords: construction, EPC projects, project control, lean manufacturing, lean management, lean project control

Abstract

The construction industry has been suffering from the bad performance or even failure of its projects. Cost overruns and delays have become the normality for EPC projects. The productivity of the construction industry has been therefore declining or in the best-case scenario stagnant. Scientific research refers the failure of EPC projects to weak and inefficient project control system used in the construction industry. Experts underline the pressing demand for developing efficient and flexible of project control systems that fulfill the needs of today's projects with higher complexities and larger sizes and scopes of work. The demand for such control systems needs to be urgently fulfilled to remain the profitability of the EPC projects, especially in the wake of the large investments poured into the construction industry, which are expected to even grow overtime. This research uses a qualitative secondary analysis to responds to the pressing demand of the construction industry by developing a proactive, efficient, flexible, and proactive project control system that fulfills the needs of today's mega and capital EPC projects. The newly developed project control model uses the application of "Lean thinking" principles to guarantee a steady and uninterrupted workflow and meet the clients' requirements in terms of duration, quality, cost and safety while employing continuous improvement and minimizing any kind of waste. Lean principles, that have showed astonishing results in increasing the productivity of the manufacturing industry are used by the developed controls system model with the aim of increasing the productivity in EPC projects. This is achieved by the means of effective flow control, real monitoring and control visual panels and real time reporting and control digital tool, all applied by the proactive project control model developed in this research. This research also provides methods for measuring the performance of the proposed project control model. The proactive project control model developed in this research proofs to have many advantages over other conventional project control system used in the construction industries.

List of Abbreviation

BOM .... Bill of Material
CBS....................................... Cost Breakdown Structure
CCPM .... Critical Chain Project Management
CII .... Construction Industry Institute
COAA .... Construction Owners Association of America
CPM...................................... Critical Path Method
CWP .... Construction Work Package
EPC....................................... Engineering, Procurement and Construction
EVA .... Earned Value Analysis
EWP .... Engineering Work Package
FEL .... Front End Loading
GCR...................................... Global Construction Review
IPA .... Independent Project Analysis
LCI.. Lean Construction Institute
NPV .... Net Present Value
OBS .... Organization Breakdown Structure
PCS .... Project Control System
WBS .... Work Breakdown Structure
WIP....................................... Work in Process
WTP...................................... Work Task Package

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Executive summary

A project is a collaboration of assignments that are needed to be done in a specific sequence to achieve a certain predetermined aim within a specific time frame using dedicated budget. An engineering, procurement, and construction (EPC) project is a specific form of contracting in the construction industry, in which a contractor is responsible for the executing the project starting from the engineering until the commissioning and start-up. A project control system is defined as the set of efforts including management tools, software, policies, principles, standards, and methodologies that are used by the project team to manage the project's performance.

Over the last three decades the productivity of economic resources has almost doubled in the manufacturing industry. On the contrary, it has been stagnant or declining in the construction industry. At the same time many projects have faced the unpleasant situation of failure. Most of the mega projects are still facing either cost overruns or schedule delays or even both.

This shows that construction industry is in desperate need for an improvement of conventional control and management systems used in EPC projects. The conventional control systems are proved to not flexible enough to absorb the unforeseen challenges of the complex projects. Such control systems also seem to be uncapable of adapting to the dynamic nature of EPC projects execution. Besides, these systems are not able to enrich the planning and scheduling processes by integrating the project team feedbacks and lessons learned in the companies' best practices to prevent the reoccurrence of issues and challenge during the project's execution.

In this research, a qualitative secondary data analysis of present scientific literature on control systems of EPC and lean thinking principles is used to develop a new project control system. Moreover, first-hand data of the author's previous professional roles are included to enrich the developed control model with a higher practicality and applicability. The center piece of this research is the project control model developed by the author to fill in the demand gap for efficient project control systems. This research provides a deep understanding of the EPC lifecycle, existing approaches and systems of project control, and the different workflow systems. Furthermore, it identifies lean management approaches, and applies them in the proposed new lean control model. Lastly, this research provides methods for measuring the performance of the proposed project control model.

Any project has a lifecycle consisting of different phases. A project's lifecycle starts with the

business planning where the economic viability of the project is assessed. Then, it extends to the facility planning, which guarantees an optimal project's solution, followed by project planning, which is known as the FEED design. A project must pass through these gates to reach the execution (EPC) phase. This research focuses on the control of the EPC project's phase.

One of the easiest and most used tools of project control is the project's breakdown structure. The work breakdown structure is the decomposition of the project into smaller manageable elements. The same concept is applied to produce a cost breakdown structure or even organization breakdown structure which draws the boarders of responsibilities within the project. The proposed control system model is inspired by some successful control tools of the production industry. In the production industry, the flow in the production control system is the continuous motion of items in the added value chain for producing a final product. Flow is controlled in the production industry either by a push or pull flow system. The push flow system is based on "make to stock" concept while the pull flow system is based on "make to order" concept. The same concepts of flow systems can be used in EPC projects. This is achieved by firstly decomposing the work into small packages. These packages are comparable with the products in the production system, while different project phases are comparable to the production process. In this way, the same concepts of workflow can be applied to the EPC projects. The flow control system is responsible for regulating the project's activities reflected in the master execution schedule. Projects' execution schedules are mostly created using the critical path method (CPM) which was abandoned by the manufacturing industry three decades ago due its proven ineffectiveness. The Critical chain method (CCM) is proven to be a more flexible and effective substitution for the CPM. CCM is based on the idea of having an explicit buffer activity rather than having self-owned contingencies in every schedule activity. The CCM proved its positive impact for decreasing EPC projects' duration and cost.

The "Last planner system" is a project control system commonly used in EPC projects. It is based on establishing a construction sequence for the project. This is followed by the elimination of constraints to make activities ready for execution. The activities are then included in the lookahead schedule. The ready activities are determined and approved to be executed in the corresponding period. The activities' execution is then monitored, and their completion is recorded at the end. However, the Last Planner System does not describe clearly how to fill the gap between what should be done and what can be done.

Another control system that is broadly used in EPC projects is the advanced work packaging, which is based on the idea of “starting with the end in mind”. Its aim is to have projects’ workflow driven by the sequence of construction. The project is decomposed into construction work packages which are then split into engineering work packages. This system introduces the idea of workface planning, which focuses on organizing and providing all the elements necessary for the installation work package. The latter is the ground zero achievement given to team on site for execution before the work commences. This system’s requirement of the workface planner’s participation in developing the IWPs is not reasonably supported. Moreover, this system does not entail the participation of the different stakeholders of the project for completing the IWPs. This research proposes a new project control model that applies lean thinking principles to cover the gaps of conventional and ineffective control systems and enables an efficient project control in EPC.

While the construction industry’s productivity is declining, the manufacturing industry’s productivity has been striving because of applying lean thinking principles. Lean thinking is based on increasing the added value while minimizing the waste in terms of non-adding value processes. The following are some prominent principles of lean thinking. The Jidoka lean principle is defined as the ability to stop the production process in case errors arise in order to increase the productivity and eliminate the waste of resources. Besides, the Mieruka lean principle entails the visualization and streamlining of work processes to facilitate the work’s understanding and monitoring. For example, the Andon is a very common visualization lean tool broadly used to alert the occurrence of issues. Furthermore, the Poka Yoke lean principle aims to assure that every process’s step is done in the right manner to avoid occurrence of any defects in the first place and makes the production line “error-proofed”. Moreover, Kanban lean principle improves the manufacturing’s efficiency by visualizing the work status using Kanban cards, where every job card moves according to its status for easier monitoring and control. Lean management proved an enormous positive impact in industries where it was applied. Case studies in construction industry conclude that a higher portion of time was spent on non-adding value activities. Consequently, it is obvious that applying lean principles in the EPC project control will positively influence the productivity and performance of the projects.

In this research, a proactive live monitoring and control model is proposed. The model is inspired by the lean principles of visual management, error-proofing, optimization of work, content and schedule, organizational commitment, people involvement, optimization of construction system, and proactivity. The model firstly adopts the idea of breaking down the project work into easy manageable elements. The usage of level-4 activities breakdown into work task packages (WTPs) is recommended in this model, to avoid the complexity of work. These WTPs are defined according to the scope of work, time duration, cost, and constraints. The WTPs flow is controlled by a push control system in the beginning followed by a push-pull and finally a pull, depending on the different project stages. In the front-end loading stages a push system is used as the gate relation between the successive different front-end loading stages. While in the EPC stage firstly the push flow is adopted till the channels are adequately loaded with enough WTPs for creating a pull flow. The transformation of the flow system from a push to pull flow takes place through a push-pull interface. In the EPC phase the execution schedule is created by the critical chain method. Moreover, the workflow is controlled by a pull flow according to the rate of construction. The downstream requirement starts with the last WTP in the execution schedule and then continues to the predeceasing WTPs in the agreed sequence. On the other hand, the long lead items (LLIs) are generally managed by a push flow as their installation takes place based on predetermined dates. Hence, the entire construction is managed by a pull flow till the LLIs installation and contractual milestones. The LLIs can be managed by a pull flow too but the risk for this should be assessed first. In this case, the LLIs delivery dates will be able to float according to the actual progress on site, while the lead times are verified with the suppliers to trigger the delivery. By the end of the lead times the LLIs are delivered completely.

Moreover, the model proposes the creation of an integrated breakdown structure that reflects the work breakdown structure (WBS), the cost breakdown structure (CBS) and the organization breakdown structure (OBS). This provides easier management, incorporation, alignment, and boarders of responsibilities in the project. Kanban cards for every integrated WBS are created and easily visualized, monitored, and managed by the Kanban approach.

Besides, the model proposes that the WTPs are planned and managed in different stages. Meetings for every stage is performed for easy handling and planning of the WTPs to assure an uninterrupted and steady workflow during the construction phase. This starts by the 120-90 days lookahead planning meeting and continues to reach the 1-week lookahead planning meeting. During the lookahead meetings the constraints of WTPs are discussed and eliminated. As a result, the execution week is reached with the ready WTPs to be implemented with no stoppage and within idle time to reach high levels of productivity.

Furthermore, the model proposed the creation of color-coded visual control panels for the different levels of the project. The color-codes on the visual panels reflect different work statuses. These panels are created for the sub-system level, the system level, the area level, and the project level. The respective project responsibles are given access to the respective visual panels. This enables live monitoring and proactive control of the project.

Furthermore, the model proposes digitalized live monitoring and control of projects by using a mobile based software and database. The foremen responsible for the ongoing WTPs can report the work status using the reporting mobile application. The different work statues which can be reported range from working smoothly, to challenging, expecting a delay, in emergency or other issues. These live work statuses of all the respective ongoing WTPs are demonstrated with different color-codes on the visual control panel for the different project levels. This enables the project responsibles of proactively controlling the project rather than remaining in the reactive control mode. Moreover, this digitalized reporting system communicates site issues that prevent the work progress to the respective project responsible in order to solve the problem easily and avoid long idle and non-adding value times.

Lat but not least, the proposed model provides methods and approaches for measuring the performance of the proposed control system. These performance indicators can be used to assess the efficiency of the system. These indicators are the workflow steadiness indicator, percent plan complete, constraints analysis, availability, and utilization of resources indicator.

In conclusion, the application of this proposed system allows having real time monitoring and control of the project, which helps the project to absorb the effects of unforeseen challenges. Moreover, the proposed system contributes positively to having a noninterrupted and steady workflow with the least idle and non-adding value times. In addition to, it incorporates lessons learned in companies' best practices to be considered during the implementation of remaining project' activities. This provides the project with a "mistake-proofing" mechanism and assures the progression of the project's performance. The using of a digitalized monitoring and control tool allows effortless and costless real-time reporting and minimizes the waste of resources

Like any other research, this one has limitations too. Firstly, this research is based on analyzing one reasons for projects failure which is the inefficiency of project control system. Secondly, the proposed model has been not applied in reality to measure its actual performance adequately and modify it based on its best practices.

1. Introduction

There are several reports, studies, and papers putting forward the large ratio of mega construction projects that are late, overbudget, behind schedule or completely “fail”. The reason behind project’s cost and schedule overruns are various (David Knox et al., 2017). Nevertheless, in most cases project’s bad performance can be referred to rigid and weak control systems. The conventional control systems are functioning in a reactive way to get back the vehicle back to the right route rather than guarding it from getting out of the track in the first place. The Construction Industry Institute (CII) states that a project control system is substantial for the success of any project. Not all project control systems are incompetent. Research on some best practices suggests that when control systems are applied in the right way, they can show remarkable performances. Nevertheless, looking into the construction industry, it is observed that the ineffectiveness of control systems is the reason for the poor performance or failure of projects (CII, 2015).

This research firstly illustrates the failure in current projects’ execution, the weaknesses of project control systems and the urgent need of non-conventional control systems. Moreover, this research highlights the benefits of applying lean principles to project control systems. A new project control model that applies Lean principles is proposed by this research. It is a more flexible one and proactive, control system, which enables project responsibles to observe the real time work status in the bottleneck stage of the EPC projects. The research also proposes the application of digitalization for the monitoring and control process of EPC project. This aims to make the process easy and flexible enough to absorb any unforeseen issues.

2. Background

Traditional project management aims to bring order and discipline to large teams of specialists working on a joint goal. It was built on the implicit assumption, that the world is predictable and stable enough, and that technologies for establishing projects such as highways, industrial plants, aerospace and powerplants are comprehended enough, that the plan developed by professional planners is guaranteed to be a "good plan" for the whole duration of the project. (Raymond E. Levitt, 2011). Nevertheless, projects of the present and certainly those of the future are becoming increasingly dynamic, unpredictable, and forced to finish as early as possible. Reducing a project's duration enforces an interaction between the activities and the resources in means that are not compatible by traditional project management methods. In addition to the reduction of projects durations as well as the technical and design complexity is developing. (Lauri J. Koskela et al., 2002).

Although small, and simple projects' problems can be easily solved with traditional management methodologies, they are insufficient for managing complex projects of today. The idealized theories that build the foundation of traditional management techniques as well as their inadequate assumptions lead to the decrease of complex projects' performance. Nowadays, project managers are in an intensifying need of management methods that are sufficient for identifying and dealing with uncertainty and that capable of delivering the expected results within the framework of a new definition for project control. (Glenn Ballard and Iris Tommelein, 2012).

Moreover, traditional project management is not always effective at delivering the project results anticipated by the customers while the business requires to remain profitable and competitive. Hereby it is not claimed that traditional project management approaches have not produced some highly successful results; however, the high variety of standard projects and the occasional "failed" projects suggests that there are gaps to be filled by development and continuous improvement. Furthermore, there are extraordinary projects that have a high criticality and/or delivery complexity that need an exceptional approach of project management especially if their success wants to be guaranteed (Jeff Schwisow, 2010).

2.1 Defining EPC Projects

A project is a short-term endeavor that seeks to deliver a product or service. The purpose of a project is to identify and achieve its respective owner's goals. Projects are regularly carried out by the project team with the aim of accomplishing the organizations crucial plan or service production. The execution phase of industrial projects such as Oil & Gas projects, industrial plants projects as well as petrochemical projects consists of detailed engineering, procurement, and construction activities, widely known as EPC. These activities start after the final investment decision by the projects' owners. Companies, which offer an integrated engineering, procurement and construction service are called EPC contractors. Managing an EPC project is normally complicated and needs a particular expertise of project control and technical knowledge (Kamyar Kabirifar and Mohammad Mojtahedi, 2019).

2.2 Need for non-conventional Project Control Systems

The EPC industry often faces many difficulties and sometimes even failures in controlling their large and complex projects especially when talking about capital and mega projects. The productivity and resources' efficiency of such projects have been stationary or declining for the last three decades. Besides, there is a gap between the construction industry and further industries in terms of productivity. This gap has been widening for many years. Thus, the construction industry is not managing its projects in an effective way, or the project control approaches applied in the industry are not sufficient for achieving the aimed results. The CII states that projects' scope, difficulty, and the necessity for speedier project implementation has grown enormously (Resulali Emre Orgut, 2017). This highly requires constant development of project control systems. The CII underlines that the project control system is crucial for the success of the project, which is why the need of capability of improvement in project control systems increases enormously (Resulali Emre Orgut, 2017). Additionally, significant investments are expanding in the construction industry. Overall, a pressing demand of instant and constant development of EPC projects' control systems is necessary to meet the needs of capital projects and maintain their profitability.

The following sums up some facts about the construction of large projects, especially mega projects, and justifies the crucial need of advancements in project control systems in the EPC industry. It also creates a motivation for the author to pursue this research on advancing project control approaches of EPC projects.

- projects' scope, complexity, and the requirement for rapid execution has been growing enormously
- capital investment in the construction field is increasing massively
- key investments are taking place in mega projects, which need strong project control system to remain profitable and be successful

- many EPC projects, in particular mega projects, are currently facing great challenges and failures
- productivity of the construction industry is rather low compared to other industries, has been decreasing overtime, while the productivity of other industries – for e.g. the manufacturing industry – is increasing, hence the productivity gap is widening
- EPC projects' failure and its declining productivity can be linked to malfunctioning systems of project control, as a project crashes in case of the deterioration of all project's elements (mainly quality, schedule, budget, scope, and safety), hence the failure of projects is caused by among others budget overrun, time overrun, inadequate quality, damaging environmental impact
- project control is created by strong control systems, hence poor control of EPC projects reveals the incompetence of the control systems
- conventional project control has a reactive nature and acts after issues occur
- project control systems are demanded to have a proactive nature that avoids the occurrence of issues and discrepancies and ensures the delivery of real time control
- instant continual development in control systems are required to offer a preferred state of excellence to project control

Conventional project control systems are not enough to provide the whole scope of needed project control for large projects. Failure or poor performance of projects shows that control systems are insufficient of controlling the different elements of the project. The failure or inadequate implementation of projects is referred to as project not accomplished according to the targeted time frame, cost, the defined scope or with the required quality. Thus, a project's failure is caused by shortage of control which indicates inadequacy in the project's control system during the implementation and delivery of the project. The gross annual investment in the construction industry will be doubling during the next decade. Hence, it is crucial for the EPC industry to initiate developing its project control systems very soon (Sriram Changali et al., 2015) . The huge number of construction projects using conventional inefficient project control system could intensify the already existing feeble execution of the industry, and possibly have a negative impact on the global market (Glenn Ballard, 2000).

Below in table 1, a general guideline of the thresholds for cost overruns and time slippages in EPC projects is illustrated. As published by the Independent Project Analysis association

(IPA), cost overruns can be quantified by comparing the project's final actual cost to the budget planned prior to the project's execution. A cost competitiveness of a project is measured by looking into the final actual cost of the project and comparing it to the cost of projects with similar size and complexity. The time span starting the beginning of project's execution till the completed installation and commissioning is represented in the execution schedule. A slippage in the execution schedule is calculated by comparing the real time schedule to the schedule planned prior to the project's execution. Comparing the execution's duration to the one of comparable projects represents the schedule competitiveness (Edward W. Merrow, 2012).

Performance Indicator	Failure Thresholds
Cost overruns	above 25%
Cost competitiveness	above 25%
Slippage of execution schedules	above 25%
Schedule competitiveness	above 50%

Table 1: Thresholds for failure of project - (Edward W. Merrow, 2012)

Observing how the failure of a project can destroy construction companies' profit of many years of sheds the light on the importance of project control systems (Glenn Ballard, 2000). The following sheds the lights of the failure of construction mega projects as well as the decline of the industry's productivity and hence the necessity of developing non-conventional and efficient project control systems.

2.3 Failure of Mega Projects

According to management consulting firm McKinsey, mega projects have a bad performance. Mega projects of billion dollar and above will be responsible for a greater share of the construction industry developments. McKinsey claims that 98 % of the mega projects worldwide have more than 30 % cost overruns. Besides, 77% of the mega projects worldwide have a time slippage of 44% or above (Sriram Changali et al., 2015). In the following, figure 1 demonstrates data of expenditure overruns and time slippages of capital projects.

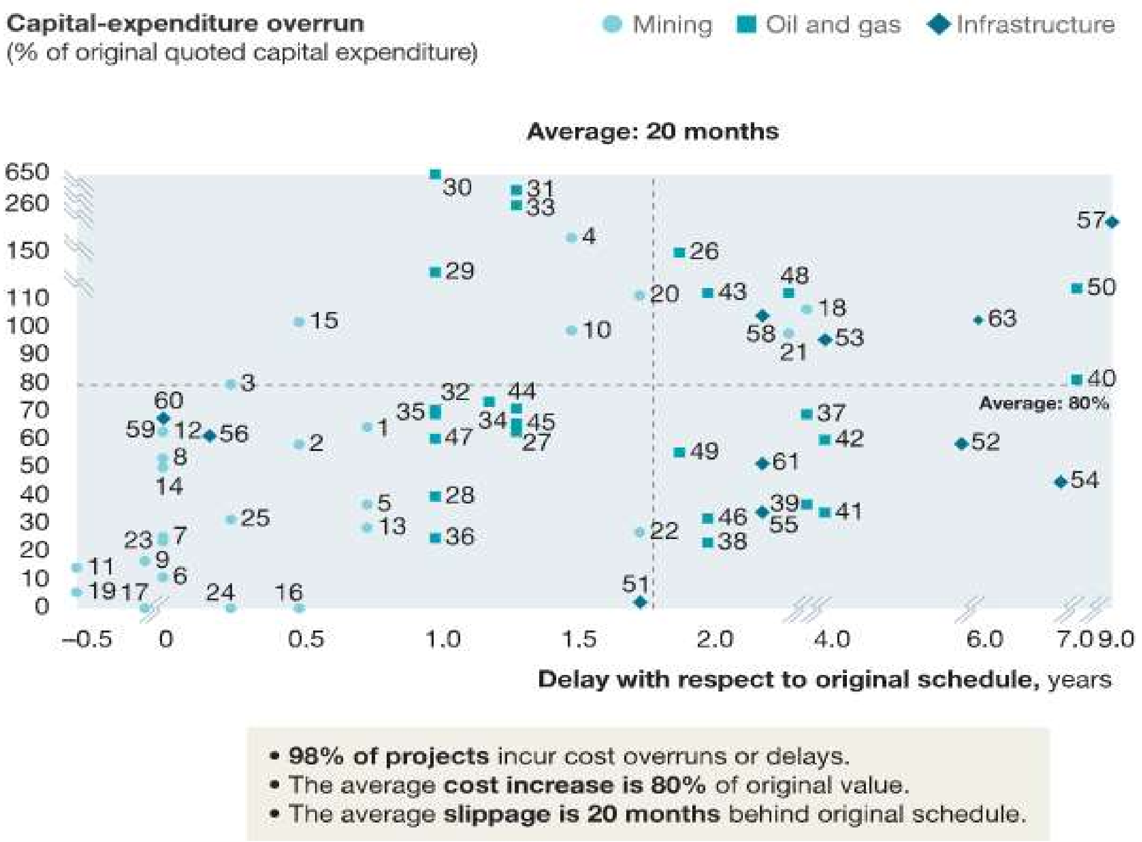


Figure 1: McKinsey's data on expenditure overruns and time slippages of capital projects(Sriram Changali et al., 2015)

In 2014, the International Energy Agency (IEA) estimated an accumulative investment of 22.4 trillion US dollars in the international Oil & Gas sector between 2014 and 2035, equal to an average annual spend of more than 1 trillion US dollars (The International Energy Agency, 2014). The global multinational services network Ernst & Young identified 365 projects with a planned capital investment of mora than 1 trillion US dollars in the following industry segments: upstream Oil & Gas, LNG, pipelines, and refining. These include projects that have been planned but have yet to reach the final investment decision (FID), as well as those that have passed the FID and are in the construction phase but have yet to start operations. Cumulatively, these projects consist of approximately 2.6 trillion US dollars and are allocated across the four segments worldwide.

Research shows that most projects are facing challenging delays and/or cost escalations. These overruns are common in all the industrial segments and geographical locations. Around 64% of the projects are facing cost overruns, while 73% are reporting schedule delays (Axel Preiss and Doug Burcham, 2014). The following are some examples of disreputable construction projects reported by the Global Construction Review (GCR) (Stuart Wilks, 2015):

- Gorgon LNG Plant in Western Australia: the project is about to deliver 15 million tons of liquefied natural gas (LNG) per annum at its peak, and the production is estimated to last until 2074. But the project’s cost increased 45% and delayed 18 months.
- Olkiluoto 3 Nuclear Power Plant in Finland: the project is one of Finland's two nuclear power plants, with power of 1600MW. The project’s value increased 166% and has an expected delay of eight years.
- The Big Dig in the USA: the goal was to move the ugly and traffic-clogged interstate 93 expressway by a tunnel which cuts through the heart of downtown Boston. The vastly complex project became known as the most expensive highway job in the USA. The project’s cost increased 685% and delayed 6 years.
- Dubai Metro in the UAE: the project was subject to a raft of disputes. Several billion US dollars were supposed to be at stake in the various arguments arise out of the light rail project, which is designed to relieve some of the congestion in the rapidly expanding emirate. The project’s budget increased 85% and delay of 5 years.

2.4 Decline of the Construction’s Productivity

The American Association of Cost Engineers describes the construction labor productivity as a “measure of work process efficiency that needs optimization. It can be defined as the ratio of the value labor produces to the value invested in labor. Productivity increases as needed labor resources are minimized and wasted efforts eliminated from the work process” (AACE, 2004). Construction productivity statistics are also an indicator for the performance of project control systems. The construction industry productivity data of the construction industry similarly shows the necessity of improvement in project control system. In the following productivity data of the construction industry is illustrated and put into comparison with the productivity data of further industries.

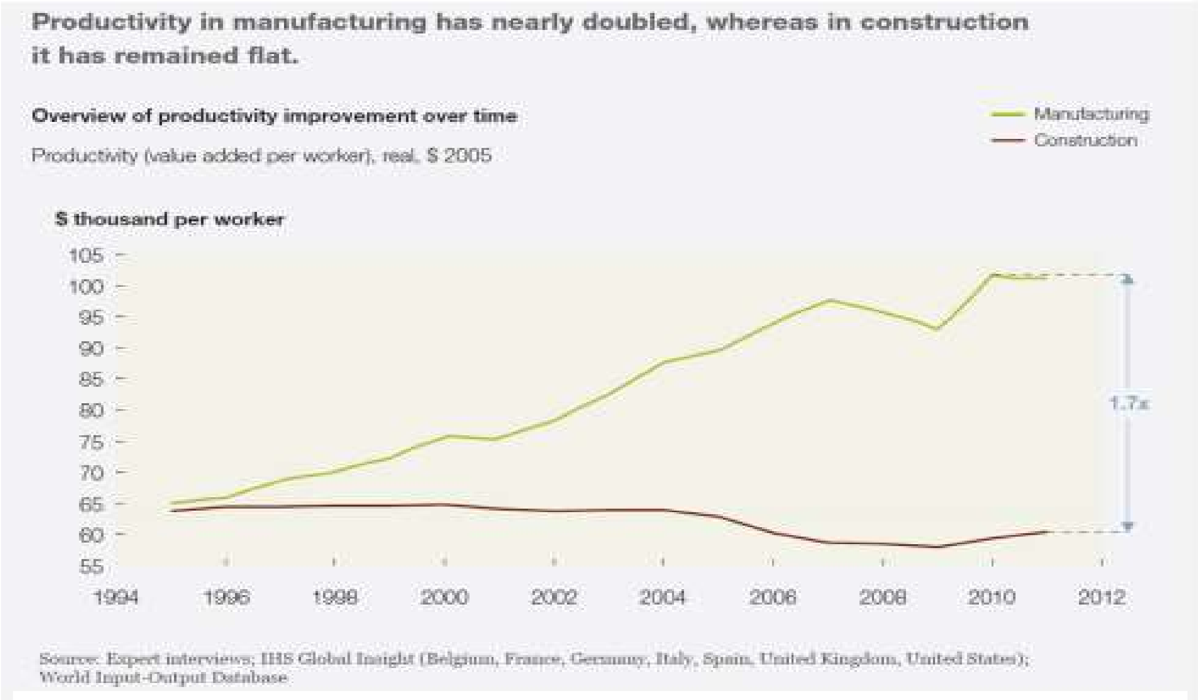


Figure 2:Decline of construction's productivity in comparison to manufacturing productivity (Sriram Changali et al., 2015)

The data show that the productivity of the construction industry has been either falling or staying nearly fixed while the gap of productivity between the construction industry and further industries have been expanding since almost 3 decades. The construction industry's productivity has been static for decades while the productivity of the manufacturing industry has been multiplied by two within the same time span (Phillip Barutha et al., 2018) as illustrated by figure 2. The graph shows that the construction industry's productivity has been either static or dropping in the time span between 1994 and 2012. The gap of productivity between construction industry and manufacturing was also expanding for this period.

On a global level, the labor productivity progress in the construction industry has been around only 1% per year over the past two decades, compared with a growth of 2.8% in the total global economy and 3.6 percent in the manufacturing industry as shown in figure 3. Analyzing a sample of countries reveals that over the past ten years, less than one quarter of construction firms have matched the productivity growth achieved in the overall economies. Besides there is a long tail of usually smaller firms with very poor productivity. Accordingly, construction projects suffer from deteriorating productivity levels (Filipe Barbosa et al., 2017).

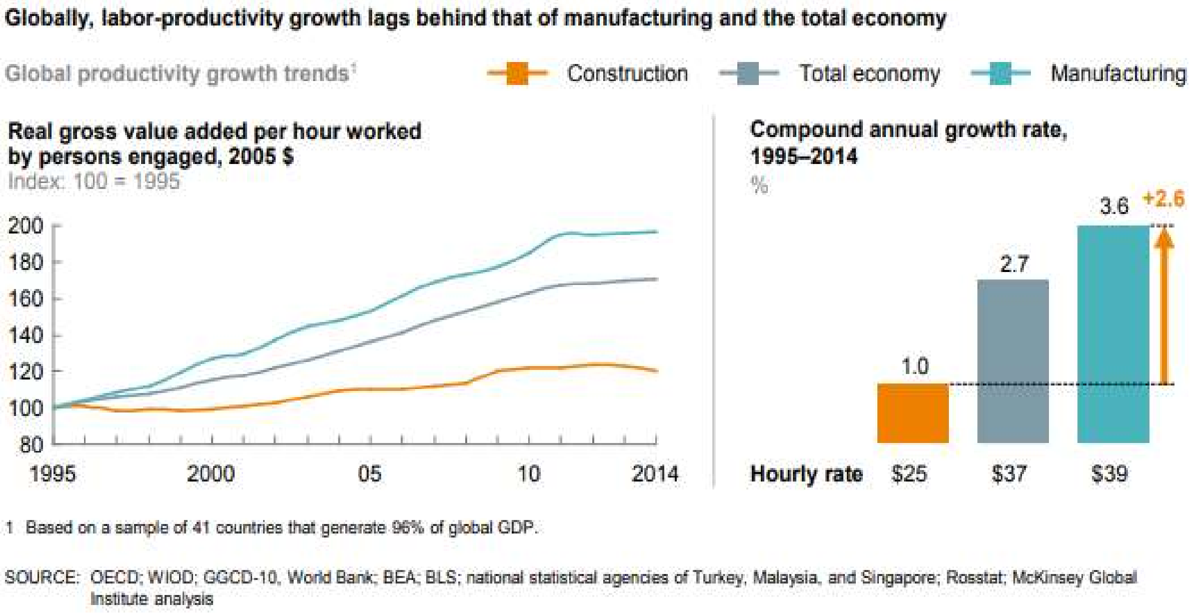


Figure 3: Global Labor Productivity (Filipe Barbosa et al., 2017)

3. Research Objectives

The previous data show that the construction industry has major challenges in controlling their projects, specifically mega projects. Several projects fail, while the projects' productivity levels are rather low. As illustrated above, the massive investments and growth in the construction industry – especially mega projects that are complex and fragile in nature – creates a pressing demand for the development of control systems. Controlling a project is accomplished by the means of a project control system. Consequently, there is a necessity and urgency of constant development in project control system that delivers sufficient control for overcoming failures of EPC and megaprojects and making them profitable. This improvement must take place very soon to sustain the massive construction investments in megaprojects, in the present and the future and respond to the construction market's need.

Improvement of project control systems must be continual to properly respond to the needs of recent construction projects' deliveries. Nowadays, construction projects are much more complex and have a much wider scope than in the past. Besides, there is a need for speedier project deliveries while maintaining a higher quality. Such demands are not exclusive in the construction industry, what is rather exclusive in the construction industry is the inadequate supply offered to the demands of the market.

The necessity of improving project control systems to offer a sustainable treatment for cost overruns, delays and low productivity of projects represents a research gap in the study objective of project management, specifically in the field of project control. This research aims to respond to the construction industry's demands of developing advanced and sufficient project control systems that fulfil today's complex project's needs.

The hypothesis of this research is that a project' s success or failure depends on the efficiency of its control system and that current project control systems are insufficient for fulfilling the needs of the complex EPC projects' desired delivery. Furthermore, in this research I hypothesize that current project control needs can be fulfilled by developing proactive control systems using the so called "lean management" approach – a cluster of methodologies that have contributed enormously to the growth and success of the manufacturing industry. Hence, this research aims to propose a new model of EPC project control system to fill the gap in the project control field. It seeks to discover approaches that make project control systems have a proactive nature to contribute to the development urgently needed for project control systems. The research objective will be chased by the following research methods design.

4. Research Methods and Design

The research objective of this paper is followed by conducting different types of methods and approaches. The main research methodology used in this paper is a qualitative secondary data analysis of existing scientific data and literature on EPC project control systems and lean management approaches. The secondary data analysis is a broadly used research method for generating quick results in an effective and cost-efficient way while enjoying an access to large data sets and longitudinal data (DeKoekkoek et al., 2015). In addition, the author uses some firsthand data that originates from working documents of his previous professional role and as a project planning and control Engineer for pursuing the above highlighted research objective. This intends to enrich the conducted research with a sense of practicality as well as to facilitate the understanding of the reader. The centerpiece of this paper is the scientific modelling of a new project control system proposed by the author. The proposed model is based on the conducted secondary data analysis and aims to fill in the above highlighted research gap. The proposed model of a non-conventional project control system is applied on some practical examples from the author's firsthand professional experience to furtherly illustrate the model in a practical way.

The latter scientific methods are conducted within the framework of a research design, that starts with analyzing the "current state" of approaches and techniques of project control systems. Secondly, the "desired state" of project control systems, which responds to the emerging market needs is identified. Finally, efficient project control approaches and methodologies are used to construct a model, that fills the gap existing between the "current state" and the "desired state" of project control systems. The research design of this paper consists of the following steps:

1. Providing an understanding of the EPC projects life cycle
2. Providing an understanding of existing theories of project control in the construction industry
3. Identifying the current project control system applied in the construction industry
4. Explaining various flow systems which are used in the construction industry and other industries as well
5. Identifying other industries' lean management approaches, which its application in the construction industry makes project control efficient
6. Constructing a new model which enforces a proactive project control system

5. State of Research

When a project, a portfolio, a system, or an activity fails, it is often referred to the malfunction of its control mechanism. Every system or project contains various factors which require to be controlled. EPC projects have a variety of control factors which are mainly project's duration, budget as well as the scope and quality of work. In this part of the research, scientific contributions on present concepts and practices of project control system are highlighted. Further, concepts and practices of lean management are illustrated. The following presents a literature review

5.1 EPC Projects

Dartmouth University states that "capital project" is a classification of new category of construction, renovations, improvements, maintenance projects, and equipment, which is classified according to the project's cost. This classification policy was established to support project managers and others carrying on the important task of distinguishing between capital and non-capital costs. Costs that are capitalized are devalued over the useful life of the projects, while costs that are not capitalized are recorded as an expense in the year incurred. The capital of so called "capital projects" should be more than or equal to 50.000 US dollars. EPC projects are a widespread form of work in modern organizations. Megaprojects can be seen as the wild beasts in the project world as they are hard to control. They are well-known with their complexity, huge size, expensive cost, and long timeline. These projects can create big differences in the geography of countries and the life of people. Some of these megaprojects become landmarks for some countries and bring significant prosperity to the countries people, but also some become unforgettable management catastrophes. There is a scientific consensus that Megaprojects are defined as projects with a cost that exceeds one billion US dollar (Agnar Johansen and Youcef J-T. Zidane, 2013).

5.2 Life Cycle of EPC Projects

Scientific literature provides a definition for projects activities' stages with gates: Front End Loading (FEL), Engineering, Procurement, Construction (EPC) and Start-up. These stages are shown in Figure 4. and furtherly explained below.

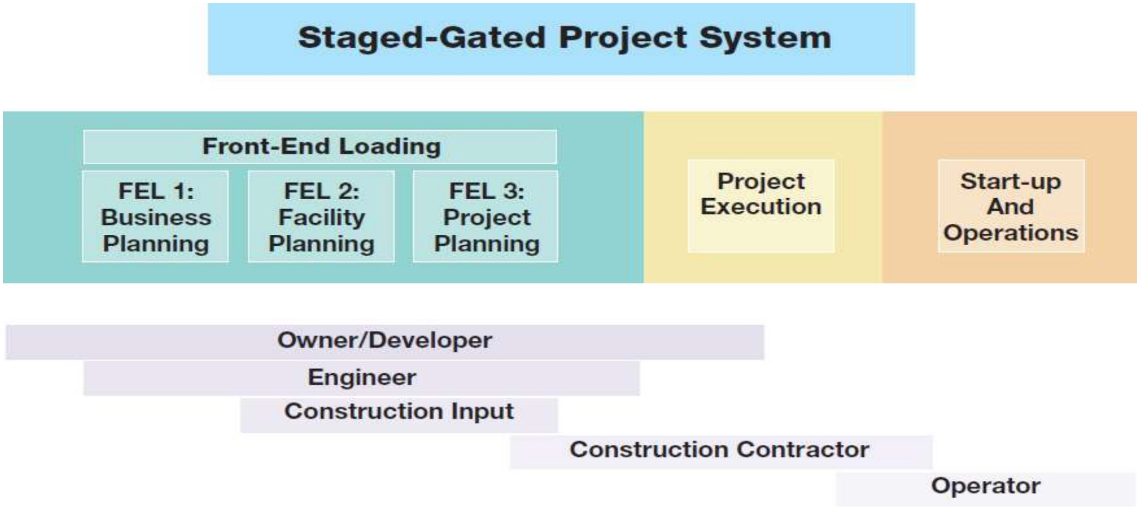


Figure 5: Different project stages (Pablo F. Navarrete and William C. Cole, 2001)

5.2.1 Front-End Loading

- **Business Planning – FEL1**

Before commencing a project, the owner/investor – the organization funding the project – must demonstrate the economic viability and the need for the project, for example whether the project will generate the required returns and revenue. This phase captures the reasoning behind initiating the project and can take considerable time to prepare. This phase includes the analysis of the business case, strategic objectives, project expectations, competitors review, environmental constraints as well as the conduction of economic analysis and market analysis.

- **Facility Planning – FEL2**

The aim of this stage is carrying on the facility planning, which is sometimes referred to as feasibility, preliminary, or pre-FEED. This seeks to guarantee the selection of an optimal solution and add more details following the project. At this point, the physical viability and estimated cost of the project can be identified, to guarantee that no pointless time and energy are wasted. This stage of the plan can take from 2 to 6 months varying based on project complexity. This phase includes the examination of environmental and social issues, detailed definition of the proposed facility, process selection, process design, creation of regulatory and governmental requirements and preliminary schedules.

- **Project Planning – FEL3**

Project planning or the front-end engineering design (FEED) phase creates the authorized and selected solution by narrowing the cost estimate to approximately 15% and developing a higher level of an advanced schedule. At this point, any project showstoppers would have been recognized as part of the environmental and social impact assessment process and suitable mitigation measures would be agreed on with the relevant stakeholders as a part of the project consent. Only when stakeholders' approval has been granted that project sanction takes place. Particularly, only then material orders for long lead items (LLIs) would be placed to meet the development schedule. The project planning stage could last 6 to 12 months vary based on the complexity of project.

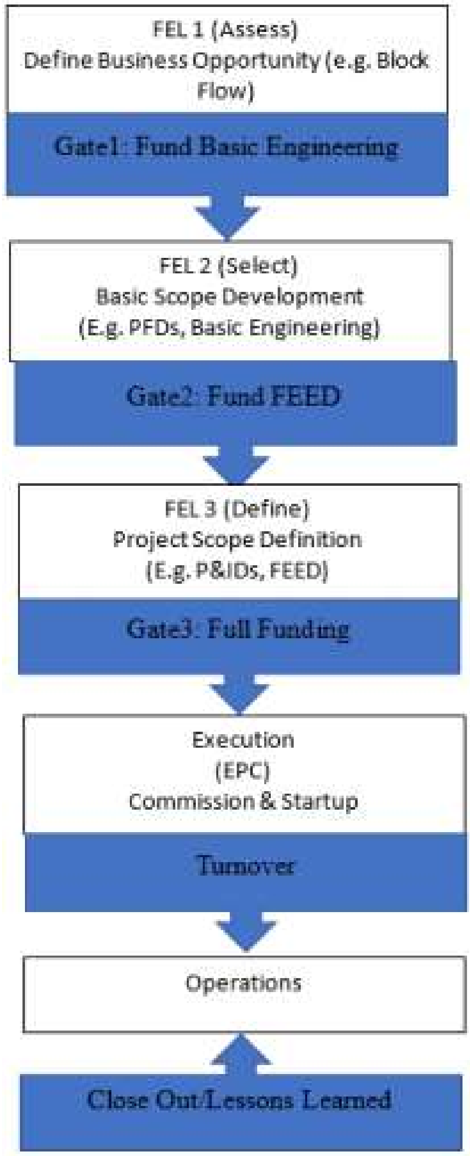


Figure 5: Life Cycle of EPC Project (Hollmann, 2016)

5.2.2 Engineering, Procurement and Construction

This stage is the execution phase of the project starting from the contractor selection. It contains the detailed engineering, procurement, construction, commissioning followed by another stage, which is the project start-up. Figure 5 provides an explanation on the relation between the FELs project stage and the EPC stage.

5.3 Breakdown Structure of Projects

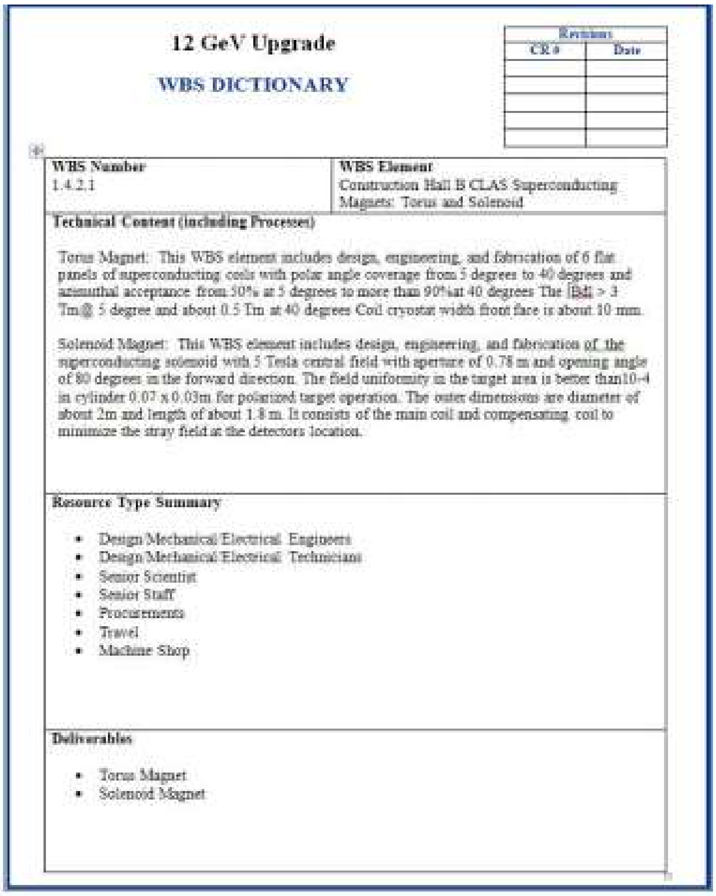
The CII describes the breakdown structure as the logical splitting of the project into elements. The breakdown structure has the purpose of successfully defining the ownership, scope of work, budget, management, schedule, and control within a project. It empowers the responsibility of the different stakeholders as well as the project's planning, control, assessment, and reporting. The breakdown structure is a hierarchically categorized method – from the top to the bottom (Vasile ZECHERU and Bianca Georgiana OLARU, 2016). In the construction industry, there are the following mostly used break down structure approaches:

Work breakdown structure (the What): as capital projects have a high complexity; the work's scope must be split into manageable chunks. The work breakdown structure decomposes the project in limited work packages which are easily implemented and controlled, as the example in figure 6 illustrates below

- **Work breakdown structure Dictionary** represents an accompanying dictionary to the WBS, which aims to give explanatory information for each WBS component. The WBS dictionary defines the scope of each work component in details - including deliverables – identified in the WBS. It can additionally outline the type of resource needed to deliver each component, as the example in figure 7 highlights below.
- **Organization breakdown structure (the Who)**: draws borders of responsibility for work packages at the different project's levels. These responsibilities include reporting, control, management, assessment, and efficient workflow as the example in figure shows.
- **Cost breakdown structure (How much)**: defines the budget for work packages at the different project's levels and allows a more accurate estimation and cost control of the whole project (Alberto De Marco, 2011).

Project Name: Technology & Engineering Development Facility						
WBS Level						WBS
1	2	3	4	5	WBS Title	Number
X					**TEDF Project**	**1.0**
	X				**Project Planning**	**1.1**
		X			Conceptual Planning	1.1.1
		X			Planning	1.1.2
	X				**Engineering and Design**	**1.2**
		X			Design Services	1.2.01
		X			Pre-Construction Services	1.2.02
		X			Pre-Construction Project Management	1.2.03
	X				**Construction**	**1.3**
		X			Conventional Facilities Construction	1.3.1
			X		Civil/Site and Early Procurements	1.3.1.1
			X		TED Building Construction	1.3.1.2
			X		TL Building Construction	1.3.1.3
			X		TL Renovation	1.3.1.4
		X			Furnished Furniture/Equipment	1.3.2
			X		TED Furniture/Equipment	1.3.2.1
			X		TL Furniture/Equipment	1.3.2.2
			X		TL Ren Furniture/Equipment	1.3.2.3
		X			Construction Management Services	1.3.3
			X		Construction Management	1.3.3.1
				X	TED Construction Management	1.3.3.1.1
				X	TL Construction Management	1.3.3.1.2
				X	TL Ren Construction Management	1.3.3.1.3
			X		Commissioning	1.3.3.2
				X	TED Commissioning	1.3.3.2.1
				X	TL Commissioning	1.3.3.2.2
				X	TL Ren Commissioning	1.3.3.2.3
			X		A-E Support	1.3.3.3
				X	TED A/E Support	1.3.3.3.1
				X	TL A/E Support	1.3.3.3.2
				X	TL Ren A/E Support	1.3.3.3.3
		X			Project Management	1.3.4

Figure 6: WBS example (Jefferson Lab, 2012)



12 GeV Upgrade

WBS DICTIONARY

Revisions	
CR #	Date

WBS Number	WBS Element
1.4.2.1	Construction Hall B CLAS Superconducting Magnets: Torus and Solenoid

Technical Content (including Processes)

Torus Magnet: This WBS element includes design, engineering, and fabrication of 6 flat panels of superconducting coils with polar angle coverage from 5 degrees to 40 degrees and azimuthal acceptance from 50% at 5 degrees to more than 90%at 40 degrees The ∫Bdl > 3 Tm@ 5 degree and about 0.5 Tm at 40 degrees Coil cryostat width front face is about 10 mm.

Solenoid Magnet: This WBS element includes design, engineering, and fabrication of the superconducting solenoid with 5 Tesla central field with aperture of 0.78 m and opening angle of 80 degrees in the forward direction. The field uniformity in the target area is better than10-4 in cylinder 0.07 x 0.03m for polarized target operation. The outer dimensions are diameter of about 2m and length of about 1.8 m. It consists of the main coil and compensating coil to minimize the stray field at the detectors location.

Resource Type Summary

- Design Mechanical Electrical Engineers
- Design Mechanical Electrical Technicians
- Senior Scientist
- Senior Staff
- Procurements
- Travel
- Machine Shop

Deliverables

- Torus Magnet
- Solenoid Magnet

Figure 7: WBS Dictionary example (Jefferson Lab, 2012)

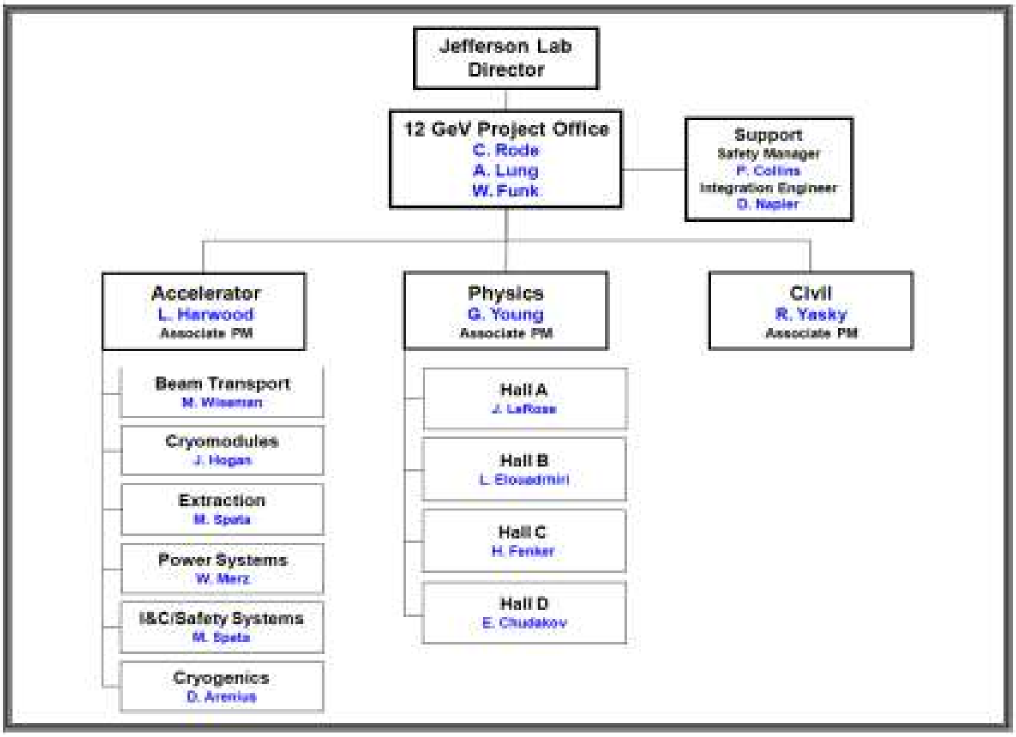


Figure 8: OBS example (Jefferson Lab, 2012)

5.4 Project Control Systems

The history of project management recites the history of mega projects of the last 4,500 years such as the Giza Pyramid, the Parthenon, the Colosseum, the Gothic Cathedrals of Europe, the Taj Mahal, and the Transcontinental Railways. These were not irregularities in history but rather projects delivered in an organized manner with very comparable characteristics to today's projects. (Kozak - Holland and Mark. Oshawa, 2011).

A project control system is a structure which is set for remaining in control of the project. It entails skills, equipment, work processes, procedures, policies, tools, software systems, principles, and a work environment that jointly operate in the organization. According to the CII a project control system contains the persons, planning and execution tools and methods for the different project's, which consist of among others planning, estimation (of cost, time and resources), scheduling, progressing, cost control, change management, and forecasting". The CII states that project control systems consist of several (estimating, planning, scheduling, cost control, change management, progressing, and forecasting). These functions come into action during the different phases of a project. The following furtherly explains the seven functions of a project control system:

- **Estimation:** the process of forecasting the time, resources, and cost for the delivery of a work package.
- **Planning**: the process dedicated to visibly identify, define, and determine the implementation methodologies and tools essential to accomplish the goals of the project. This process takes place prior to the implementation and might also include work packaging.
- **Scheduling**: the procedure of assigning sequence, durations, and deadlines to the different activities of the of the project. Scheduling also includes assigning the respective resources to the different project's activities.
- **Cost Control**: the procedure of listing and evaluating the project's actual cost in comparison to the planned. This serves the purposes of identifying cost time-trends, challenges, and chances during the project. It does not only contain of accounting the cost.
- **Change Management**: the process of efficiently recognizing, assessing, and demanding determinations on modified and latest work scopes of work and controlling execution. This happens in an efficient and organized style.
- **Progressing**: the process of defining the level of the project' actual progress by applying

a reliable methodology that primarily contains the earned value analysis.

- **Forecasting**: the procedure of endlessly estimating the results of budget, duration, and resources needed to accomplish a project (William O'Brien and Kareem Mostafa, 2012).

Project control systems are constrained with the triple constraint, which conventionally contained only time, cost, and scope. These are the main challenging project constraints. The triple constraint is illustrated in fig 2.6 in the form of a triangle to visualize the project work and see the relationship between the scope/quality, schedule/time, and cost/resource. Projects may have further constraints that has to be balanced with the demands the needs of the stakeholders and the project goals.

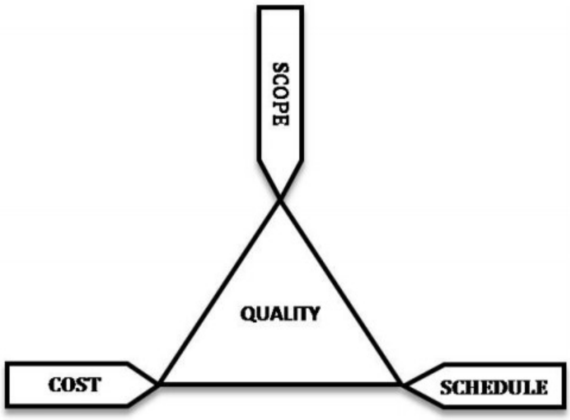


Figure 9: a schematic of the triple constraint triangle. (John M. Kennedy, 2016)

An example of a project in which quality was cut due to a cost constraint is given by the Petrobras-36 oil platform shown in figure 10. It has been the largest footing production platform all over the globe able of processing 180,000 barrels of oil per day and 5.2 million cubic meters of gas per day. Located in the Roncador Field, Campos Basin, Brazil, it was operated by Petrobras company. In March 2001, it became destabilized by two explosions and then sank in 3,900 feet of water, killing 11 persons. The sinking has been referred to a complete failure in quality assurance, and stress for increased production leading to corners being cut on safety procedures. It is registered as one of the extremely costly accidents in the industrial history with a price tag of 515,000,000 US dollar.

Figure 10: The Petrobras P-36 oil platform. P36 No 010 by Richard Collinson

5.5 Reasons for Improving Project Control Systems

Scientific literature report that "controlling a project is the capability to define the project's progress in correlation to time and schedule. As projects' plans are constantly being changed, having a control mechanism is crucial. It allows managers to take corrective actions in the right time to keep the project on track (Harvard Business Review Staff, 2016). Hence, conventional control systems are rectification systems and not really control systems. It is built on the assumption that the project will variate from the original plan. Thus, it is based on the idea of corrective mechanisms taking place once the projects' progress diverges from the original plan. This assumption clearly demonstrates the reactive and responsive theory, on which project control systems are built.

Besides, the

Project management systems are defined as systems that include comparing the real project's performance to the planned one with the purpose of undertaking the proper corrective action or guiding the responsible to act towards producing the desired project's outcome when significant differences occur (PMI, 2017). Project control systems are described as project control as a corrective mechanism that provides a constantly measure the performance of a project to undertake an action when the project's performance deteriorates. Accordingly, the main purpose of project control systems is to monitor the work progress, to compare it to the baseline plan and budget, to analyze the performance, to detect the variance, to find the cause of the variance and finally to take a corrective actions with the aim of bringing the project back to the baseline track of cost and time. Hence, it is a corrective mechanism and not proactive one that prevents project from going out of control. This reactive approach is applied in the construction industry as well, while the corrective actions often take place very late.

Furthermore, Patty and Denton define project control systems as an effort to control a real time process using an accountancy system. Three decades ago, the manufacturing industry was abandoning the critical path method (CPM) due to its proven inefficiency. At the same time, the EPC industry started implementing the CPM scheduling because it was believed to be adequate for controlling construction projects (Robert M.Patty and Michael A.Denton, 2010). Overall, such project control philosophies are way too small and way too slow. The reason behind this is that data gathering tools are time and money consuming, in particular for live activities. Project control systems always depend on the backward recognition of variances. A great shortage of live control mechanisms in the current project control systems can be clearly observed (Glenn Ballard, 2000).

Moreover, the earned value analysis (EVA) which is broadly applied for controlling projects, proofs to be imperfect. The evident weakness in EVA is that even though it displays the planned budget, profit, and productivity of a project, it cannot collect data on the project's work and whether it takes place correctly and promptly. The EVA approach depends on comparing the figure of the actual work to the figure of the planned work by looking at the project S-curve. In this case, site responsibles are always concerned with demonstrating the work progress on the project S-curve. Consequently, they often perform work, which is not consistent with the needed quality, sequence, duration, planned progresses or even perform it in a random way. This ultimately precedes divergences from the critical path, embarrassment, simultaneous work overload, and conflicts. After all, accusations and blaming takes place once the project is already delayed (Glenn Ballard, 2000).

Additionally, the increased management levels in current project control systems creates a problem regarding the validity of project data. The reported data may turn out to be invalid in the moment they arrive to the decision makers. Besides, stakeholders and sponsors push for quicker execution without certainly allocating enough duration for planning. So, projects end up being "driven" with inadequate planning and more rescheduling work coming to the surface. There is also lessons-learnt philosophy inside the construction business by communicating improvement ideas through industry forums. However, there is no common improvement suggestions for the planning approach at this moment. Planning is still performed using the same conventional techniques, which are proofed to be inefficient (Kareem Tarek Mostafa, 2017).

5.6 Flow Control in Production Systems

In comparison to production control systems, it is obvious that project control systems in EPC are very different. In project control, an action is taken when the situation is already out off track. For example, schedule controls act when the project is already delayed and behind the original schedule. On the other hand, production control is a proactive system which avoids defects and errors in the first place (Glenn Ballard, 2000). It is proofed that observing the outcome and performance of manufacturing data while not being aware of the workflow is not sufficient for controlling a production system. Therefore, it is beneficial to visualize the added-value creation achieved by a production system in the form of a flow of data and material. (Glenn Ballard, 2000). The control of production systems entails verifying whether workflow takes place in compliance with the agreed plan and approved principles or not. The purpose of production control is to highlight vulnerabilities and shortcomings, if any, to rectify them and prevent their repetition. In contrast, in projects there is no repetition of the exam same process, and that is the key reason for the difference in the two control concepts. As Drucker indicated out, “the synonym for control is direction … control deals … with the future” (John Lewis et al., 2015). Hence, production control is mainly concerned with what will take place during the next production phase.

One of the concepts that need to be understood of manufacturing control systems is the flow. In manufacturing, it is the progress of goods, batches, and resources in the added value chain sequence, and that ultimately transforms into a finished product. Controlling of flow produces the required cycle and level of the resources flow, that go across the added value chain sequence (Koskela, 1999). In an added value chain, a flow control system maintains the steadiness and the reliability of the production’s flow.

The two main types of flow systems for controlling production that exist are highlighted in the following.

- **Push Flow**: this refers to the “make to stock” approach, where the production order is not built on a real demand of the market. Nevertheless, the flow rate is controlled by a pre-defined date and depends on forecasting rather than on real demand. This system depends on creating stocks and storing them. Push flow systems have unnecessarily high inventory (Mark L. Spearman and Wallace Hopp, 2004).
- **Pull Flow**: this refers to the “make to order” approach. The flow rate is regulated by the amount of the different processes or by demands of costumers in the added-value chain. In this case, the flow depends on the system’s condition for example the volume of goods/work in progress (WIP) as well as the condition of existing tasks. The pull flow system sets limitations on WIP and decreases inventory (Mark L. Spearman and Wallace Hopp, 2004).

There are many very good reasons that make the pull flow system favorized over the push flow system. For example, it has the benefits of lower goods/work in progress, lower inventory, reduced resource waste and an improved workflow. It also results in an increased flexibility, an increased ability to react to changes, and allows the duration of project to be decreased via decreasing of single task periods.

5.7 Flow Control in EPC Projects

Throughout the project's EPC phase, the workflow is the steadiness and availability of execution requirements such as the material, drawings, tools, workface, and resources that are needed for adding value. It is performed by organizing work process systems so that tasks become apparent and ready to the responsibles for performing the work at the required location and in the required time (Robert M.Patty and Michael A.Denton, 2010). Projects are seen as production flow system, in which resources stream to perform several smaller chunks of work defined as work task packages (WTPs). The WTPs then sum up to a project (Glenn Ballard, 2000).

As projects are a production flow, it is essential to have a flow control system to sustain the required sequence and rate of the workflow. In the "Push" approach, WTPs are driven to the executers to add value at the workfaces On the contrary in the "Pull" approach, WTPs are dragged by the executers based on their need, status, and pace to add value at the workface. The task plan completeness is verified by the task leads, who are responsible for each WTP. While the durations are determined by the task leads, the management verifies the resources' readiness. The workface is made clear by the task leads, who have the responsibility of keeping the managers up-to date and informing them of the progress. Upon the final notice of workface readiness, the subsequent WTP starts progressing. Any finished workface pulls the next WTP creating the execution sequence in the most logical order. The execution sequence is identified in the master execution schedule by the different stakeholders (Robert M.Patty and Michael A.Denton, 2010).

As mentioned before, any flow system can have either a pull or a push approach. To implement a pull flow system, it has to get started with a push flow then move to a pull-push interface and finally reach the aimed state of the pull flow. This can be also applied to the flow systems of EPC projects. Patty and Denton underline that "pull systems don't activate outside the existing production's time frame, requiring a push flow for long-term resources' allocation and balance. The latter requires a push-pull interface or a tradeoff, in which a shift from a push flow to a pull flow takes place in the project" (Robert M.Patty and Michael A.Denton, 2010).

When the project's execution begins– commencing with detailed engineering –, a push flow is preserved till the channel is loaded with WTPs. This happens when the WTPs are completely developed. The complete development of WTPs is achieved when the human and other resources are allocated, the material is prepared, and the information is fully provided. Once the channel is loaded, the flow can be switched to a pull flow. This explains how a push-pull interface works in EPC projects with a large scope of work. The pull flow is regulated in accordance with construction's rate. It starts when the channel is loaded by the push flow of the previous process. As an example, when construction starts to "pull", the procurement and the creation of task packages should maintain the same pace as construction to continue pulling. Similarly, detailed engineering as well as documents reviewing should keep the same pace as procurement to continue pulling in accordance with the need of construction. Additionally, sufficient material and equipment should be purchased to load the channel for the procurement phase. As soon as construction is commenced and the channel is loaded, the flow is controlled with a pull system in accordance with the construction's demand. Besides, easily purchased items are procured according to the pull flow system. On the other hand, long lead items are procured as per the execution schedule according to the push flow system to avoid risk and uncertainty. Figure 11 illustrates four processes of the flow control system. Shall we consider the processes as an EPC value chain, one can assume the following processes highlighted in the table below.

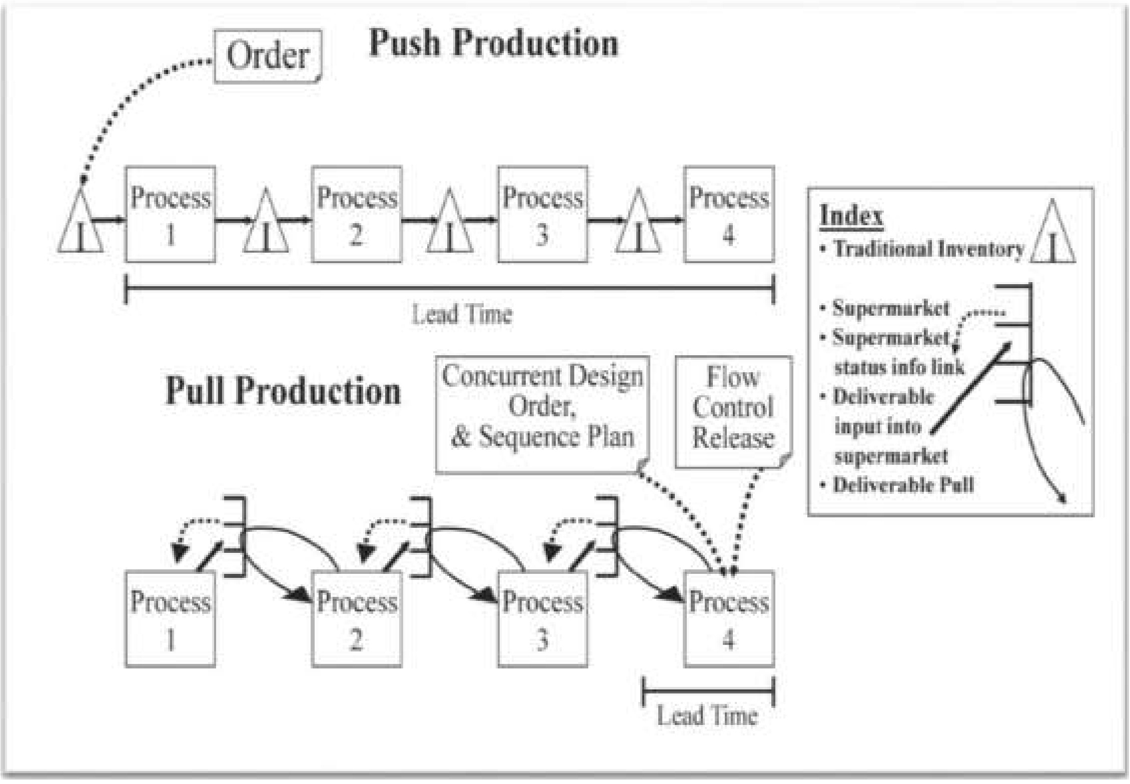


Figure 11: Types of workflows (Robert M.Patty and Michael A.Denton, 2010)

Process	Name	Output
Process 1	Engineering	detailed design or drawing issued for construction
Process 2	Procurement	purchase materials and subcontract services outside the company per design
Process 3	Material Management	handle materials purchased, pack it or kit it, then site delivery
Process 4	Construction	fabricate and components site erection

Table 2: Processes in the EPC value chain

As shown in figure 11, the purpose of usual inventory (indicated as "I" in the figure) is to keep the outcomes that result from the different work process. The "supermarket" contains a buffer of scheduled and ready WTPs. It is a transient, restricted amount of WTPs ready for the subsequent workface. In-process packages can be stored as a buffer in the "Supermarket" for some time (Robert M. Patty and Michael A. Denton, 2010).

The flow rate in a push system is controlled by a pre-defined date. The products stored as inventory are utilized for the subsequent activity according to its production rate the amount of availability in the buffer. On the other hand, the flow rate in a pull system is determined by the demand rate of the slowest or the final process.

Similarly, EPC projects require a flow system, which considers the construction phase as the bottleneck of the project. The construction phase is followed by the commissioning and start-up phases. Consequently, the flow is to be controlled by the construction phase which is illustrated as process number 4 in the figure.

There is a need to fill the channel for commencing the construction process (number 4). The in-process packages are stored in the "supermarkets" of the engineering process (number 1) to the construction process (number 4). Once the channel is sufficiently loaded by the processes of engineering (number 1), procurement (number 2) and material management (number 3), they become ready to sustain the construction process (number 4). Thus, the construction process begins pulling and the pull flow system starts. This phase, where the push flow shift into a pull flow is defined as the push-pull interface. The procurement process can be considered the bottleneck of the project (rather than the construction process) in particular stages mainly during the erection of long lead items (LLI), for example transformers, boilers etc.

This is explained by the fact, that the fabrication and shipment process (procurement) of long lead items requires most of their erection's duration, not their installation or their construction process. Consequently, in this phase, the flow is regulated by bottleneck process, which is in this stage the procurement process. Usually, suppliers provide a fixed delivery date for the long lead items. Therefore, long lead items are reflected as milestones that are controlled by a push flow system or in other words a pre-determined date.

A manufacturing schedule reflecting the accurate progress is created in cooperation with the supplier, while the date of supply is permitted to float in accordance with the project's progress. Once the readiness for site installation is identified, the delivery date must be fixed and is not allowed to float anymore. Therefore, these delivery dates become interim milestones, that enable a pull flow to occur between them. The pull flow takes place between these milestones while still floating in accordance with the construction rate. A balance is accomplished by having a sufficient time buffer in addition to lead times for on time delivery in advance to the installation. This balance offers a rational flow control, avoids build-ups of site inventory that can be hard or expensive to be stored, guarantees adequate lead time of suppliers' delivery.

Below, figure 12 illustrates the concept of pull and push flows in EPC projects.

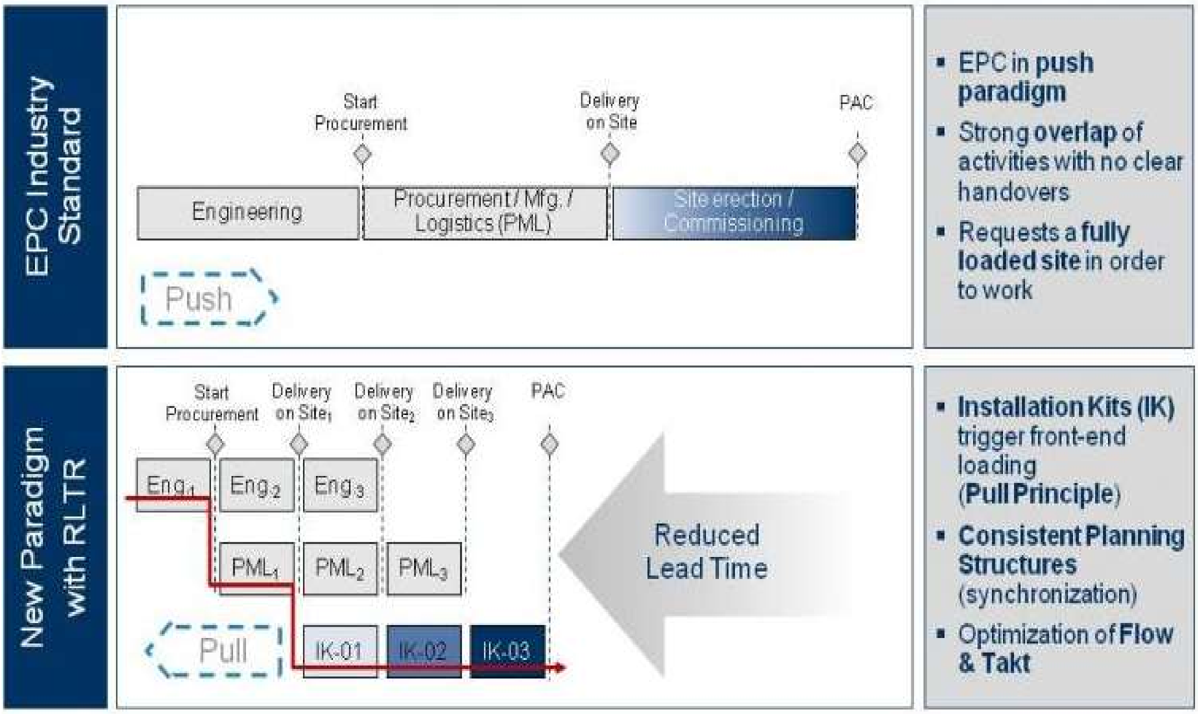


Figure 12: EPC Pull vs. Push System (Mark L. Spearman and Wallace Hopp, 2004)

Both, the push and pull flow, which represent planning and control in figure 12, are essential to run an EPC project (Robert M. Patty and Michael A. Denton, 2010). The value chain of Engineering, Procurement and Construction represents a mix of push and pull flow as well as push-pull interfaces. This helps achieving projects objective of establishing the most suitable flow control system that enables meeting the customers' requirements in a steady and reliable way.

5.8 CCPM vs. CPM

Critical chain project management is based on the theory of constraints. This theory entails that every system has a restriction, which constrains its performance. The constraint of any system is the softest part of the chain. Even if other parts of the chain get enhanced, the chain remains weak until the weakest part of the chain is strengthened. (Goldratt E.M. and Cox J., 2004). This can be achieved by developing the critical path method (CPM) into the critical chain method (CCM).

Firstly, to develop a CCM, a resource loaded CPM schedule should be generated. Time estimations in the creation of CPM are built on the basis of worst-case scenarios. Hence, in CPM a large portion activity duration is maintained for contingency. Schedulers maintain contingencies to defend their plans from "universal cuts". Such cuts may be required later during the project's execution by the top management with the aim of meeting the clients' expectations. As you illustrated in figure 13, each task completion duration is characterized as a probability distribution, not as a constant. The graphical representation of the activity expected duration in the terms of conventional project management. The risks are involved in

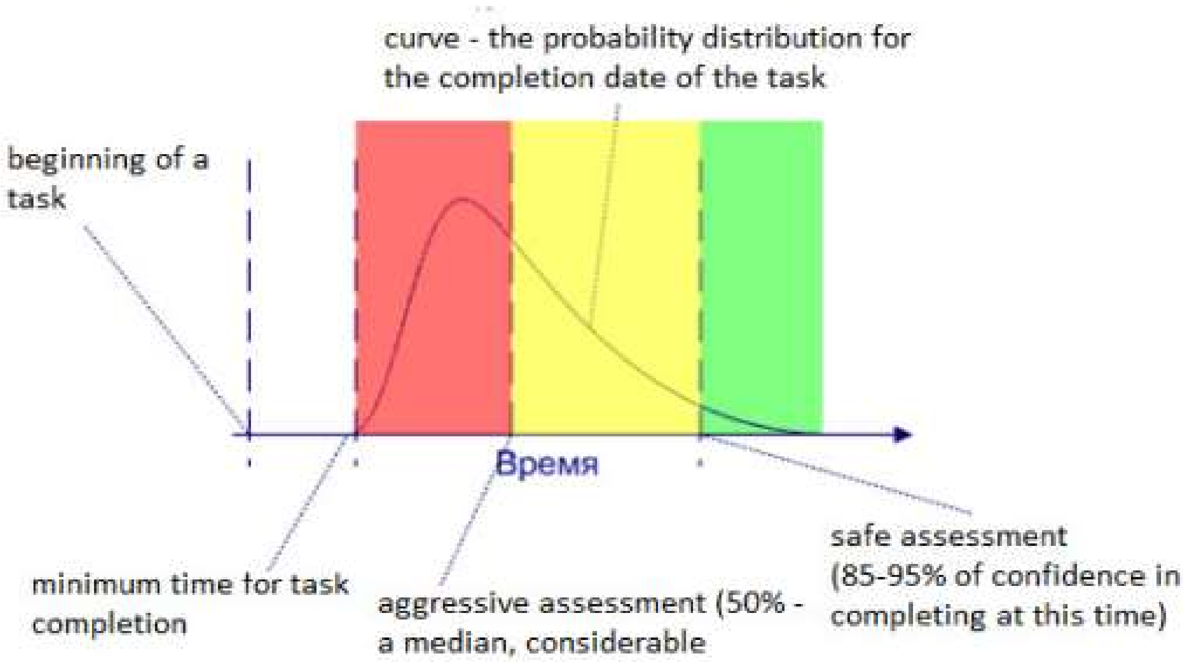


Figure 13:Time of the Completion as a task probability distribution (Azar Izmailov et al., 2016)

activity duration estimation to minimize Murphy's law effect.

Moreover, contingencies are kept due to the fact claimed by "Parkinson's Law". It hypothesizes that work enlarges to suit the time duration allocated for its accomplishment. Hence, if a greater time duration is allocated to complete an activity, the accomplishment of the respective activity would consume the whole duration (including the float) assigned for its completion. Besides, the "Student Syndrome" underlines another argument that speaks for keeping contingencies: an activity is started only when the residual time duration is compressed to be just sufficient for meeting the activity's completion deadline. Hence, assigning extra time for accomplishing an activity does not accelerate the activity's starting date.

In CPM, finishing an activity early does not mean that the project will complete early. This is caused by contractors having a different schedule containing other activities. In this case, they are not able to start their activities execution early – before the initially scheduled time. Therefore, the early accomplishment of an activity cannot give a boost to the dependent activities and accelerate its accomplishment. On the other hand, the delay of an activity leads to the delay of the dependent activities. Thus, all the risks were originally included in every separate activity, as shown in figure 14 below.

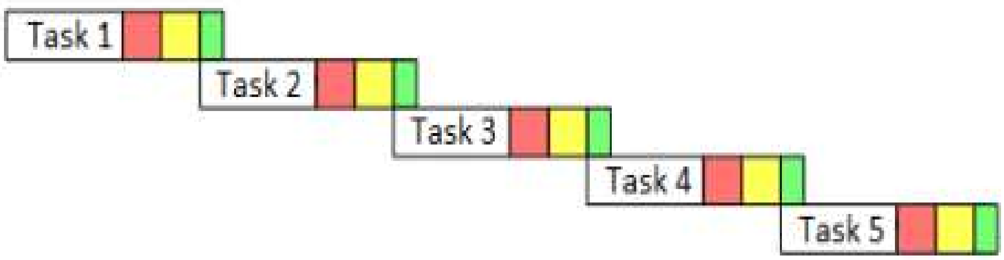


Figure 14: CPM Activities chain (Azar Izmailov et al., 2016)

The combination of rigid completion dates together with the need of "safe" time estimates include contingency leads to the Parkinson's law. As mentioned previously, the effort of all resources on an activity in traditional project management takes all the time committed to it. To get rid of this problem, CCPM proposes the construction of the schedule using dense tasks duration estimations. Normally, CCPM recommends taking an estimate of 50% risk coverage, so called "Aggressive Estimate". The usage of a rigid tasks' accomplishment date is then removed. To protect the final project completion date, time and resources buffers are used. These buffers are actually the uncertainty durations, which are cut from the activities' duration assumption step. The contingencies distributed over all activities are accumulated to the single project buffer, which now exists at the end of the critical chain, as figure 15 highlights.

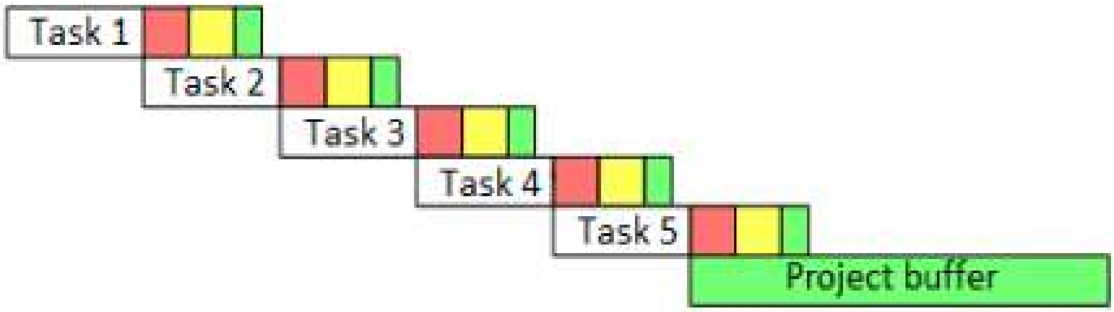


Figure 15: Project buffer in the end of the chain (Azar Izmailov et al., 2016)

Scientific literature illustrate the positive effect of the CCPM compared to the CPM. For example, this was mentioned by Shurrab, who had used 120 combination of randomly generated project networks to study and evaluate the effect of using CCPM compared to CPM. The findings of this study are illustrated in figure 16 and figure 17 below.

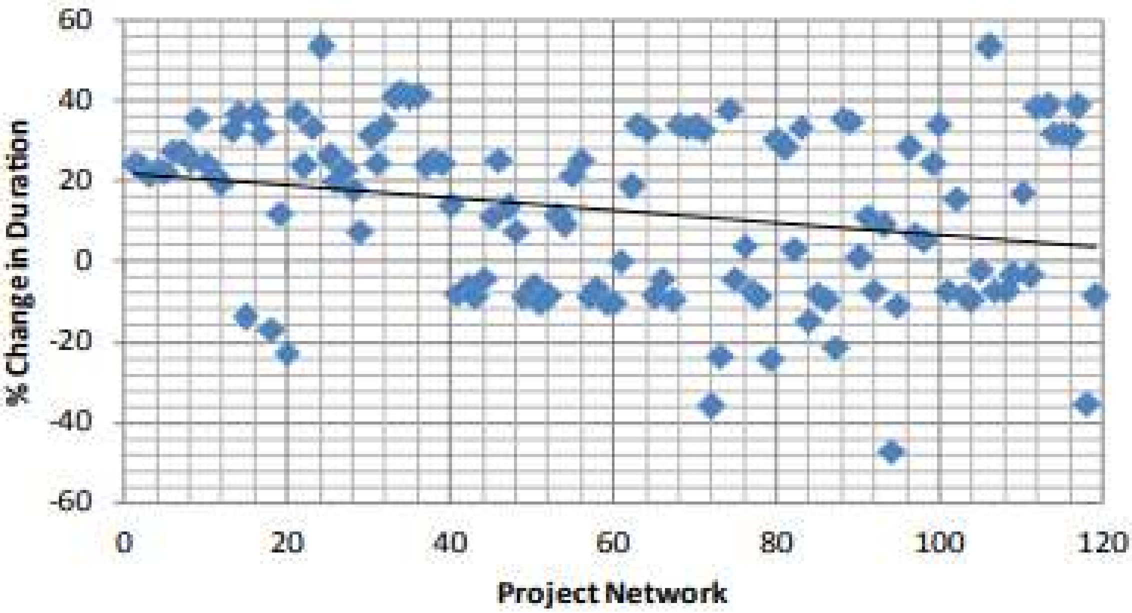


Figure 16: Changes in duration using CCPM method. (Shurrab M, 2015)

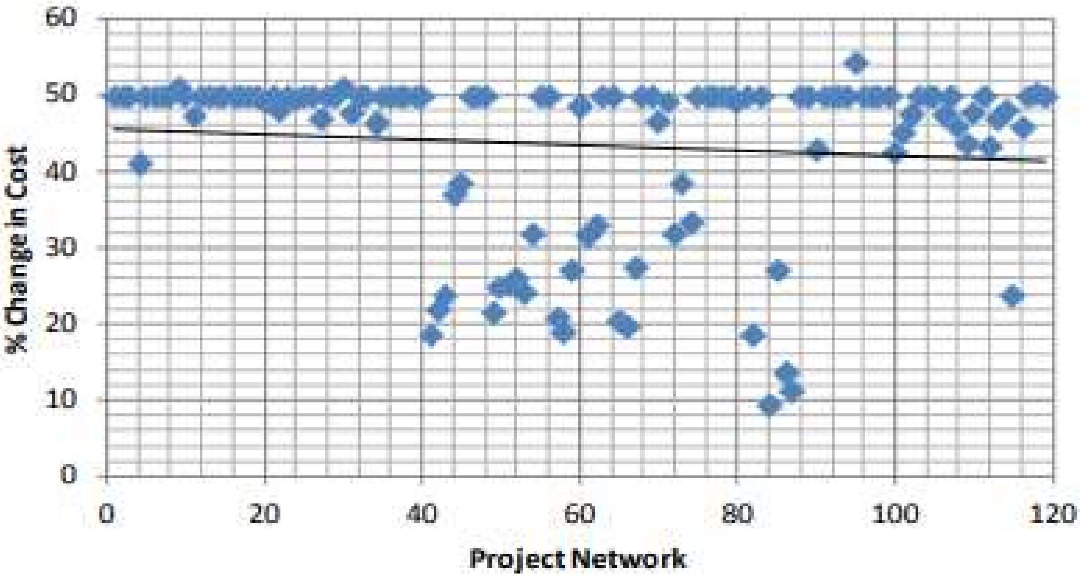


Figure 17: Changes in duration using CCPM method. (Shurrab M, 2015)

To summarize, the positive impact of CCPM in comparison to CPM is very clear as mentioned by Shurrab. The CCPM method showed an average saving of 13% in duration and 43% in cost, with a standard deviation of 21 for duration and 11 for cost. Therefore, EPC projects are advised to adapt to using CCPM instead of CPM.

5.9 EPC Project Control Systems

There are several project control systems, that are currently applied in the EPC industry. The most two widely acknowledgment systems among them, that are used in EPC projects nowadays, are the last planner system as well as the advanced work packaging system. In the following, both systems are fully illustrated.

5.9.1 Last Planner System

The Last Construction Institute (LC) introduced the so-called Last Planner System (LPS) two decades ago. It is pull system based on the concept of "Should-Can-Will-Did" and "Assignment" that delivers ready work directly to the so-called "Last Planner". The "Last Planner" in this context refers to the person responsible for channeling the assignments to the work executors, while assignments refer to the work what must be accomplished soon – whether within a day or a week. In the LPS, the "Last Planner" is responsible for scheduling the assignments (Glenn Ballard, 2000). Nevertheless, the LPS does not clearly describe how assignments are scheduled, established, and delivered to the workface. This system can be defined as a method for converting what "SHOULD" be accomplished into what "CAN" be achieved. Consequently, it creates an inventory of ready work. This inventory is then used for the creation of “weekly work plans”. The “Last Planner” is responsible for creating the “weekly work plans”. “Last Planners” aim to match the “CAN” load with the capacity of the “WILL” to be performed. The weekly work plans are then passed to the foremen or group chiefs to inform them on what they “WILL” perform (Glenn Ballard, 2000). The work planned has to be “applicable”, hence all execution requirements has to be ready and all resources has to be accessible. The “Last Planner” is not responsible for increasing capacity of the resources or sustaining it with the workload. Besides, the packages that will be progressed must have accessible resources. It is logical and certainly useful to perform packages, only for which the resources are accessible, nevertheless, it is more helpful to have a system, which can offers resources or capacities according to the demand or load of the work. In this case, what “SHOULD” be performed will transformed into what “CAN” be done. The Last Planner System is concerned with converting “SHOULDs” into “CANs”. However, the LPS does not explicitly describe how to narrow the gap between the “SHOULDs” and “CANs”. Below, figure 18 illustrates how the Last Planner System works in a more detailed way.

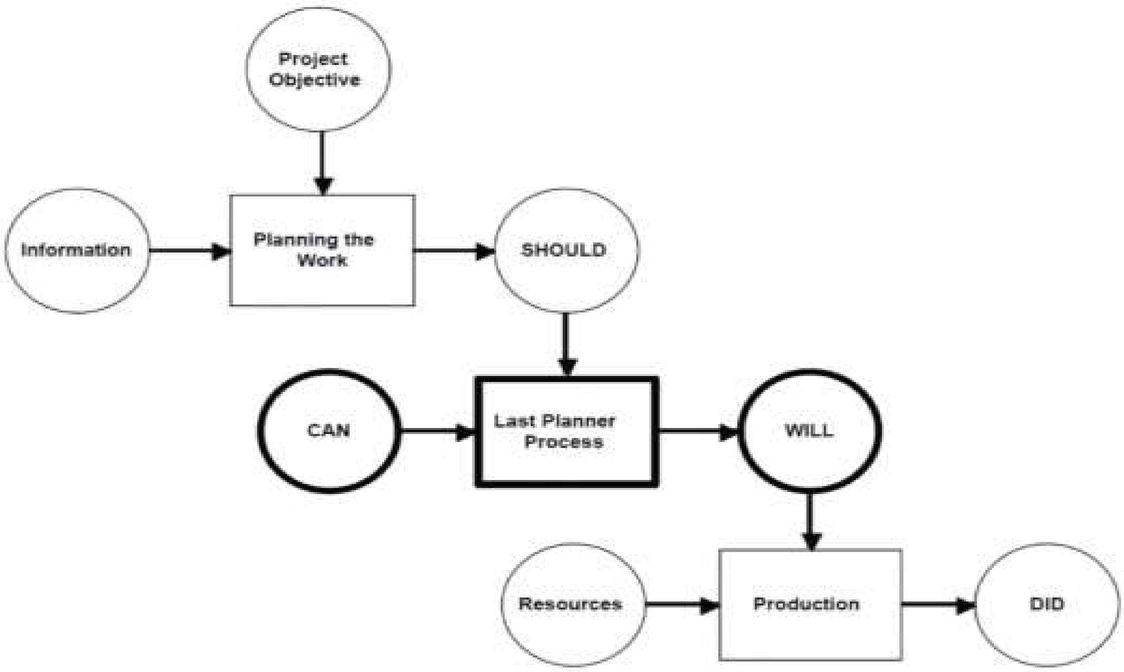


Figure 18: Last Planner System (Glenn Ballard, 2000)

5.9.2 Advanced Work Packaging System

The Advanced Work Packaging system (AWP) is a workflow system established together by the CII and the Construction Owners Association of America (COAA) in 2013. AWP is the general flow process flow of all the full work packages. It refers to a pre-determined and prepared as well as a workable process that shapes work within EPC projects. It starts with the initial preparation and continues to the detailed engineering as well as the execution of construction. AWP provides the outline for a dynamic and a gradually progressing construction and assumes the presence of a construction plan. It is a construction driven process, which is based on the concept of "staring with the end in mind" (COAA, 2015). The process of arranging and providing all the essentials required for an installation work package prior to the commencement of work is called "Workface Planning". It enables work executers to accomplish the job safely, effectively, and efficiently. The construction work can be broken down into installation packages (CII, 2015). There are mainly three types of "Work Packages" in the advanced work packaging system, which are explained in the following and illustrated in figure 19 and figure 20.

- **Engineering Work Package (EWP)**: EWP is an engineering and procurement deliverable which is managed to produce Construction Work Packages (CWPs). It depends on the sequence and urgencies of construction. It contains the scope of work, bill of Material (BOM), line lists, equipment lists, general arrangement, equipment installation drawings, vendor data (CII, 2015).
- **Construction Work Package (CWP)**: CWP illustrates a manageable portion of work in the construction scope. It is generally a level-3 activity and is the basis of developing a detailed execution schedule. Moreover, it contains more than one EWP and includes all safety and environmental requirements, schedule as well as quality and resources requirements (CII, 2015).
- **Installation Work Package (IWP)**: IWP is a deliverable which allows a construction team to execute the work safely and predictably. It also offers a measurable approach for the execution of construction work. The IWP takes place within an average duration of a week. It must get verified by the project responsibles, while any constraints must be mitigated prior to issuing the IWP to the construction site. It includes a work package summary, quantity work sheets, safety hazards analysis, material safety data sheets, drawings, BOM, quality approval documents and completion validation signatures (CII, 2015).

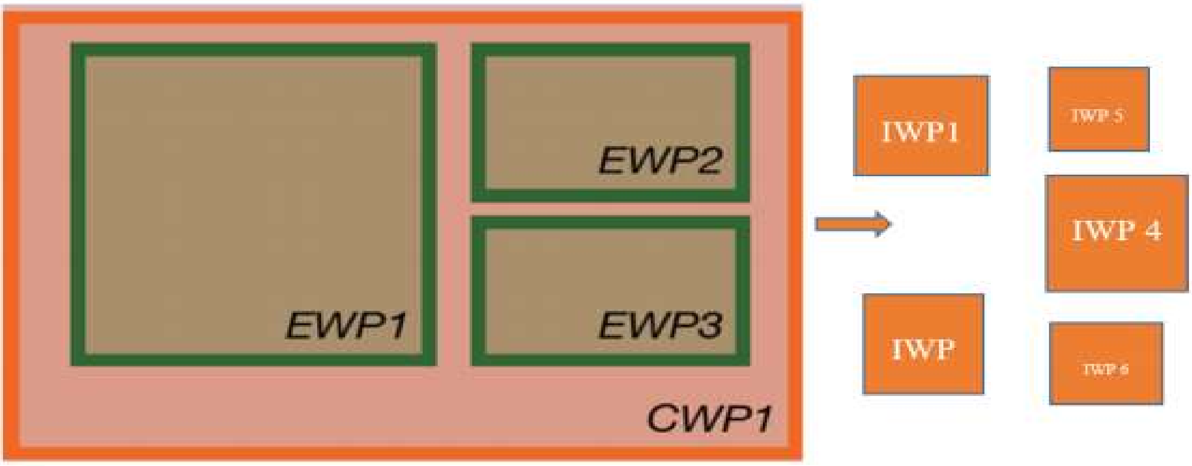


Figure 19: IWP & CWP (CII, 2015)

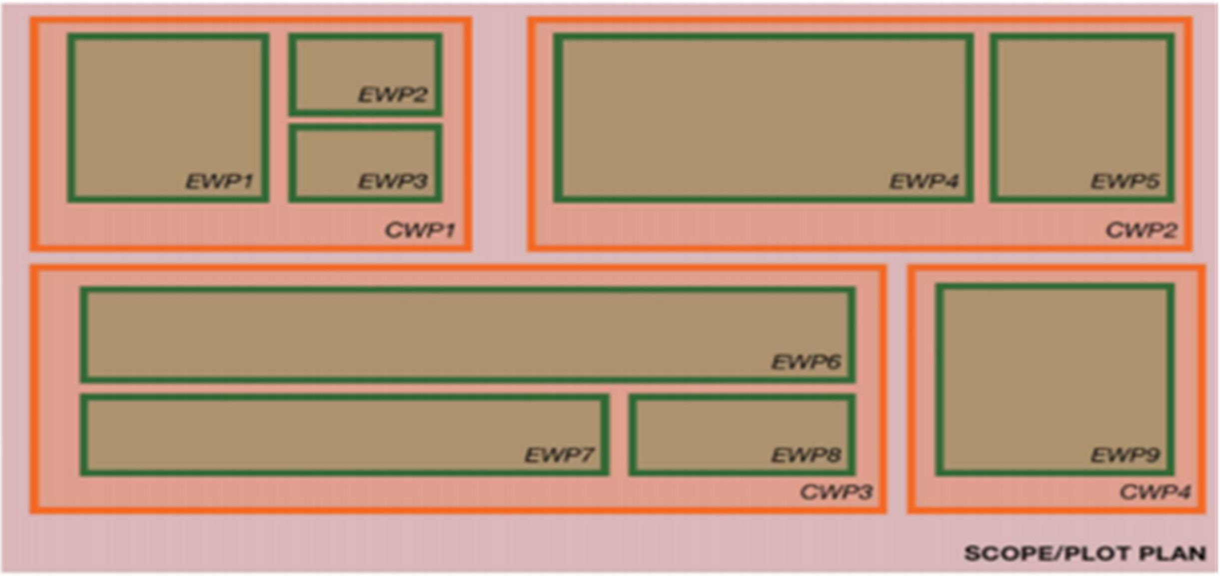


Figure 20: CWP & EWP (CII, 2015)

The life cycle of AWP commences by the start of the project, from the project definition stage (FEL1) to the start-up and commissioning. AWP suggests beginning the work packaging process at an early stage of the project (designing phase). The following only deals with the control part of the AWP and consequently does not provide details of the AWP life cycle. The overall AWP life cycle is illustrated in figure 21 below for further explanation.

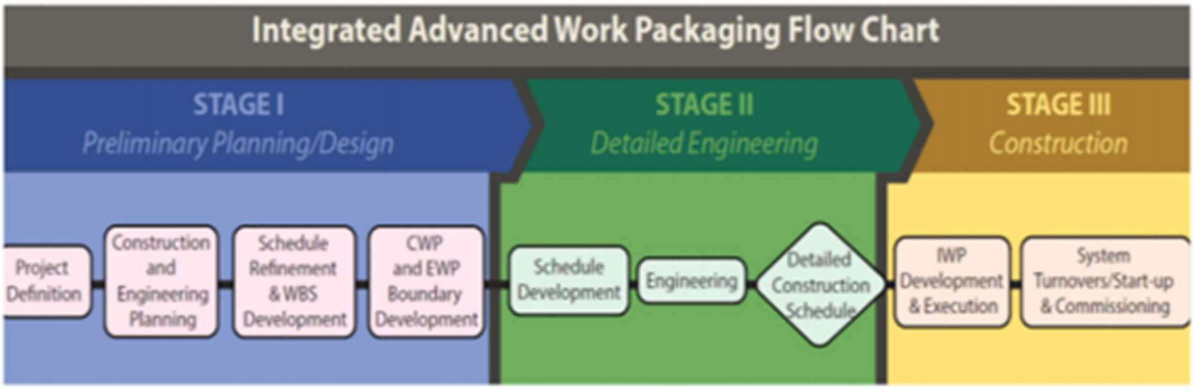


Figure 21: overall AWP Flow Chart (CII, 2015; COAA, 2015)

The construction stage of the AWP lifecycle mainly depends on the IWP. The IWP lifecycle starts with IWPs creation, document control, IWPs issuing to the field, IWPs control then IWPs close-out, as shown in figure22.

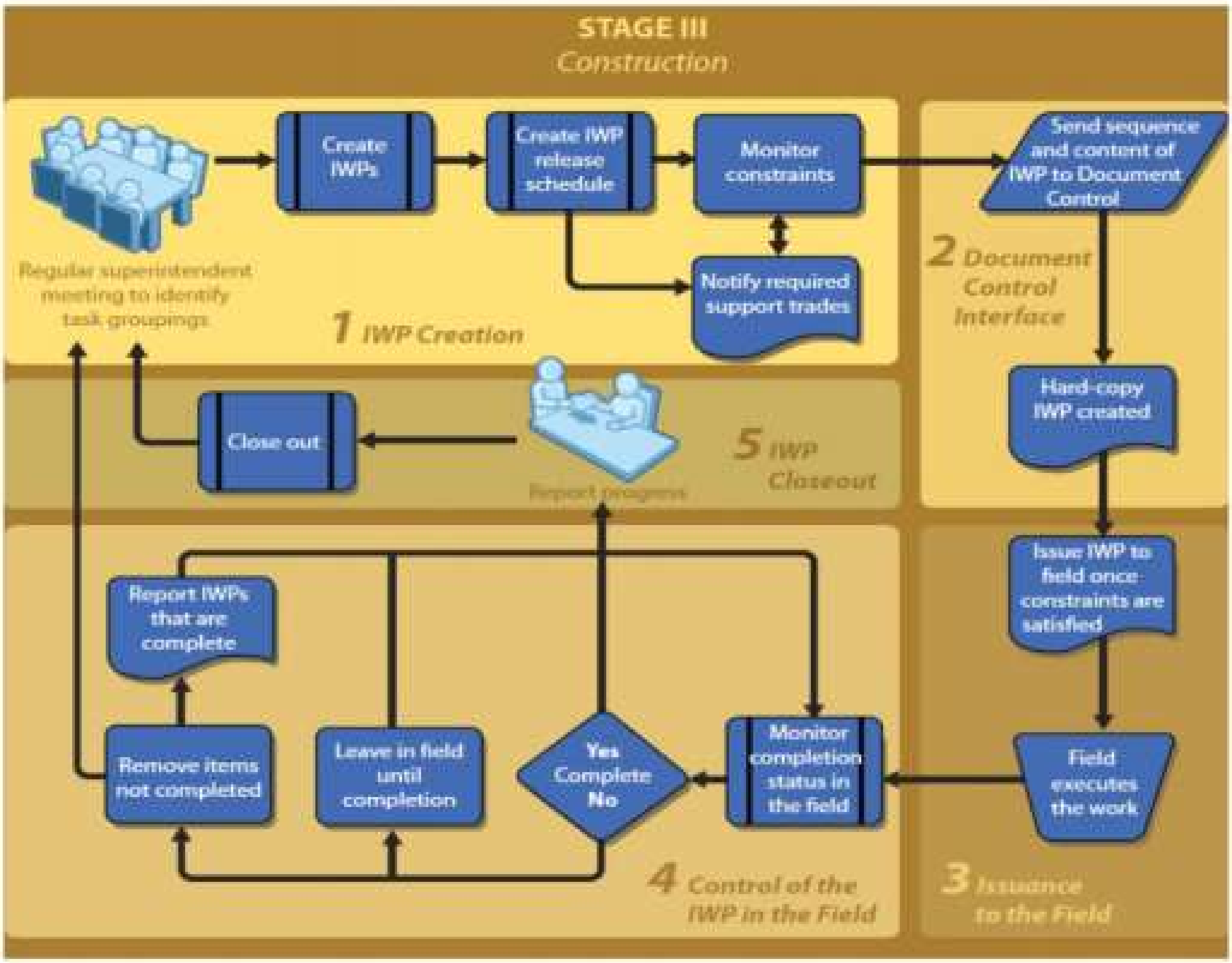


Figure 22: IPW flow chart (CII, 2015)

The need of a workface planner participation to produce the IWP is not effectively justified in the AWP system. The workface planner has comparable skills as the general foreman. Hence, in case the system supplies the required resources according to the requirements, the workface planner can be substituted by the general foreman for producing the IWPs. Besides, the general foreman along with his team is accountable for the implementation of the IWPs. Thus, the participation of the general Foremen in producing the IWPs would provide him with a sense of ownership for the work. In addition, it can encourage the general foreman and his team to maintain motivation and commitment for the work. The contribution of the general foreman in the production of IWPs can enhance his understanding and working skills. This also makes the standardization of work very solid. Unfortunately, the AWP system does not enforce the utilization of company's best practices and the industry's standards that are very valuable for the work packaging success. Additionally, it does not systematically include the participation of different project team members such as superintendents, procurement team, material management team, safety, and quality teams etc., that can be engaged efficiently to confirm and complete the IWPs' progress. Likewise, it does not discuss the demand for a system that involves all the project responsibles by offering actual time monitoring of the IWPs progress.

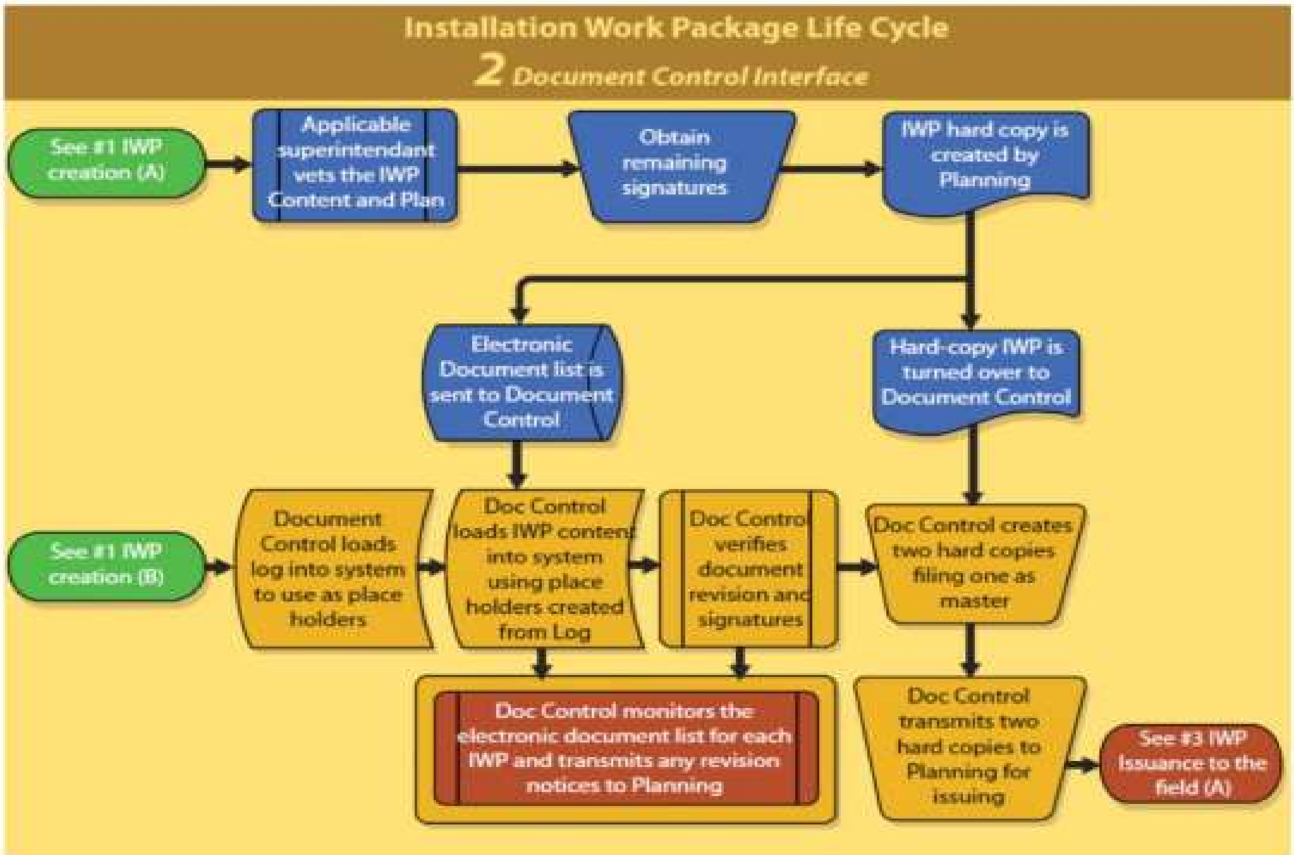


Figure 23: IWP Lifecycle illustration (CII, 2015)

6. Theoretical Framework: Lean Thinking

As illustrated in the state of research, conventional project control systems used in EPC are rather reactive and full of shortcomings. The objective of this research is to propose a new proactive project control system for the EPC industry, that is flexible enough to respond to the demands of today's complex projects. After intensive research, I believe this can be achieved by the application of Lean thinking to project control systems. Lean is a philosophy that is concerned with delivering more, while consuming less. Its core concept is the minimization of wasting human effort, resources, equipment, time, and space. In addition, it aims meeting the customers' requirements and needs in the best possible way (Womack and Jones, 2003). Lean is not a destination but rather a journey of continuous improvement by the means of ongoing and never-ending elimination of waste. The concept of "Lean" is mainly inspired by the Japanese founder of the Toyota automotive firm. Lean Thinking application is focused on securing the right things to the right place at the right time in the right quantity with the aim of achieving the perfect workflow, while minimizing waste and being flexible and clever to adjust to unforeseen change. The concept of Lean can be applied to an organization, a work process, a system, or anything where continual development can be accomplished. If Lean thinking is used within an organization, it will be possibly known as a Lean organization. In the same way, if Lean thinking is applied to a system, it can be referred to as a Lean system. The following highlights some very important general principles of the Lean thinking, that inspired the construction of the proposed proactive control system.

6.1 General Lean Principles

6.1.1 Jidoka

The "Jidoka" lean principle is one of the production control system pillars invented by the Japanese firm Toyota Motors Company. After its invention, it has been broadly applied in various manufacturing industries seeking the benefits and competitive advantage promised by its application. Toyota refers to "Jidoka" as "the ability to stop production lines, by man or machine, in the event of problems such as equipment malfunction, quality issues or late work" (Baudin, 2007). The literal translation of the Japanese word "Jidoka" is automation. Though, the word has taken other meanings due its usage in the manufacturing industry. The main meaning of "Jidoka" refers to "line stoppage variation".

According to the "Jidoka" principle, every worker should be given the authority to be responsible for stopping a production line when a defect occurs. This aims to draw all the attention and efforts on solving the problem to be able to restart the production line. As a result, a permanent solution for this problem will be enforced. Let us imagine two production lines, of which one was stopped immediately once a problem arises while the other production line was never stopped even when trouble occurred. At the first sight, the line which was stopped frequently will seem to have a lower output. Nevertheless, after several months the situation will change. On the one hand, the line that never stopped still will still have the same problems. This has a negative impact on its productivity as it creates the need of rework, which lowers the efficiency of the production line. On the other hand, the line that was stopped frequently at the beginning, experiences an increased productivity, and proved to be overall more efficient (Agnieszka Szmelter, 2012). The following figure summarizes the steps and positive outcomes of applying the "Jidoka" lean principle.

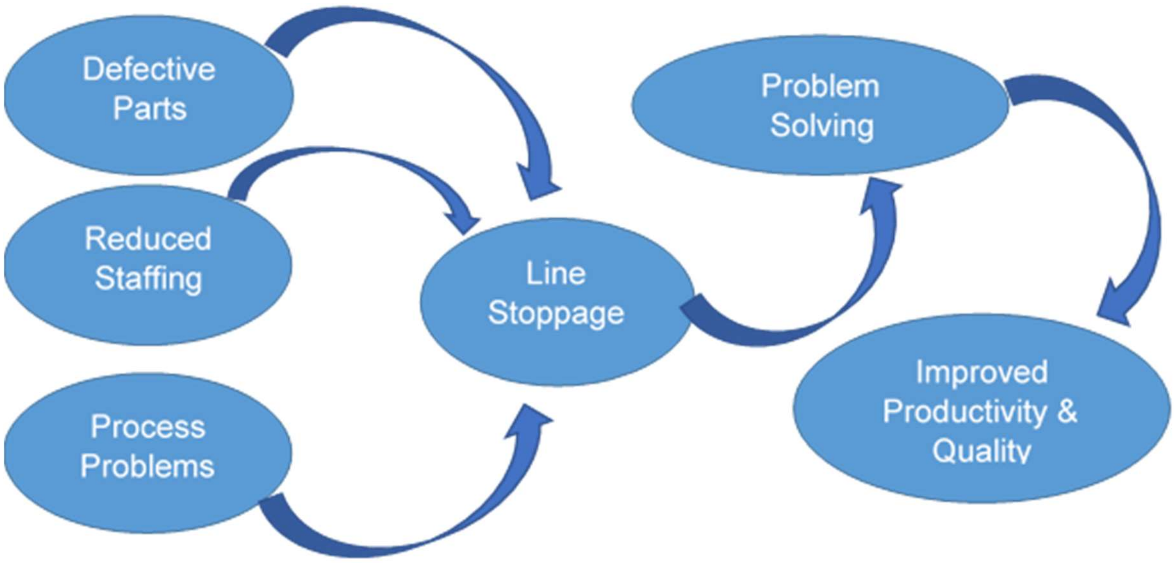


Figure 24: Jidoka main steps (Agnieszka Szmelter, 2012)

6.1.2 Mieruka

The Japanese terminology "Mieruka" refers to "visual control" and is considered a very powerful lean management principle. Visual control aims to visualize information on the process application with the aim of simplifying its understanding. In addition, the visualized information is supposed to be fully comprehensible on the first sight to help the responsible person make the right decision on how to proceed within very limited time. Visual control can be performed in form of visual signals, visual instructions, visual measurements as well as visual representations. While visual signals aim to define areas, visual instructions indicate the type of behavior that should be followed in the respective areas. An example of visual instructions are color-coded lines on the floor, that help individuals differentiate between the different areas of a site. Visual measurements on the other hand, highlight the achieved performance in comparison to the expected performance, which functions as an aid in assessment procedures. Moreover, visual representations explain the steps of a process or several activities such as a project's Gantt diagram (Severino Abad, 2019). The benefits of visual control are increased efficiency and effectiveness of work processes and activities as well as elimination of time waste. This is achieved due to the increased visibility of the processes' steps, which makes them easy to remember for the work team members (Algan Tezel et al., 2016).The visual tool for controlling an air pressure gauge illustrated in figure 25, is a basic yet a very good example of the application of the "Mieruka" principle.

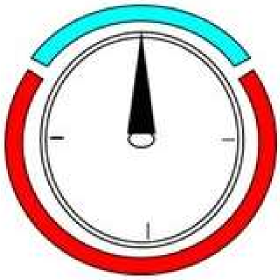


Figure 25: Visual control example (takuminotie.com, 2015)

A broadly used visual tool for communicating problems in lean production is the so called "Andon". The Andon principle intends to enhance the production quality by visualizing the status of the production line and communicating it to managers. This tool visualizes hidden problems in the manufacturing process which consequently enforces a good quality of production (Clarissa Biotto et al., 2014). An "Andon" light is one of the most popular Lean tools of visual management that is applied in manufacturing industry. It is a key Lean tool because it is extremely effective for maintaining a smooth running of operations. In Lean, the term "Andon" refers to a signaling structure used to call for help when an abnormal condition is recognized, or when some sort of action is required (Mohd Soufhwee Abd Rahman et al., 2019).

Figure 26: Andon light example (Mohd Soufhwee Abd Rahman et al., 2019)

6.1.3 Poka Yoke

The "Poka Yoke" principle is also one of the most valuable principles of lean manufacturing that has been applied to lean management. It was first applied by the Japanese engineer Toyoda in 1986 who later established the Toyota Motors Company. The terminology "Poka Yoke" means "mistake-proofing" or more literally "avoiding unintentional errors". The principle of "Poka Yoke" aims to guarantee that any process step is executed within the right conditions and hence avoiding the occurrence of any defects in the first place. If preventing defects is not possible due to some given circumstances, "Poka Yoke" aims to eliminate any defects in the process as early as possible by performing a detective function. The "Poka Yoke" principle is so valuable in lean management because it helps humans as well as processes to function in the right way in the first time, which makes defects rather impossible to occur. The application of simple "Poka Yoke" methods in process design acts as a filter for human or mechanical defects. In this sense, process steps become behavior shaping constraints that seek to avoid any defective operations. A very important characteristic of the "Poka Yoke" principle is its cost-related flexibility. The application of "Poke Yoke" methods can be tailored to the size of the firm or project and has not to be costly. A very simple example of a "Poka Yoke" process step is when a driver is obliged to press the clutch pedal before starting an engine of a car that has a manual gearbox. If he skips this process, the interlock will prevent the car from moving unintendedly. Overtime the behavior of the driver will be constrained to the requirements by repetition and habit. This "Poka Yoke" process step acts in this case a behavior shaping constrained as mentioned above (Rajan Kumar et al., 2016). Another real-life example that proofs the importance of simple Poke Yoke process steps is the sinking of the first Indian ballistic missile submarine because a hatch was left open, which allowed seawater to rush into the propulsion area. The application of a simple Poka Yoke process step to ensure that the hatch is always closed before operation would have saved the Indian government 2.9 Billion US dollar (Kyle Mizokami, 2018). All in all, we can say that the "Poka Yoke" principle is a technique for assuring quality without executing a quality assurance system but rather by preventing the occurrence of defects in the first place (Abraham Zhang, 2014).

6.1.4 Kanban

The Kanban method, which is part of the "Just in Time" Lean principle was invented by the industrial Toyota Engineer Taiichi Ohno, which is considered the father of Lean thinking. He established the "Kanban" principle to increase the manufacturing efficiency. The system got its name from the cards that track the production within a factory. In the automotive sector, “Kanban” is known as the "Toyota nameplate system" (Waldner, 1992). Kanban is a workflow management method for defining, managing, and improving services that deliver work knowledge. It intends to improve the visualization of the work as well as the maximization of the efficiency, and the continuous improvement. The Japanese terminology “Kanban” means billboard or signboard originating from manufacturing industry (Glenn and Gregory, 2003). Recently, it began to spread to the business units of various industries. Kanban has an easy process for following and managing the workflow, during the work progress using a series of status boards such as “Work To Do”, “In Progress” and “Work Done” etc. (Luke Pivac, 2019). An example of the “Kanaban” method application is shown in figure 27 below. The “Kanban” framework is based on three following concepts.

- Visualizing what can be done using status boards. Seeing items visually can help interpret patterns and see potential work streams naturally. This process can be very informative.
- Reducing the amount of work in progress to enable controlling the workflow more steadily in short iterations. This allows the ability to control the work stream without having to commit too much at once.
- Enhancing the work stream, so when an item is completed, the next highest priority from the backlog is worked on next (Luke Pivac, 2019).

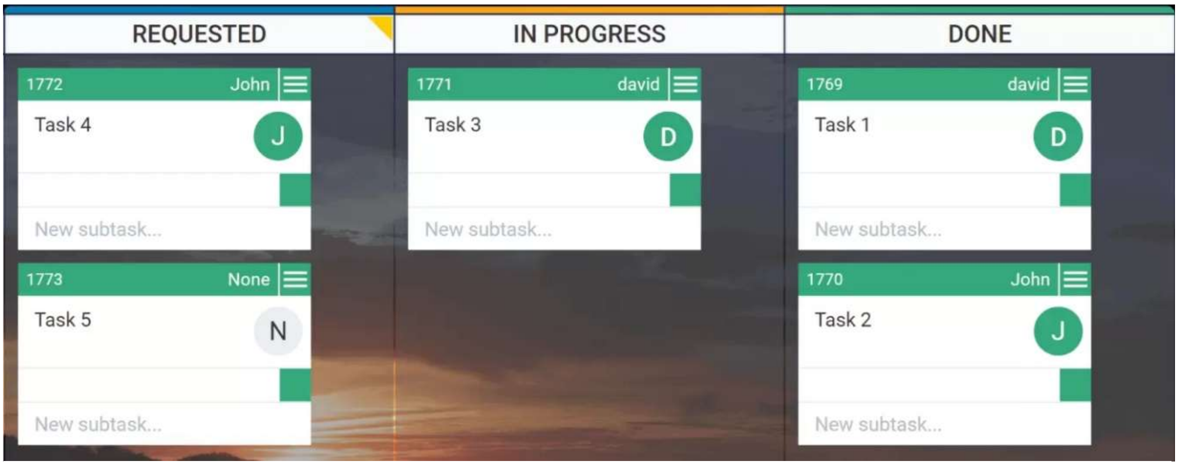


Figure 27 Sample of Kanban board (Luke Pivac, 2019)

6.2 Benefits of Lean in Different Industries

Lean principles have changed almost the entire manufacturing industry, the ship construction industry, the aerospace manufacturing industry, and other industries. Many experts are convinced that Lean principles an greatly help the construction industry (Robert M.Patty and

Michael A.Denton, 2010). According to CII, a lot of industries have massively benefited from the Lean thinking, which can assure a high potential of benefits for the construction industry. The following shows a few examples of how some industries profited from Lean:

- Japanese auto manufacturing industry became above 30% productive than competitors in the USA and Europe by 1985. Toyota automotive firm was able to cut down the typical engineering man-hours, that are needed to design and structure a production line for a new-found model from 3 million down to 1.7 million. Toyota was also able to decrease the commissioning/startup duration for the production rates and specifications by 62%.
- Aerospace, Atlas 5 vs Atlas 2 production, the workshop assembly duration could be decreased by 70%, while schedule could be decreased by 70% (Robert M.Patty and Michael A.Denton, 2010).
- ABS, a steel industry procedure, has benefited from lean too. Its total production lead time could be reduced by approximately 70%, while the average of inventory could be reduced by 90%.

6.3 Lean in Construction Industry

According to Patty and Denton., obtaining knowledge and understanding for Lean principles is essential for successfully applying and incorporating Lean in the construction industry. In a survey conducted by the CII, six projects from the construction industry are investigated to examine results of value-added work as shown in table 3 below.

Activity Classification	Waste Classification	Steel Erection			Piping Installation		
		C.S. #1	C.S. #2	C.S. #3	C.S. #4	C.S. #5	C.S. #6
Value Adding							
	Value Adding	25%	11%	10%	10%	8%	#
VA Total		**25%**	**11%**	**10%**	**10%**	**8%**	#
Not-Value Adding but Required							
	Material Pos	13%	14%	9%	12%	4%	#
	In-Process Ins.	0%	0%	½%	2%	8%	#
	T.W.S.A.	9%	21%	15%	7%	7%	#
NVAR Total		**22%**	**35%**	**25%**	**21%**	**19%**	#
Not-Value Adding							
	Waiting	28%	24%	46%	27%	31%	#
	Extra Proc.	6%	4%	%	14%	19%	#
	Transport	2%	7%	5%	11%	8%	#
	Motion	17%	18%	15%	16%	15%	#
NVA Total		**53%**	**53%**	**67%**	**68%**	**73%**	#

Table 3: Value Adding, Non-Value Adding but Required, And Non-Value Adding Work (CII 2005)

It can be observed that five from the six case studies illustrated above have a value adding work ranging from 8% to 10%. Hence, there is a chance of dramatic improvement by considering applying Lean principles to the construction industry as it was done in the manufacturing industry. The CII has established five main Lean principles in the construction industry.

- Focus on costumers
- People and Culture
- Standardization of work
- Elimination of waste
- Continuous improvement and quality built in

For a better understanding of the Lean construction principles, the CII has invented a so-called Lean wheel, that furtherly explain the principles into details as shown figure 28 below.

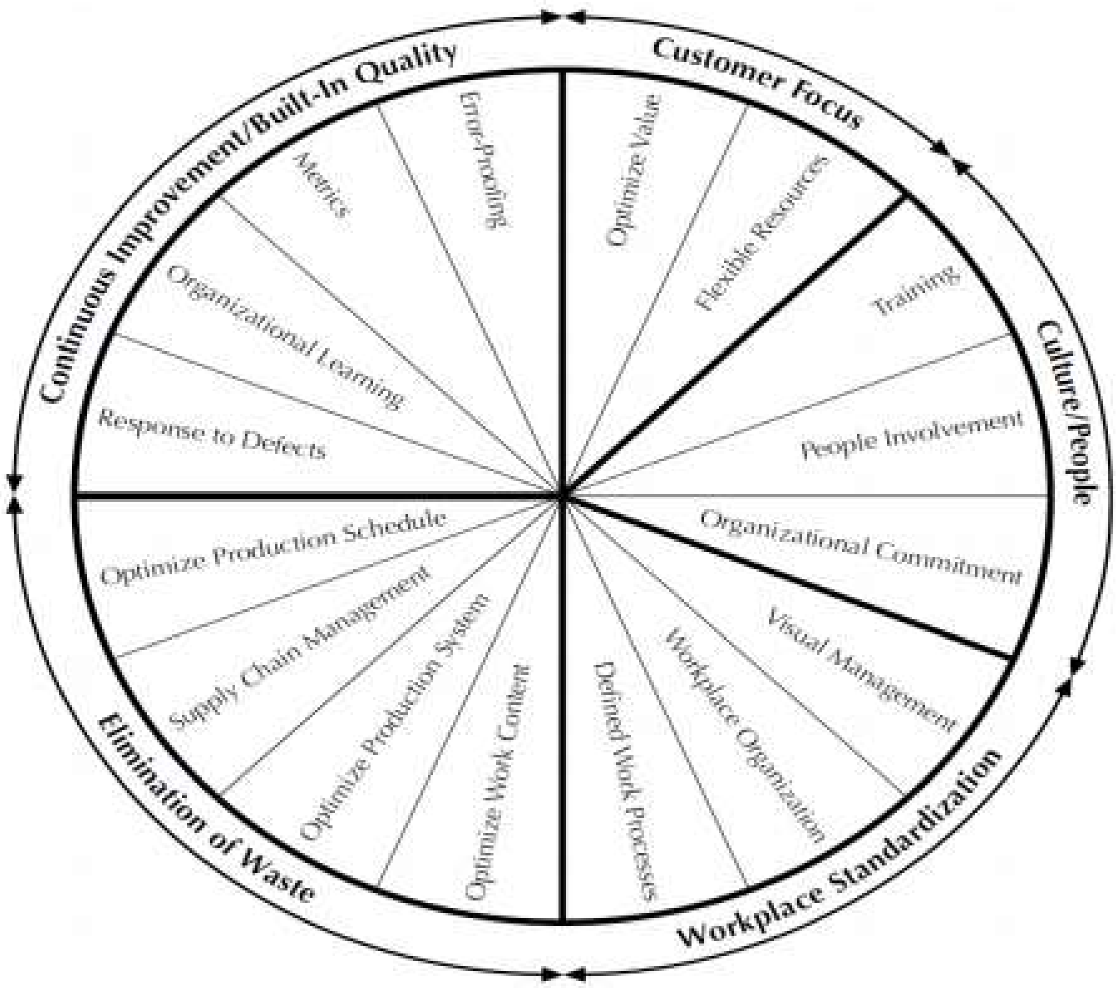


Figure 28: Lean principles approved for construction (CII, 2010)

In the following, I intent to propose a new model of a project control system in the EPC industry. The proposed system is inspired by many of the above illustrated Lean principles (see figure 28). The proposed EPC control system is mainly based on the lean principles of error-proofing, response to defects, visual management, definition of work processes, optimization of schedule, optimization of work content and system, people involvement, organizational commitment and metrics. The new control system aims to respond to the demands of today's complex projects, as conventional control systems have failed to fulfill the sophisticated needs of these projects. This is achieved by constructing the control system to be proactive rather than reactive like other conventional control systems, that are in EPC used until today.

7. Lean Model: Proactive Project Control System

As illustrated before, present project control systems applied in EPC have a rather reactive nature and proofed not to be efficient for guaranteeing complex projects' success. The demand for more flexible and proactive control systems in EPC is dramatically increasing. This chapter illustrates the new EPC proactive control system, which is exclusively constructed by the author in this research.

The new system is based on the idea of applying a pull flow system and push-pull interface as well as real time control, inspired by the Jidoka Lean principle. This assures the continuous workflow while using the Andon (*visual management*) tool. The new proactive control system includes protocols for raising early warnings to prevent any project from leaving its track from the beginning (*error/mistake-proofing*) on the subsystem level, which then rolls up to the project level. Moreover, it contains criteria for the simplification of managing the work packages (*optimization of work content & schedule*). In addition, it contains procedures for highlighting defects and errors through engaging the line supervisors (*organizational commitment, people involvement*). The proactive control system incorporates tools for anticipating the project's performance or at least evaluating it reliably to be communicated transparently to the responsible disciplines (*"proactive" response to defects*). Consequently, the continuity of on-site jobs is facilitated while assuring a high quality and minimum waste of time and resources by the application of digitalization (*optimization of construction system*). Digitalization is crucial for the new high-tech era of megaprojects which has sophisticated control requirements. The application of a digitalized EPC control system is an exclusive contribution of this research.

In the following, a general framework of the proposed control system is demonstrated to help the provide the reader with a helicopter view on the system.

7.1 General Framework

As previously mentioned, the main aim of the model is to propose a proactive control system. For creating such a control system, it is advised to apply a push flow between the front-end loading stages and then shift to a pull flow in the EPC stage. In addition, the project's breakdown structure has to be aligned. The work breakdown structure, the organization breakdown structure of the involved departments such as engineering, construction, procurement, and project control department and the cost breakdown structure has to be aligned together. In the proposed system, the Kanban method is applied to the WBS for easy monitoring and management. Moreover, the critical chain method is used in developing the master schedule, which reaches only level-4 (WTPs) to avoid extra complexity. Besides, the WTPs development in the EPC life cycle must have development stages: 120-90 lookahead schedule, followed by a 60 lookahead schedule, then a 30 days lookahead schedule, followed by a 1 week lookahead schedule. Meetings should be held for discussing the schedules, where different stakeholders develop WTPs with the executer partner. In these meetings, constraints are removed and readiness of WTPs is assured before getting amended it in the weekly execution schedule. The WTPs should depend on the company's best practices and standards. Furthermore, lessons-learned are gathered and put into consideration for the development of new WTPs. The proposed system also creates a visual panel for the top project level to the subsystem level which consists of different WTPs to give instant status feedback. This is realized by using a mobile application that is linked to the master schedule. In this digitalized solution, the WTPs in the 1 week lookahead schedule represents the active WTPs in the software database, which will be presented for all the users. Before the time planned for the WTP execution by one working shift, the WTP is sent to the responsible foreman, where he will be able to provide the live status feedback on the job. If he faces any difficulty, a notification can be sent to the respective stakeholder. The stakeholder can intervene directly saving a lot of non-desirable and non-adding value efforts. Besides, the mobile software will also send the status to the visual panels of the WTP, which rolls up to reach the project level. This system helps provide a proactive "live-monitoring" project control system. A detailed visual illustration of this general framework is shown below.

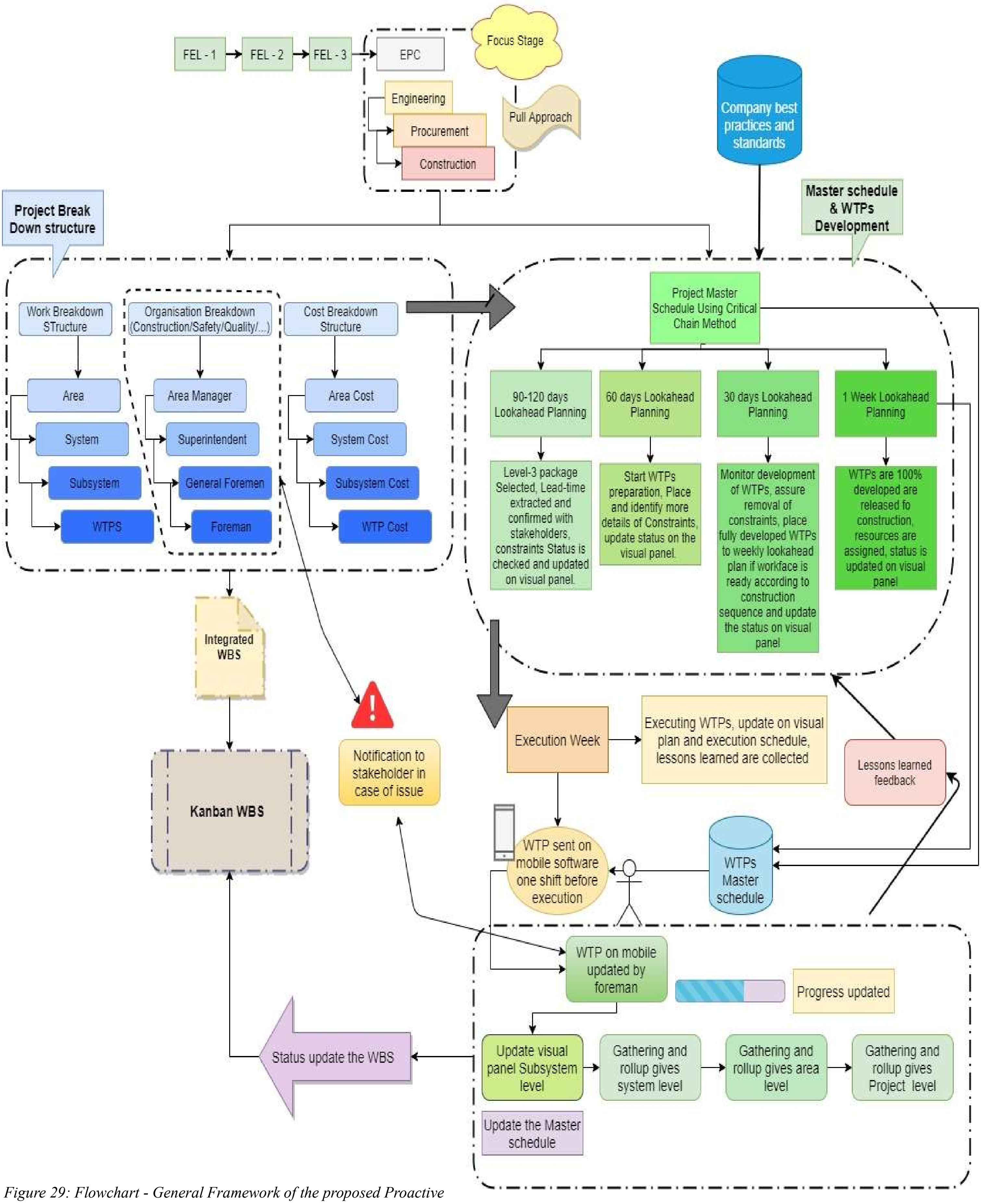


Figure 29: Flowchart - General Framework of the proposed Proactive EPC Control System (developed by the author using "draw.io" software)

7.2 Break-down of the Project

A1000 miles journey always starts with one step. This also applies on breaking-down an EPC project into WTPs. It is a mandatory step to provide a solid base for the project in order to achieve a better workflow control (Robert M.Patty and Michael A.Denton, 2010). EPC projects benefit from stronger control by getting divided into smaller manageable work packages (Glenn Ballard, 2000).

The term "Work Task Package (WTP)" is used to describe smaller units of the project that need to be performed for the project's accomplishment (Robert M.Patty and Michael A.Denton, 2010). WTPs are also the main component of the level-4 schedule. In this research, the WTPs are used to provide a better understanding for the proposed workflow control system. Level-4 breakdown is the main working level for applying the CPM or CCM. It shows the activities which should be progressed by each team. Thus, it reflects the project status as well as the work constrains when it is rolled up on the project level.

The project must be divided in WTPs of reasonable sizes, that can be easily managed, updated, and validated. Furthermore, WTPs are defined according to the scope of work, time duration, cost, and skills, needed for accomplishing the work. According to Ballard, each WTP can cover up to 400-600 manhours, while using only one team for accomplishing each WTP. Generally, each WTP is executed within a duration of approximately one week. A WTP contains work processes as well as targeted costs and should be delivered by an experienced manager, who is responsible to execute the job (Glenn Ballard and Iris Tommelein, 2012).

For example, in engineering, the WTPs must be created by the engineering responsible, while the general foreman should prepare the field work package. Creating WTPs should be based on each company's best practices as well as the international industry's standards. In figure 30 below, I provide an example on how to create a WTP, that was published by Robert Patty.

ELECTRICAL CONTRACTORS LTD.
Project: ________________________________

Cable Installation Field Level Task Planning

Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat

Construction Work Package (CWP) ____________________ Cost Code 7030
Check List
☐ IFC Drawings Received ☐ Material on Site ☐ FLRA Completed
☐ Permits in Place (see below) ☐ Tools on Site (see below) ☐ Crew in place

Permits		**Tools / Equipment**		**Crew**	
Work Permit	_____	Reel Stands	____	_________	____
Hot Work Permit	_____	Tugger c/w ropes	____	_________	____
Confined Space	_____	Shives/rollers	____	_________	____
Safe Work Plan	_____	Cable cutters	____	_________	____
Excavation Permit	_____	JLG (s)	____	_________	____
_____________	_____	___________	____	_________	____

Task Planning
Planned Start _____Finish______ **Is crew available for start date_________**
Boom Truck/crane? __________ **Is material at work face_______________**
Scaffolding required?__________ **Are tools at work face ________________**
Scanning required? ___Done? ___ **Cable Pull Sheets done? ______________**

Triggers	**Who**	**Done**		**Who**	**Done**
Cable trays, sleeves ready?	___________	____	Excavation required?	_____________	____
Duct Bank Complete?	____________	____	Tray grounding completed?	________	____
Tray cover to be installed?	____________	____	Advise QC ready to check	________	____

Comments (*was the task completed as planned,* Yes No *why or why not?*)
What went well and should be repeated on other projects ☺__________________________
____
____
____
What needs to be improved ☹____
____
____

Figure 10: Work Task Package (Robert M.Patty and Michael A.Denton, 2010)

7.3 Workflow of the Project

As discussed previously in the state of research, flow systems can be categorized into a Push or a Pull system. Moreover, shifting from a Push system to a Pull system and vice versa is can be achieved by the Push-Pull interface. In the proposed Lean model, the flow system is flexible and is not restricted to a certain type of flow. Nevertheless, the flow type that is more beneficial for the project's delivery and will provide the highest quality and minimum waste is to be used, as illustrated into details in the following. According to recent scientific literature, the pull system is simple to apply and had a huge positive impact when applied in the manufacturing industry. Still, the applicability of the two flow systems in the construction industry has been approved by the CII and the LCI.

7.3.1 Development stage – Front End Loading

During the FEL stages, the project work is still in the early defining stage. In these stages, a workface, from which a flow can be "pulled", does not exist yet. In other words, the next project's deliverables are defined based on the outcome, that has been just accomplished. The workflow system is a gate system, like a channel with in-series gate valves; once a gate is fully open, the workflow can pass to the corresponding valve. Hence, until FEL1 is accomplished, FEL2 cannot be commenced.

In the FEL stages, work standards which include the company's best practices, value improving workshop of engineering, techniques, measures, in addition to control tools for best deliverables, should be available for the assigned team. Besides, a schedule for each stage of each FEL should be available too. Usually those standards are produced by the company or outsource consultants and are based on the industry's best practices as well as the company's records combined with the experience of the company's employees and stakeholders. The standards should also include performance measures and controls.

FEL stages are the base stone of capital projects. Therefore, the assigned team should provide intensive care and commitment for predefining the process of work and its duration. In the following, a visual demonstration of the workflow control systems in each FEL stage is provided (see figure 31).

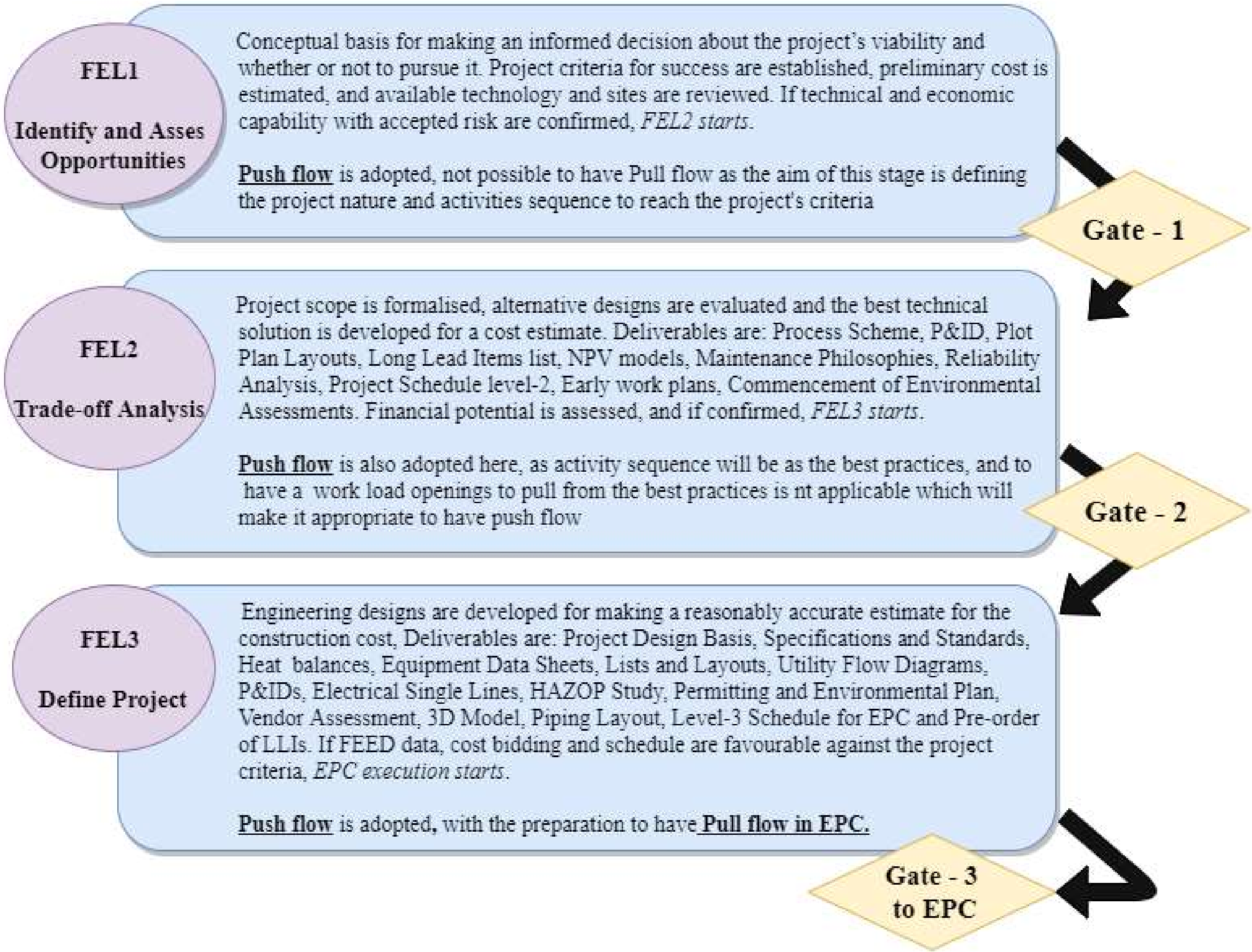


Figure 31: FEL stages flow control system (developed by the author, 2020)

As shown in the figure above, the FEL stages are delivered by the Push flow system. This is referred to the "gate" nature of those stages. Therefore, no process can start until the predecessor process is completed due to the lack of work activities that are needed "pull" the resources. Besides, the FEL stages mainly consist of processes that are based on ideas, analytical thinking, past experiences, and data gathering, where there is no need to "pull" anything. Usually, the three FEL stages are performed by same resources of skills and stakeholders. Once a stage is accomplished, a new stage becomes ready to be performed. Through FEL stages, all essential decisions must be taken to avoid interruptions, or loops of reengineering or construction rework during the EPC stage.

7.3.2 EPCC Stage

Engineering, procurement, construction, commissioning, and start-up are the phases following the FEL. Conventional control systems are based on critical path-built schedules, which are based on the Push flow system. The aim of such schedules is controlling the work as well as the contractors, to perform according to predetermined dates and pre-identified durations. Nevertheless, in the reality, the dates as well as the durations keep changing. The main reasons for this change are the inadequate planning of tasks, shortage of material or resources, unavailability of the contractor or equipment on the predetermined dates. The conventional project control systems are not flexible enough to absorb consequences of this kind of changes. Conventional schedules get extended in these situations while recovery plans are required as well. In this case, the required recovery plans are difficult to produce, because the control systems are rather reactive. Thus, at the time the recovery plans come into action, the schedule variation would be already wider. Usually, the recovery plans are based on the idea of activities crashing by increasing the assigned resources, hence decreasing the activities durations. Recovery plans can also depend on the concept of fast tracking, which entails increasing the resources and planning more activities to be executed parallelly. In both solutions, more resources are needed, which require extra cost and preparations, while the output is not certain.

In most of the EPC Projects, a weekly reporting system is adopted for certain WTPs, while for the whole project a monthly report is usually the respected one. Even if the weekly reporting is sustained for the whole project – which is a massive work to do – the control system remains reactive. Such a control system is not effective for controlling the project in short time intervals, which is why it is substituted by a reactive one in the proposed model. The main aim of the proposed system is to enable accomplishing the construction work in the shortest time duration possible while respecting the project's criteria of quality, safety, and budget. For these purposes, having a proactive project control system is mandatory. Turning a control system into a proactive one is achieved by attaining a flow of just what is needed, when it is need for every work package. This is to be achieved while maintaining a realistic resource levels to have optimized budget.

To summarize the above proposed flow system, Engineering and Procurement are applied within a Push flow in the beginning, as there are no open tasks to "pull" from yet. They are pushed until sufficient work is done to allow the commencement of the construction work. The construction is the main deliverable activity of EPC projects, where a Pull flow can be maintained, except for the long lead items. The long lead items are mostly purchased according to predetermined and agreed delivery dates. Therefore, they cannot be controlled by the same flow as the rest of the construction. Managing long lead items with a Pull flow might be advantageous. However, manufacturers of long lead items do not have the flexibility in delivery dates. Hence, it is advised to perform a risk assessment for evaluating the applicability of managing long lead items by a Pull system. In the proposed model, the long lead items installations take place on predetermined dates and hence are managed by a Push flow and are considered as milestones. So, the whole construction process is managed by a Pull approach until reaching the milestones of long lead items installation.

Based on the outcome of FEL3, engineering must be able to identify the needs for site preparation and provide all information for allowing the detailed design to perform according to the construction path. If this has not been achieved yet, the engineering maintains a Push flow until this condition is fulfilled and a Pull flow can be established. When the EPC execution commences, Engineering and Procurement are controlled by a Push flow until reaching a certain amount of ready WTPs that can sustain a Pull flow. Detailed design, purchased material, kits, preassemblies and installation WTPs are placed in the “Supermarkets” prior to the completion of the subsequent processes. As demonstrated previously, the “Supermarket” is a lean concept and is defined as the location, where a predetermined inventory is stored for supplying downstream processes and enabling the tracking of downstream usage and requirements.

Once engineering and procurement have advanced adequately in comparison to the construction, a sufficient workflow is achieved for starting a Pull system to control the construction process. This shift is achieved by applying a push-pull interface. Long lead items, detailed design and procurement are initiated in advance of the construction. In most of the contracts, the long lead items are controlled by milestones, and the work progresses to achieve these milestones. The constraints of the LLIs installation are removed by the work progress achieved during the construction process. Hence, the Push flow for controlling long lead items installations is complemented with a Pull flow that controls the work task packages, which then enables long lead items installation.

The Construction Pull system is based on the idea of having the own pace of field work task packaging, procurement, and engineering according to the achieved rate of construction. Besides, the Pull system can absorb any changes in frequently changing construction rate. So, the construction will Pull the required WTPs while keeping the same rate. Consequently, the rate of work task packaging demands the procurement to maintain the same rate, and the procurements demands detailed engineering to maintain the same rate, all regulated by the rate of the construction.

The Pull system positively affects the schedule's speed up and flexibility, the reduction of inventory, the decline of the work in process, and the improvement of cash flow. Nevertheless, it does not have an impact on the project end date and the milestones identified by the contract, while all the remaining dates are permitted to float in accordance with the actual work progress.

The delivery dates of LLIs can float as well depending on the actual progress. In this case, it is more feasible to get informed by the supplier on the duration needed for the items delivery more than negotiating the delivery date. So, the lead times are known and negotiated for deliverables. By applying this concept, activities are created in the schedule to notify the arrival of lead times. Thus, the LLI's manufacturing activity is generated to carry on, while the delivery is carried out at the end of the lead time (Robert M.Patty and Michael A.Denton, 2010). For easier control, the lead time can be split in successive activities to achieve the site delivery. Examples for these activities are shop drawing, documents approval, fabrication start, different stages of fabrication progress like 25%, 50%, 75% and 100%, final inspection and packaging. This helps ensure that the anticipated lead duration is achieved.

Actual progress reporting as well as transparency is provided by the proposed proactive system. This is achieved by updating the WTP execution progress every time a task is achieved. The WTP is comparable with the product in a production system. Besides, the task time varies depending on its type and nature. Consequently, the overall project schedule is updated every defined time interval, which may be weekly or bi-weekly, which in turn enables following-up with the suppliers and subcontractors. Hence, they can manage their manpower and resources on and off the project. Unforeseen challenges can be rapidly noticed, and resources can be reallocated to avoid delay.

In the proposed model, the project schedule is produced based on the Pull planning concept, which is designed to pull the tasks based on the downstream demand. It usually starts with the final WTP or milestone in the agreed construction method of the company and then continue with the predecessor WTPs is sequence. Corporations are handoffs are built between the WTPs owners. Constraints such as engineering documents or material delivery are managed effectively to reduce lead times and prevent delays.

The project detailed schedule is built applying CCM. In which project activities' commencement and completion dates are not constrained in addition to having ability to float and change according to the actual progress on site. Only the contractual milestones must remain fixed, while some are linked to long lead items dates. The work will proceed with the Pull system to achieve these milestones. Figure 32 and figure 33 below, demonstrate information on the EPC phases and the workflow system of each phase as well as between the different phases.

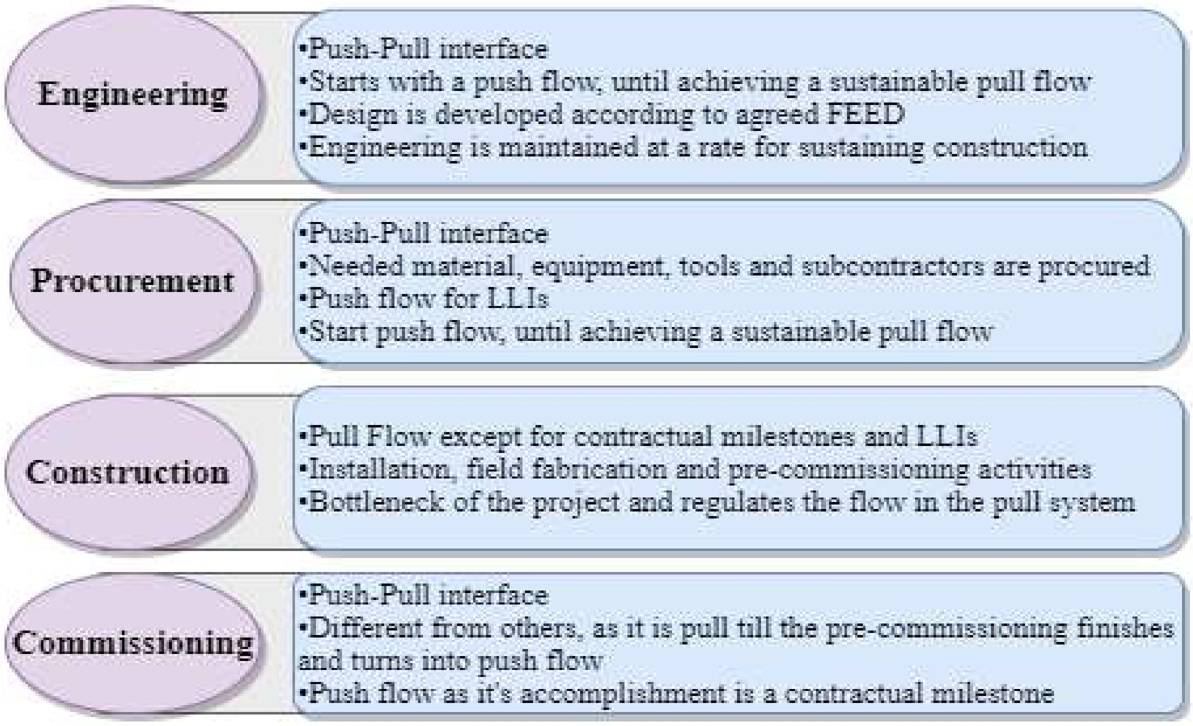


Figure 32: Lean flow of the EPCC stages (developed by the author, 2020)

Figure 33: The lean flow between the EPC Project Phases (Robert M.Patty and Michael A.Denton, 2010)

7.4 Breakdown Structure Advancement

The creation of a breakdown structure, that contributes to developing a lean proactive control system can be applied in two main steps: the first step is creating an integrated breakdown structure inspired the lean principles mentioned previously. The second step is creating a visual breakdown structure by applying the "Kanban" tool on the output of the integrated break down structure. This has a positive effect on the performance of the project control system as it provides a full update on the actual and accurate status of the WBS.

7.4.1 Integrated Breakdown Structure

Breaking-down the scope of work into smaller tasks is a well-known and common technique as explained previously. The traditional breakdown structures do not align different breakdown structures together such as the work breakdown structure, the cost breakdown structure, and the organization breakdown structure. Hence, every breakdown structure can be easily tracked on its own, but all structures cannot be tracked in an integrated way. This makes the responsibles loose the opportunity of better and stronger control.

In same time, to create knowledge, deferring commitment and optimizing the whole, are from the main principles of lean thinking. This can be easily achieved by aligning different breakdowns vertically and horizontally, integrating different breakdowns together to reach a sufficient level of details – usually level 4 because deeper levels cause increased complexity. Every structure will give its contribution to the whole picture of packages structure: WBS defines the work to be done, CBS will identifies defines of cost and budget, while the OBS defines boundaries of resources and defines the responsibles of each package level as well.

The incorporating of an integrated breakdown structure in the proposed proactive control system is vital, as it provides an improved project's integration, alignment, and coordination. Consequently, the reporting process is optimized, people involvement and organizational ownership and commitment at each level of the organization is enhanced and the evaluation process of the project is facilitated. This directly supports the flow between cost estimation and project scheduling. Moreover, this facilitate resource loading scheduling, which positively affects the project control. Hence, this simplifies management and team alignment, and improves the visibility of the workface. The following table illustrates an example for the integrated breakdown structure concept.

Level	WBS	CBS	OBS	Reporting
0	Project	Cost at project level	Project Manager / Department manager	Project level
1	Area	Stream/Area cost	Area Manager / Engineering manager	Area level
2	System	System cost	System Engineer / Superintendent	System level
3	Subsystem	Subsystem cost, like mechanical, instrumentation, mechanical of a system…etc.	Engineering Discipline Head / Craft General foreman	Discipline level
4	WTP	Work task package Beam, columns, wastewater pump …etc.	Task owner / Foreman	Task Level

Table 4: Integrated Breakdown Structure Concept

Another detail that needs to be highlighted is that the project OBS is composed of more than one department and all of them should be aligned with the CBS and WBS to have a complete integration. In table 5 below, the departments, which are in control of the projects main constraints are illustrated.

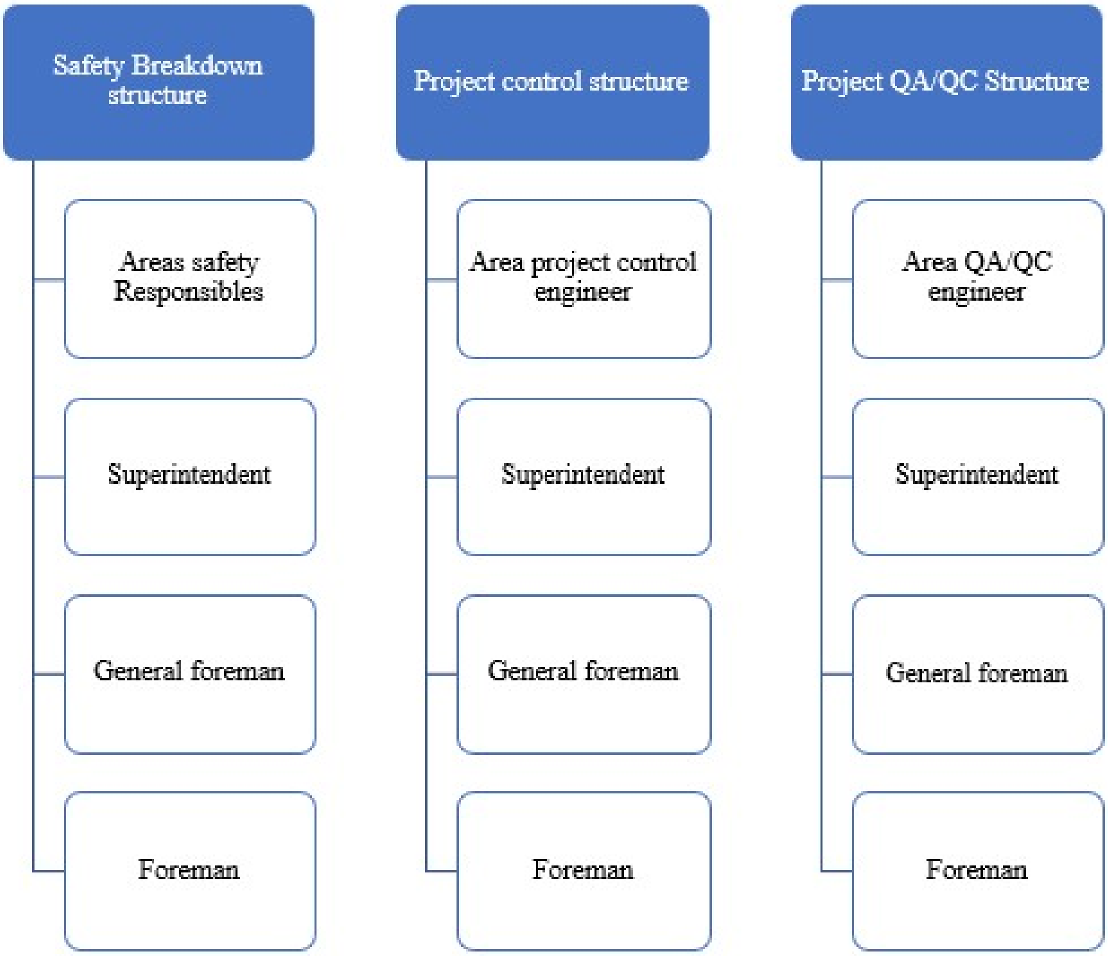


Table 5: OBS of project control, Safety , QA/QC in parallel with CBS & WBS

7.4.2 Visual Breakdown Structure with Kanban

One of the greatest things about Kanban is its applicability to any process. In the proposed lean model, the application of Kanban to WBS is suggested.

A typical Kanban system requires a Kanban board and Kanban cards that are put on the board. A Kanban board take the form of a table with at least three columns (To Do, Doing, Done). In project management the Kanban table can be increased with extra columns of backlog, constrained, or even other classifications depending on the responsible need to control the project's scope and deliverables. In reality, the Kanban board consists of many columns or horizontal lanes, depending on the status that needs to be monitored and which level of details are helpful while still avoiding complexity. Usually, each column on the board contains Kanban cards that present a work breakdown structure item. This saves time to compile a report, or set up a meeting, etc. Applying Kanban will boost efficiency of controlling the WBS and increases the productivity of the responsible teams.

To apply Kanban to WBS, a master Kanban board has to be created first, in which Level-1 is presented. This Kanban board contains all the level-1 deliverables and show its current status and priority as shown in the following example (see 34).

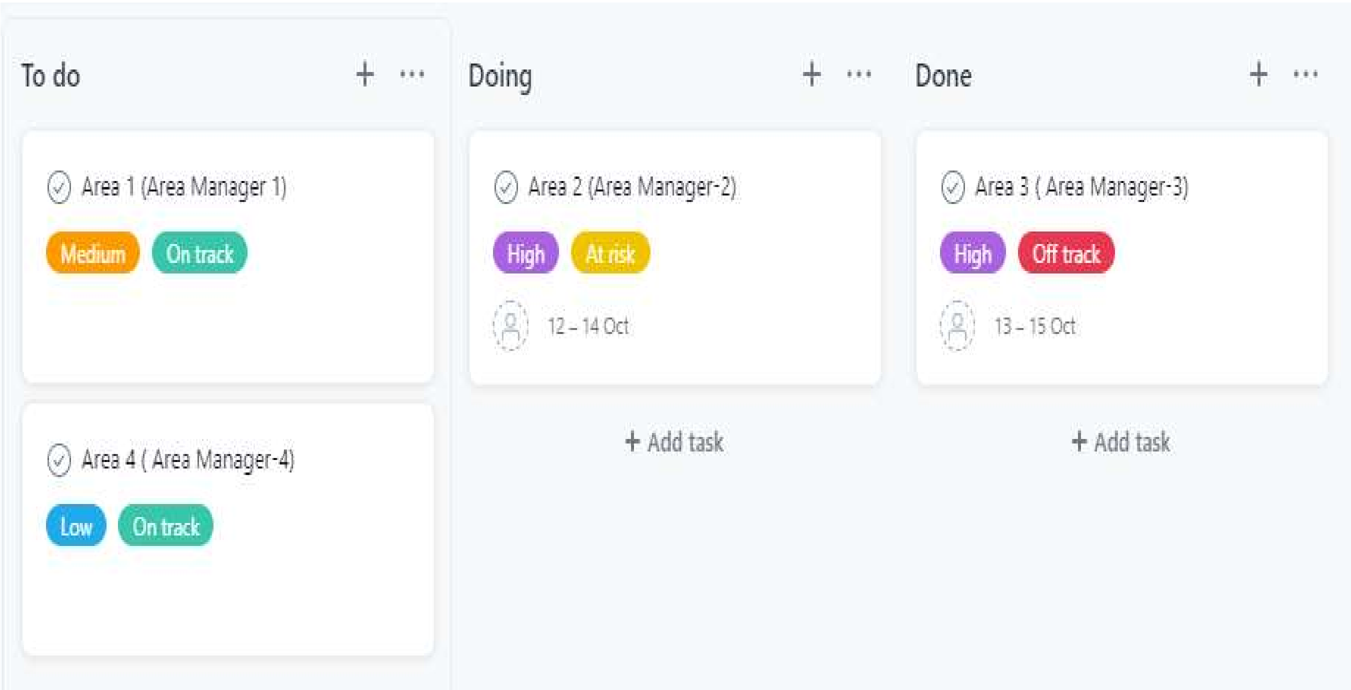


Figure 34: Level-1 WBS Kanban board (developed by the author using "Asana" online software)

Then, Level-2 deliverables are added as nested work items to Level-1 deliverables on the Kanban board. Nested deliverables can be illustrated by parent and child links between the Kanban cards. Creating different levels of WBS on different boards, allows the responsible teams to work on the level they want without getting distracted, as shown in the example below (see figure 35).

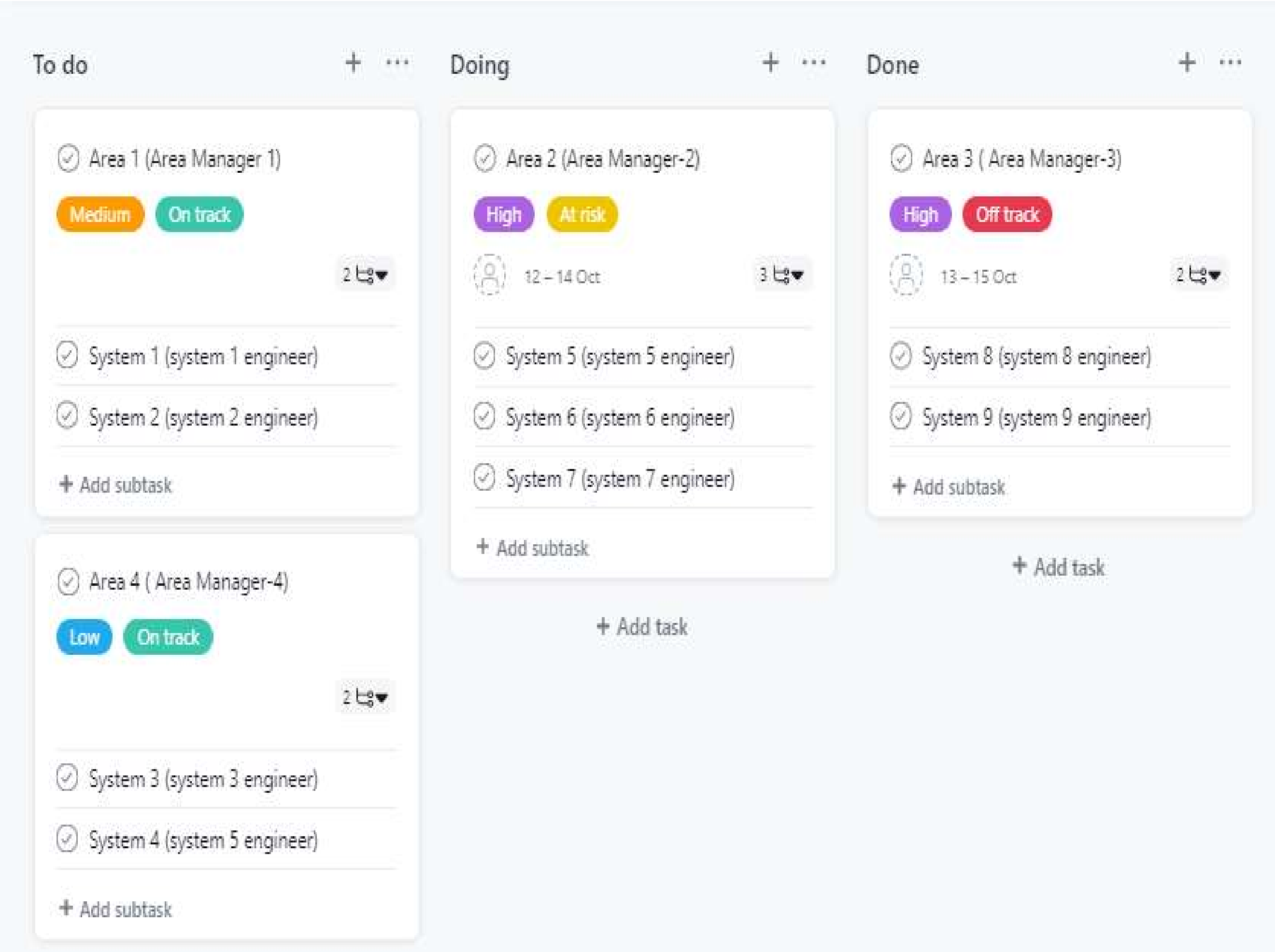


Figure 35: Level-2 WBS illustrated using Kanban visualization tool (developeed by the author using "Asana" online software, 2020).

The visual WBS approach using the Kanban tool provides on packages progress easily, which makes less reporting required and helps have easier prioritization of packages. Also, using such visualization of the WBS ensures that the information is spread between the project teams and prevents conflicts regarding priorities and unidentified dependencies.

Moreover, the color coding can be used to determine the state of each Kanban card, showing if the package on a certain card is struggling, working smoothly, or needs extra attention, which provides extra help for prioritizing the packages in very limited time.

7.5 WTP Planning Cycle

As explained previously, the construction phase is the bottleneck of the EPC. The WTP flow following the pull system during EPC is controlled by lead times and triggers. A lead time is the time, which takes places before a delivery is accomplished, starting from order placement (Glenn Ballard, 2000). The central aim of a control system is minimizing the project's duration while maintaining the required quality, budget, and safety standards. This can be achieved by fully utilizing every available workface. The “trigger” is a notification mechanism, which notifies the responsible person on the corresponding lead time. (Robert M.Patty and Michael A.Denton, 2010). Lead times and triggers help simplifying the pull flow system through the project lifecycle. The procurement team is responsible for providing the lead times while the suppliers and subcontractors are responsible for maintaining them. Besides, lead times get negotiated and approved by different stakeholders. The LLIs can have fixed dates that are included as milestones in the execution schedule.

The WTP planning is controlled by two activities. The first activity is putting the overall sequence by creating a critical chain schedule. The critical chain schedule indicates the resources needed for performing each function to achieve the desired deliverables. This activity is performed by the FEL-3 team. The second activity is controlling the process rate based on the actual speed of the construction and final.

Lead times can vary from one project to another depending on several reasons, such as the project location (remote areas vs. urban areas). In the proposed model, lead times are classified into the following four categories (which can differ from one project to another depending on the average of lead times and the limit of categorization).

1. **Very long lead times**, where the placement of orders take place in the stages of FELs. The end of manufacturing can be fixed by contractual dates while the date of final site delivery can float depending on actual project’s execution status. Typically, large compressors and large turbines may have lead times from 12 to 24 months.
2. **Long lead times** with a duration of more than 90 days in average. Such durations are not fixed, as they can vary from one project to another. For example, for projects taking located in remote areas, lead times can have a duration of up to 120 days, while the duration can drop to 60 days in projects located in urban areas near the manufacturers.
3. **Medium lead times** that have a duration of 30 to 90 days.
4. **Short lead times** that have a duration of less than the 30 days.

Based on this categorization the lookahead planning strategy can be determined to be as follow: from 90 to 120 days lookahead planning, 60 days lookahead, 30 days lookahead and one week lookahead.

- In the 90 to 120 days lookahead planning, the planning focuses on the level-3 CWP. The construction packages are selected from the updated critical chain schedule which reflects the logical sequence for achieving the contractual milestones. This kind of planning is conducted with the aim of balancing the resources of labor, site equipment and tools. In the planning meeting, needed resources such as the materials, subcontractors, equipment lead times as well as triggers are highlighted and discussed. The planning aims to verify the availability of these resources. Responsible persons on this level like superintendent, concerned general foreman and for sure project scheduler have to attend the planning meeting. It is recommended that such planning takes place every month. The resources are triggered based on the respective lead times and a time buffer can be added according to company's best practices, industry's standards, and site history. Besides, a visual panel can be created for this lookahead planning. This provides an overview of the items, which the engineering and procurement teams have to work on before reaching the construction phase. This is how the pull system is triggered. Any task that is conducted by the team and cannot be accomplished due to the scheduled time, has to be rescheduled with a reasonable time.

- The 60 days lookahead planning focuses on the level-4 WTP. WTPs are originally the details of the level-3 packages, which are already highlighted and captured in the visual panel. In this kind of planning, more details of constraints are highlighted before being released to be included in the 30 days lookahead plan. The WTPs are ready after the constraints are removed by actual or committed delivery on site. The engineering documents constraints are eliminated by the corresponding project's team members.
- During the 30 days lookahead planning, the ready WTPs are approved and included in the 1-week lookahead plan. If constraints of some WTPs still exist, the responsible team keep working on these constraints until accomplished. The general foreman places different procedures needed for the WTP execution and plans the WTP. The WTP is then approved by the respective stakeholders. Afterwards, the WTP is executed by the foreman who firstly validates everything. Moreover, other parties like the safety responsible as well as the superintendent may have to verify the working procedures to assure best practices are undertaken. The quality department and other departments – based on the nature of the project – may be also interested to verify the WTP. For example, if it is an offshore installation, the maritime department will be interested as well. Furthermore, the material management department assures the presence of all required resources, bags, tags, palletizes, or any other material according to the WTP's requirements. In that manner, the material constraints are eliminated. The WTPs have to be established in a period

of 30 days in advance to the need of execution/installation. They are stored in the supermarket until they are needed in the next phase. In the 30 days lookahead planning meeting, the entirely developed WTPs are put into the right sequence in the lookahead schedule.

- All through the meeting of the 1-week lookahead planning, WTPs which will get executed during the following week are assigned to the workface. In this meeting, all technical and human resources are allocated to the workface too. The WTPs are finally installed during the execution/installation week.

In general, at least one completed WTP has to be ready as a buffer and entitled to be pulled for assuring the continuous workflow of the project without stoppage. When applying the proposed lean control system for the WTP planning, non-added value time can be avoided. Figure 36 shows an example of non-added value time spent on site. The workers in the photo are most probably waiting for equipment, tools, cranes, material etc.

Figure 36: non-added value time spent on construction site (Trekker Group, 2018)

7.6 Real Time Control of Project's Levels

This part of the proposed model focuses on offering real time monitoring and control on the different levels of a project. This intends to maintain the workflows by updating the organization's different responsibles on the real time status of work packages. Real time monitoring and control are based on the *Jidoka* and *Poke-Yoke* Lean principles, while the visual demonstration of the real-life status is based on the *Meiruka* principle. The proposed real time monitoring and control makes problems visually obvious through the application of color codes. This *Meiruka* (*visual management*) tool is based on the integration of *Andon* lights, that are used in the Jidoka production system and flow control panels for Lean *error-proofing*. The main tool's objective is to monitor and control the construction process and WTPs' progress, sequence, and erection. Overall, the visual tool for real time monitoring and control strengthens the pull flow control. By applying this visual tool, when an issue or problem takes arises, the application of this visual tool makes issues and problems obvious to the responsibles once they arise. Whether the error or problem proofing fails or succeeds, in both ways the process is acknowledged as a lesson learned and is implemented within the continuous improvement process. Including lessons learned in the continuous improvement process prevents recurring errors and problems, which increases the effectiveness of the control system and turns it into a proactive system.

Visualization is the pillar of this system and is applied by the creation of visual control panel, where the construction process and WTPs' statuses are monitored and controlled. Visual control panels are created for the project's different levels to communicate the real time work status for the construction and WTPs to the project's responsibles. For example, the general foreman monitors the visual panels of the discipline level, while system level panels are monitored by the superintendent. The visual panels demonstrate what the responsible person needs to know to have access to deeper levels of work details. Department managers for example monitor the visual panels of the area level, while the project manager monitors the project level panels. Also, material management, safety, procurement, engineering, quality, and other departments have visual panels for respective scope and boundary of work. Providing the responsible persons and teams with visual panels for monitoring and controlling their work in the actual moment, increases their sense of ownership and organizational engagement. In the following, the application of visual panels for actual time monitoring and control for the different levels of the project is explained in to details.

7.6.1 Color Coding in Visual Panels

The proposed visual management tool contains fixed color codes for all visual panels, each color indicating to a different work status as shown in figure 37.

The **brown color code** indicates that the CWP/WTP/ is facing problems and consequently will be delayed. In this case, the lead time overruns the one planned by the stakeholders. The attention of the responsibles is drawn to the brown color-coded package to find a solution. The responsible person may need to involve other stakeholders for fixing the problem. Moreover, an immediate recovery action is undertaken to avoid the delay caused by the occurring problem and correct any subsequent errors that might come up. Besides, a root cause analysis is performed for the

	Brown	Challenging/Delay
	Yellow	Challenging / No Delay
	Green	Excellent
	White	Not Working
	Red	Emergency
	Blue	Finished

Figure 37: Legend of Andon colors in the visual control panels (developed by the author, 2020)

brown color-coded package to avoid the occurrence of the same problem again in the future. The results of the root cause analysis are acknowledged in the lessons learned to be enable "mistake-proofing". They are also included in the company's best practices as part of the continuous improvement process. The brown color-coded package is validated as 100% completed after the lesson learnt are collected. Consequently, lessons learned collection and documentation for any brown color-coded package is a crucial activity.

The **yellow color code** indicates a work status where the execution team is struggling but still expect to finish work on the planned date as the problem is being solved. In this case, the production rate is not the same as planned, and the team may be asking for extra resources to finish on the planned date. During the weekly lookahead planning meeting, it is clarified that the team facing challenges have found a solution – even if this solution means the utilization of extra resources to assure that the planned date is met. Nevertheless, the collection and documentation of lessons learned is needed for avoid the same problem from occurring in the future.

The **green color code** indicates a smooth operation of the WTP/CWP. During the installation/execution time window of one week, the green color code indicates that the work is progressing as planned or even better. It means that the planned date will be met, or they can be completed even earlier. Even in this case, any lessons learned are collected and documented to be included in the company's best practices.

The **red color code** indicates a work emergency. This is a situation that needs an intervention from the project manager. For example, it can be a safety accident or a failure of a critical resource.

Finally, the blue color code indicates that a WTP/CWP has been successfully completed while the white color code indicates the none-working of a WTP/CWP because it has not commenced yet.

7.6.2 Visual Panels for Different Project Levels

The visual panels are applied for each level of the project to be communicated with the respective responsibles – from the project manager to the general foreman level.

7.6.2.1 Visual Panel for Project Level

The helicopter view provided by this panel can be accessed by the project manager, the project control manager, and superintendents. In this visual panel, the project is divided into areas. The example below shows a combined power station, which is divided into 6 areas, each area is coded in a different color (see figure 38).

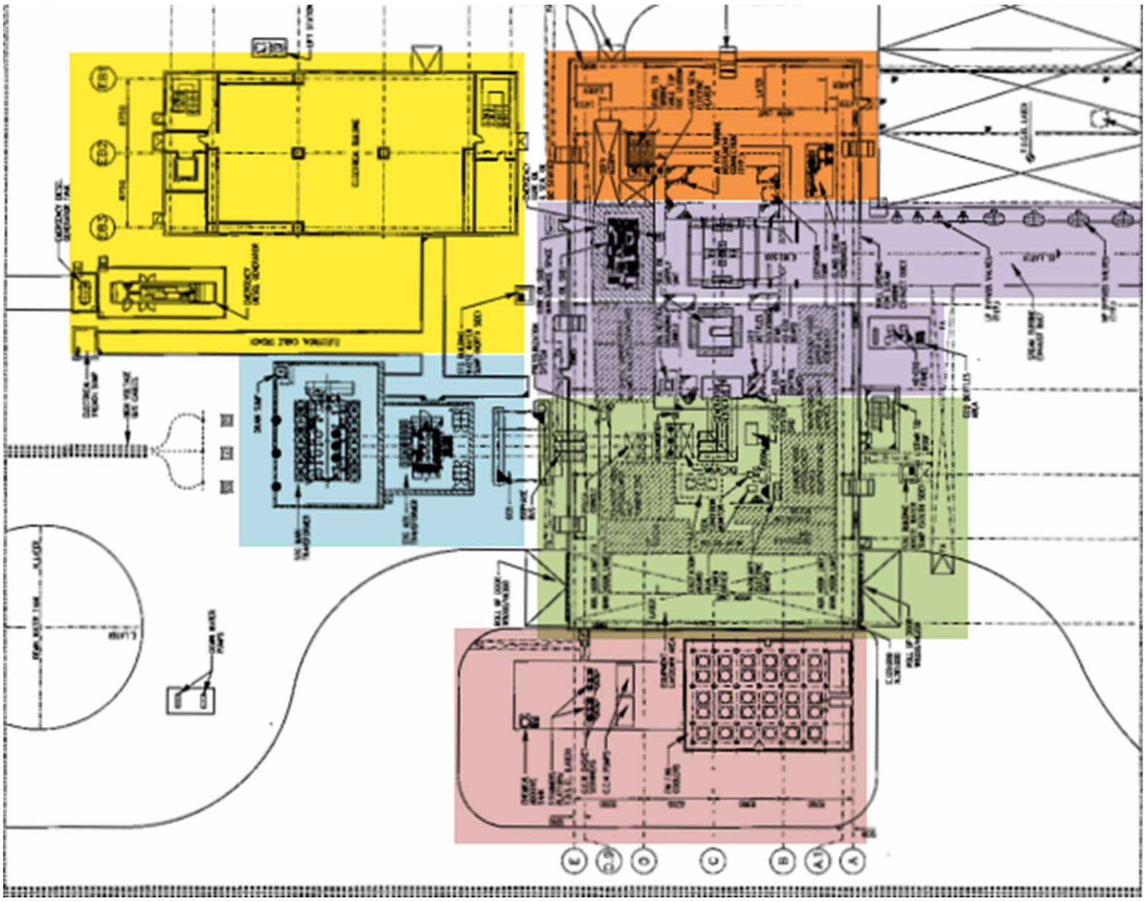


Figure 38: Combined Cycle Power Station divided in 6 areas (working document of the author)

The project manager can access all the visual panels for all levels. An example for visual panel for the project's level is illustrated below in figure 39.

Area number 5 on this visual panel is color coded in red to indicate an emergency. The project manager can go to more detailed levels by clicking on A5, which directs him to the A5 visual panel. Hence, the project manager can get acquire detailed information on the exact system that has the emergency from the A5 panel.

Week 1			Week 2			Week 3			Week 4			30-60 Lookahead			60-90 Lookahead			90-120 Lookahead		
A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3
A4	A5	A6	A4	A5	A6	A4	A5	A6	A4	A5	A6	A4	A5	A6	A4	A5	A6	A4	A5	A6

Figure 39: Visual Panel of the Project

Using the same approach, the project manager can access the subsystem panel until he is directed to the WTP which has the emergency, just with some clicks on the computer.

7.6.2.2 Visual Panel for Area Level

The visual panel on the area level reflects the work status of all the systems in the different areas. Visual panels of the respective area can be accessed by the area manager. So, he can acquire information on the current work status of the different systems, subsystems and WTPs in the respective area. As shown in figure 35, area-5 is focused on for more detailed illustration. 6 different systems of the area are highlighted in different color codes. The visual panel shows that S1 is the system in area-5 that has an emergency. The area manager can go to more detailed levels with clicking on the panel. In the example, the air cooled condenser (A5) of the combined cycle power plant is broken down into 6 systems: the steam duct system color coded in yellow, the Condensate system color coded in orange, the Steam manifolds system color coded in dark green, the vacuum system color coded in blue, the electric distribution system color coded in pink and the Fans system color coded in light green.

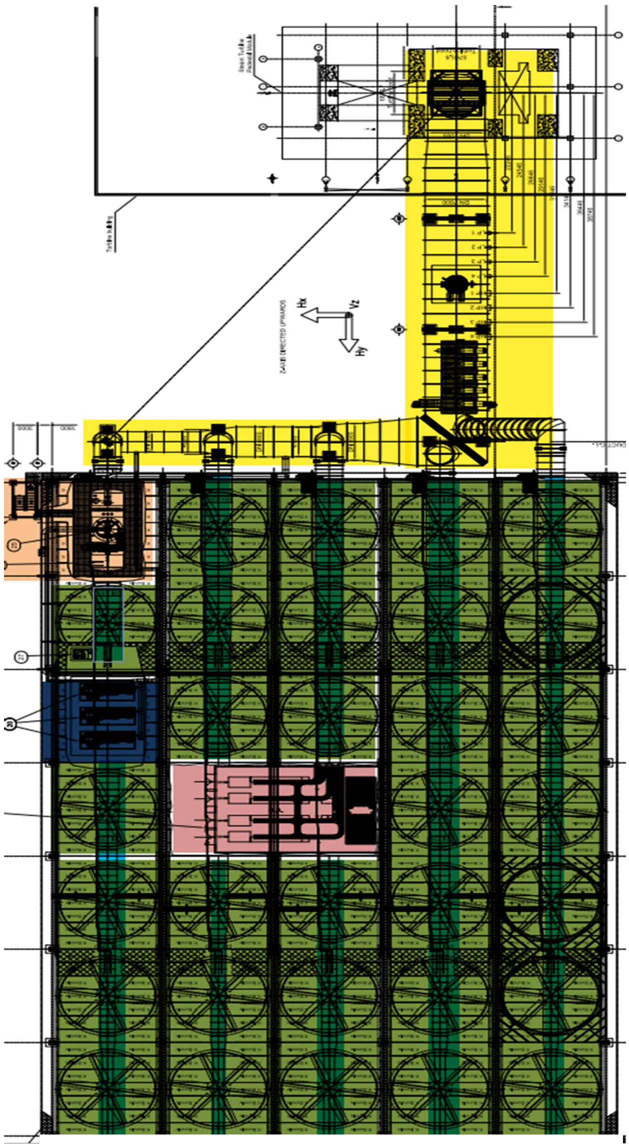


Figure 40: Area breakdown into systems, here an Air-cooled Condenser broken into Systems (working document of the author).

Week 1			Week 2			Week 3			Week 4			30-60 Lookahead			60-90 Lookahead			90-120 Lookahead		
S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
S4	S5	S6	S4	S5	S6	S4	S5	S6	S4	S5	S6	S4	S5	S6	S4	S5	S6	S4	S5	S6

Figure 41: Visual panel of the area (A5) (developed by the author, 2020)

7.6.2.3 Visual Panel for System Level

This visual panel reflects the system level, that illustrates the work status of all subsystem levels. All panels in the system level can be accessed by the superintendent can access all panels within the system. He can acquire detailed information on the work status of each subsystem from the visual panel.

In this system level, the constraints start to be placed. The main repetitive constrains in most of the construction phases are the work status of drawings issuance for construction, work permits from safety department as well as material availability. The constrains are placed by the engineering, procurement, and material management to be assessed by the responsible general foreman and superintendent. In this way, all stakeholders remain on the same awareness level and commitment. During the 90-120 days lookahead planning, the constraints and their handling are discussed and updated on the visual panel. All the stakeholders can access this level of details on the panel to monitor the level-3 task package status. The completion of WTPs as planned assures a smooth requirement of resources.

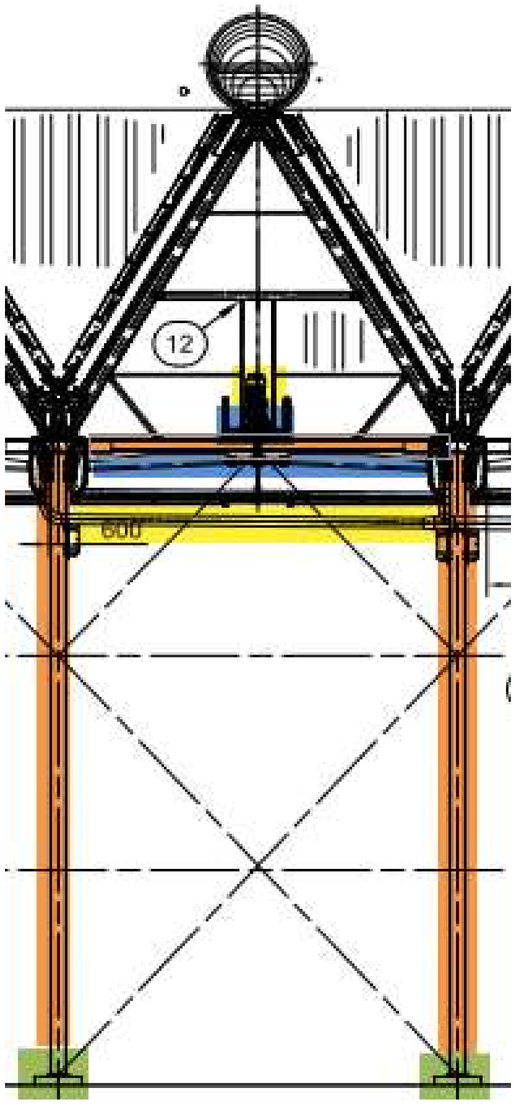


Figure 42: S1(Fan) divided into subsystems (working document of the author)

On this system level, one fan is taken as an example for system 1, which is broken into further sub-systems of disciplines. It can be observed that D5 is the one with the emergency. The disciplines in this system can be among others civil, steel structure, mechanical components like gearboxes, fan assembly, electrical, control and coating.

Week 1			Week 2			Week 3			Week 4			30-60 Lookahead			60-90 Lookahead			90-120 Lookahead		
D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
D4	D5	D6	D4	D5	D6	D4	D5	D6	D4	D5	D6	D4	D5	D6	D4	D5	D6	D4	D5	D6

Figure 43: Visual Panel of the system (S1)

7.6.2.4 Visual Panel for Subsystem Level

In this Subsystem level, different WTPs can be monitored and controlled on the visual panel. As illustrated previously, during the execution week the WTP responsible of is notified with the upcoming WTP. The responsible ensures that all the constraints are removed and that no obstacle for the WTP continuous progressing exist. Usually, the responsible works with the aim of turning the WTP into a yellow (challenged but on time) or green (smooth working) color code. During the installation week on the construction site, the affected WTP color can change according to the real work status. Below, the example of the subsystem visual control panel shows the mechanical subsystem level (D5) of the fans system (S1) in the air-cooled condenser area (A5) (see figure 44 and 45). It is now possible for the project manager or other responsibles to observe easily that WTP3 is the one with the emergency by clicking through the visual panels.

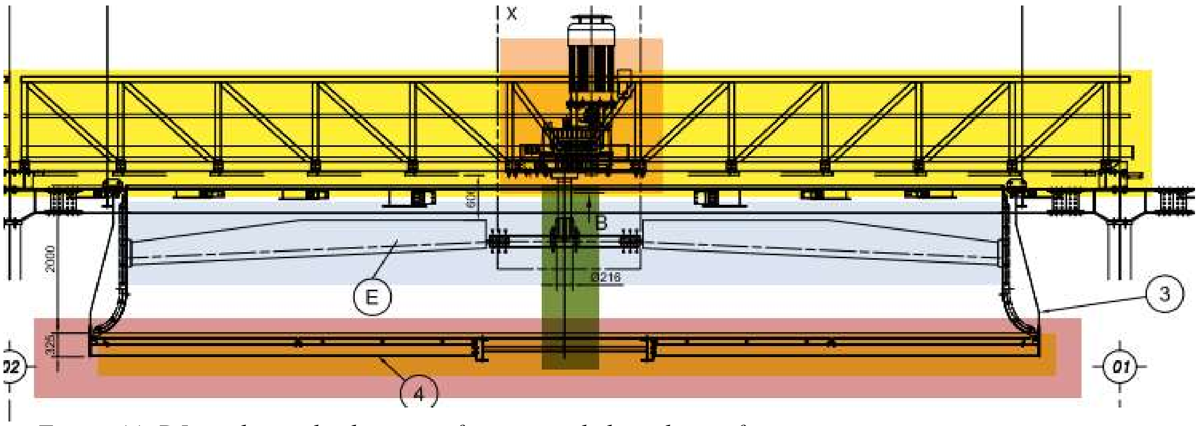


Figure 44: D5 mechanical subsystem of an air-cooled condenser fan

The 30 days lookahead plan can be updated every week using the WTPs work status acquired from the subsystem visual panel. The work status of a completed WTP is demonstrated by the blue color code.

Week 1 (Execution week)		
WTP1	WTP2	WTP3
WTP4	WTP5	WTP6

Figure 45: Visual panel of the Sub-system (D5) (developed by the author, 2020)

The following chapter proposes a digitalized tool for EPC projects' reporting and control. The digitalized tool gathers the work status systematically and automatically with very low effort and cost while enabling a high speed, accuracy and efficiency for reporting and control.

7.7 Digital Monitoring and Control Tool

As mentioned before, digitalization is no longer a futuristic or distant idea but rather necessary for today's work dynamics. Nowadays, digitalization exists broadly in our daily life from buying our metro ticket, through the arrival times of the train to the expected arrival to our destination. Such digital services, that facilitate our daily life are provided by user-friendly mobile applications. Similarly, the digitalization of work processes can also facilitate our work experience by saving time and effort, if provided with user-friendly applications and software. This also applies to the sophisticated and complex work processes of the construction industry.

The main aim of the proposed digitalized tool is increasing the proactivity and flexibility of the proposed lean project control model. The tool seeks to accurately reflect the WTPs real time status on site, which aims to help the decision makers to control the project in a proactive manner. Depending on the primitive and conventional reporting and control channels, such as fixed-date meetings, where on-site workers report on the work status, only increases the non-added value time and the wasted effort. The conventional reporting channels and control channels may even increase the project's cost by requiring extra resources for data gathering and reporting – for example human resources for updating the above proposed visual control panels.

To avoid the above mention drawbacks, digitalization can be utilized. This research proposes the development of a user-friendly mobile application linked to a database for reporting and control of EPC construction projects. A mobile application can be easily used by foremen and requires no extra devices than the regular smart phone any foreman possesses. The mobile application is linked to a database containing the project's visual control panels including the WTPs.

A foreman gets a notification on the mobile application with the upcoming WTP, one working shift in advance. This enables him to access his upcoming WTP to help him with the daily-work scheduling. The foreman gets notified with the upcoming WTP, only when the respective constrains are removed. The WTP notification, which now appears on the responsible foreman's mobile application, provides him with a link gives him accessibility to drawings, working procedures and standards, approved work permits, 3D model and any other helpful working documents. While providing foremen with such documents is not the main goal of the digital tool, this is considered an extra beneficial feature.

The main goal of this digital tool is to enable every foreman to report on the work status in of his WTP real time. The real time work status reported by the foremen on the mobile application is gathered in the database and reflected on the subsystem visual panel. Thus, the reported real time work status is rolled-up on the upper levels and gets reflected on the other levels' visual panels – system level panel, area level panel and project level panel.

The following is a possible interface for the reporting mobile application developed exclusively by the author (see figure 46).

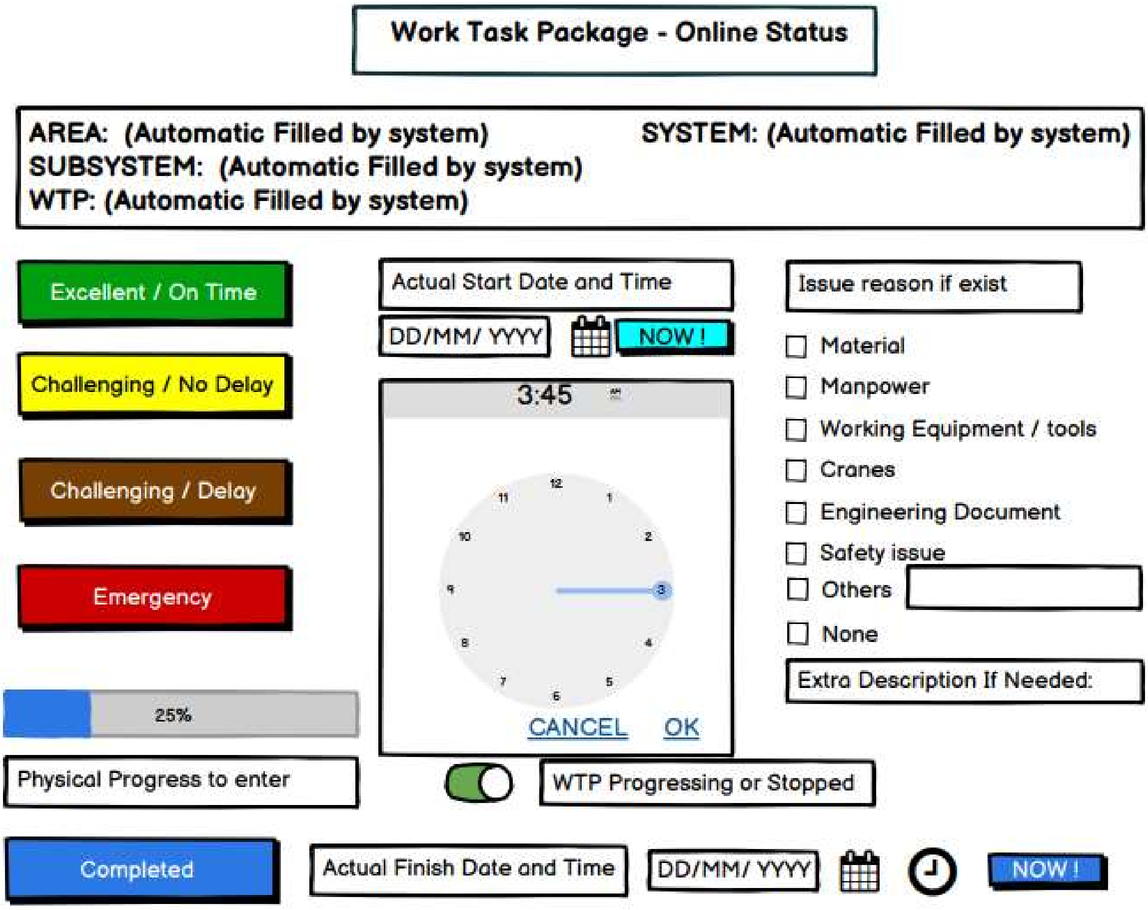


Figure 46: Digital Tool for Reporting and Control – Mobile Application Interface (developed by the author using "Balsamiq" software, 2020)

Figure 46 demonstrates the application interface, that appears on the foremen mobile phones. The above demonstrated real time status form is automatically sent to the foreman's mobile phone to notify him on the upcoming WTP one working shift in advance. The proposed digital tool automatically generates the notifications based on the 30 days lookahead plan, which is linked to the database, which is linked to the mobile application. The notification also automatically indicates the area, the system, and the subsystem of the respective WTP.

The notification contains the above demonstrated interface that enables the foremen to report the real time work status of the respective WTP. When he starts working on the WTP, he can easily report the actual start date and time manually or by simply clicking on the respective button – clicking on the "**Now**" button automatically reports the start date and of the work. The foreman can also report the exact date and time of the work completion either manually or by simply clicking on the "**Completed**" button followed by the "**Now**" button.

The reporting of all foremen done on their mobile application is collected by the database and reflected on the execution schedule. Another option is that mobile application reporting gets directed via the database to the project control responsible to be amended in the execution plan manually.

Besides, the “WTP Progressing or Stopped” button automatically turns into a green color, once the WTP start date and time are entered. If a foreman has to stop working on site for any reason, he is obliged to click on the “WTP Progressing or Stopped” button, so the “Stopped” mode is activated and the green color is turned off. Once he can proceed with working on the WTP, he is obliged to click on the same button again, to activate the “Progressing” mode, where the green color is turned on.

On the left-hand side of the application’s interface, the foreman can easily and automatically update the WTP work status by clicking on the different buttons.

- The “**Excellent**” button reports that the work is advancing smoothly and on time or even earlier than planned.
- The “**Challenging/ No Delay**” button reports that the foreman is facing some problems or challenges in the execution but still he expects to finish the WTP on time. In such a situation, some attention and closer monitoring is needed for the WTP especially from the superintendent.
- The “**Challenging/ Delay**” button reports that the foreman is facing problems or challenges in the execution and the WTP is expected to get delayed. In this case, much closer monitoring and assessment is needed and a solution needs to be developed by the responsible stakeholders. A root cause analysis as well as the documentation of lesson learned are also necessary in such a situation.
- The “**Emergency**” button reports the occurrence of an emergency situation in the respective WTP. Urgent interference of the management is required in such a situation as well as recovery plan development, root cause analysis and lesson learned documentation.
- In the “**physical progress bar**”, the foreman can report the actual physical progress of the work by entering different progress percentages in the.

The work statuses reported by the foremen through the mobile application are gathered by the database and visualized automatically and in real time on the different control panels of the different project’s levels – starting at the subsystem level and ending at the project’s level. The real time work status on site can be then easily accessed from the project manager, the departments mangers, the areas and disciplines managers, the project and site Engineers as well as the superintends through the visual control panels. Hence, the different stakeholders can easily have a detailed overview on the real time work progress on site, which shifts their decision and control mode from the reactive to the proactive mode.

On right hand side of the application's interface, the foreman can report a feedback on issues and problems to be communicated with the responsible stakeholders. The foreman can choose the type of the issue or problem by clicking on different buttons. He can also add a more detailed description of the issue in the "**extra description**" tab if necessary. This feature enables channeling a valuable and detailed feedback on issues and problems to facilitate a smooth development of the solution. The foreman can choose from the following buttons that reflect different reasons for issues and delays:

- **Material** issues: for example, shortage on bolts needed for steel structure erection. The material management responsible receives a notification to undertake a quick and accurate corrective action.
- **Manpower** issues: for example, shortage of manpower. The responsible person such as the superintendent or general foreman receives an immediate notification. Thus, the responsible person can easily and quickly re-allocate human resources between WTPs according to the current need to solve the issue.
- **Working Equipment/ tools issues**: for example, shortage or malfunction of welding machines, manlifts or ragging tools. The responsible person such as the material management foreman receives an immediate notification and is able to react faster saving no-added value time. This avoid extra communication channels to keep a continuous workflow with no stoppage.
- **Cranes** issues: for example, no availability of the cranes in the working area. The responsible person such as the material handling supervisor receives an immediate notification that allows him to act promptly to solve the problem and keep a none-stopping workflow.
- **Engineering documents** issues: for example, discrepancy between the engineering drawing and the reality on site or missing information on the drawing. The responsible person such as the project designing Engineer receives immediate notifications that allows him to respond to the foreman's needs promptly without wasting no-added value time or stopping the workflow.

- **Safety** issues: for example, missing safety equipment. The responsible person such as the safety officer receives an immediate notification that allows him to respond to the foreman's need immediately and accurately with the right solution.
- **Other** issues: the foreman can report the occurrence of any other issues flexibly by clicking on this button. He can report more details of the issue in the "extra description" tab. His line manager receives a notification immediately and gets informed about the issue in an accurate and direct way. The line manager can redirect the notification to the responsible person and cooperate with him on solving the issue.

All the notifications of any reported issues and problems are also sent to the foremen's line managers to keep him updated on the work status in real time. As mentioned previously, the work statuses of all WTPs roll up on the different levels of the project to keep all the responsible stakeholders updated on the work progress in real time and enable them to control the project in a proactive manner. Hence, proactivity of the control system guarantees a continuous workflow without stoppage or non-added value time.

The work statuses gathered from the mobile application by the database software are used to update the execution general schedule automatically or manually. The execution general plan is then used to update the lookahead plans needed for monitoring and controlling the project. Besides, the work statuses gathered can be used for creating project performance analysis such as analyzing the completed work percentage of WTPs from compared to the planned ones within a certain duration. Also, the physical work progress percentage reported by the foremen can be analyzed in comparison to the planned progress. Hence, the proposed digital saves enormous time and resources utilized for data gathering and reporting.

7.8 Measuring the Performance of the Model

As mentioned at the first pages of this research, the main indicators of a project's control system success are mainly the cost and schedule competitiveness of the project. Whether a project has been accomplished on the planned time (or earlier) with the planned cost (or less) is the strongest indicator to the success or failure of the control system used in the project. However, the thresholds of a project's failure and success also depend on the nature of the project, the location of the project, the industry's market, and a lot of other internal and external factors of the project. For example, due to the current circumstances of the corona pandemic, most of the Oil & Gas projects are suffering from extreme delays and cost overruns due to the social gathering and travel restrictions as well as the oil prices' deterioration.

In this case, the project's "bad" performance is caused by external factors, that project responsibles can have no influence on. Therefore, it is very difficult to set thresholds for the failure or success of a project that consequently indicate the efficiency of its control system. There is the general guideline developed by (Edward W. Merrow, 2012) illustrated on page 4, that determines failure and success thresholds of projects and thereby the malfunction of their control systems. However, this is just a guideline as the failure or success of project depend on various factors and conditions and developing unified thresholds for the success or failure of all EPC project very difficult if not impossible. Therefore, the following only highlights some methods, that can serve as indicators for the performance of the proposed control model.

As it has been constantly mentioned in this research, the main goal of the proposed model is enabling a proactive control of EPC projects to save any wasted non-added value time and efforts. This goal is considered when setting the following measurement method of the model's performance. The aim of measuring the performance of the proposed model is evaluating whether the model fulfills its aim and promised outcomes or not.

7.8.1 Steadiness of Workflow

The steadiness of the workflow indicates the proposed model's ability to absorb unforeseen work issues and guarantee an uninterrupted workflow by enabling proactive project control.

The steadiness of the workflow can be measured by evaluating the WTPs' work statuses from the panel. The project control responsible can compare the WTPs with an excellent (green) work status to the total number of working WTPs. Another option is also comparing the WTPS with a challenging status (yellow and brown) or an emergency status (red) to the total number of working WTPs. A high number of yellow or brown WTPs indicates that attention of the responsible persons is needed for analyzing the root cause and finding solutions, while the occurrence of one or more red WTPs needs an urgent intervention form the management.

The following thresholds can be used as a guideline when measuring the model's performance by looking into the steadiness of workflow.

- more than 75% green WTPs → excellent performance of the model
- 60% to 75% **green** WTPs → good performance of the model
- less than 55% **green** WTPs → not favorable performance of the model

- 15% to 25% **yellow** WTPs → good performance of the model
- 30% to 35% **yellow** WTPs → weak performance of the model
- 5% to 15% **brown** WTPs → good performance of the model
- 20% to 25% **brown** WTPs → deteriorating performance of the model
- more than 0% **red** WTPs → very bad performance of the model

7.8.2 Percent Plan Complete (PPC)

Secondly, the PPC reflects the proposed model's capability of accomplishing the planned work on time by providing the responsibles of the project with proactive and real time monitoring and control tools. The PPC is a measurement tool that is used in the Last Planner System. It calculates the number of activities completed on time or earlier divided by the total number of planned activities in a certain time duration (Glenn Ballard, 2000).

- A positive (upward) slope between two PPC values indicates that the control model is performing in a very efficient.
- A steeply negative (downward) slope between two PPC values indicates that the control model is performing in a deteriorating way.
- Slight fluctuations of the slope around a rather high average of PCC values is very normal and indicates a high performance of the control model and its capability of absorbing the site issues by offering proactive and real time monitoring and control. Figure 47 below illustrates a practical example of PPC values fluctuating around an average of 61.9%, which indicates a good performance of the control system of the project.

Figure 47: Example of PPC Board

7.8.3 Constraints Analysis

Thirdly, the constraints analysis reflects the proposed model's ability to identify the most frequent occurring constraints on site, which prevent a steady workflow and cause an increased non-added value time. Performing a good constraint analysis shows that the project responsibles can identify the most frequent and impactful constraints on site in an accurate and smooth way. As illustrated previously, the proposed model enables the project responsibles to gain a deep insight on the on-site constraints as they are being channeled by the foremen's mobile application through the database to the visual panels and lookahead schedules.

If the control model is performing in an efficient way, the most frequent and impactful constraints and their reasons can be gathered and analyzed. Consequently, constraints data can be easily sorted and analyzed using a Pareto chart, to identify the most frequent and impactful constraints that have a negative influence on the workflow.

After analyzing those constraints and their reasons, solution development strategies are discussed and highlighted in the lookahead schedules meetings. Besides, a comparison of the respective constraints should be performed within a fixed time interval to guarantee the efficiency of the developed solutions. If the constraints are reduced or are being eliminated before reaching the surfaces it means the proposed control model is exactly accomplishing. Figure 48 below illustrates an example of such a variance analysis.

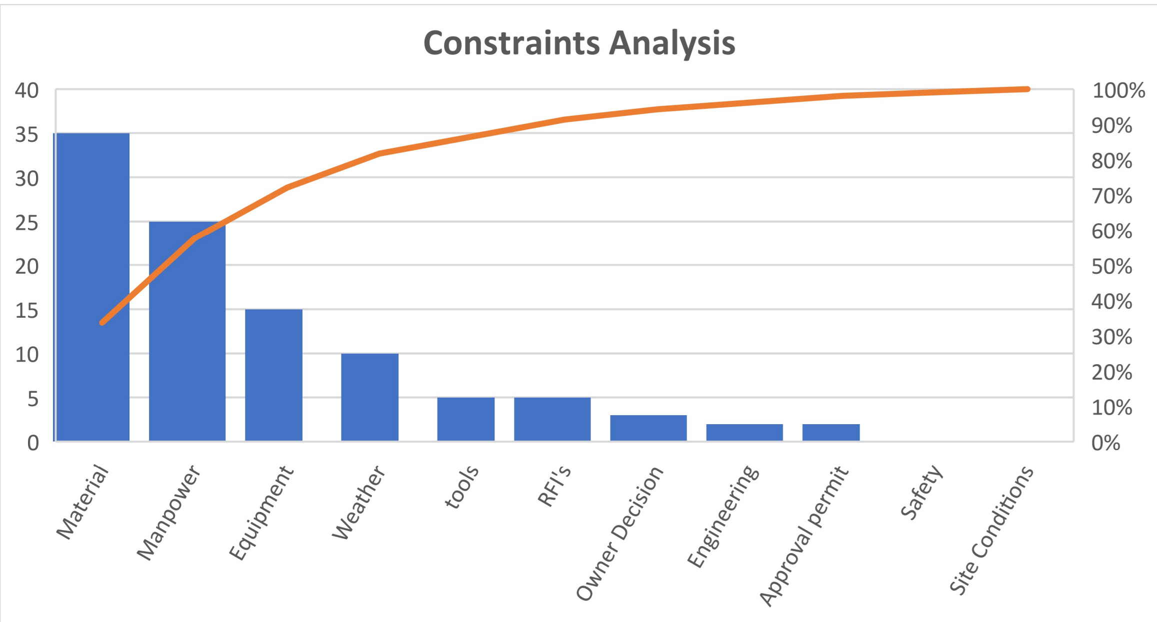


Figure 48: Example of Constraints Analysis (developed by the author, 2020)

7.8.4 Availability and Utilization of Resources

The availability and utilization of resources is an indicator for the proposed model's capability of optimizing the usage and allocation of resources in the project as it offers control system that minimizes the waste of resources and time.

As illustrated below in figure 49, the downtime and idle time can be used to easily calculate the equipment's availability and utilization. The same concept can be applied to calculate the availability and utilization of different types of resources.

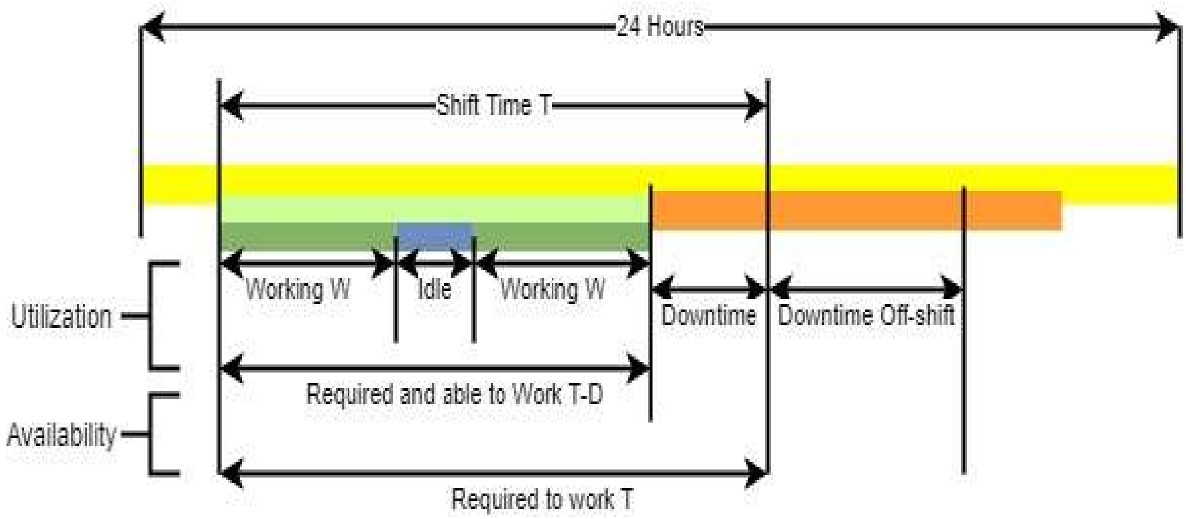


Figure 49: Illustration of Availability and Utilization (developed by the author, 2020)

7.9 Advantages of the Proposed Model

The proposed mode with its integrated live monitoring and control system definitely has more advantages than conventional control systems described previously in this research. The following advantages are the most important ones of them:

1. The proposed control model makes the respective foremen along with experienced general foremen responsible for developing the WTPs. In this case, the work executers themselves who are very aware of the work details take responsibility for developing the WTPs. On the contrary, in other control systems like the AWP, the workface planner who is not familiar with the WTPs and not aware of their details is responsible for developing the IWP. Aside from providing the foremen with a sense of ownership and organizational involvement, it enables the development of WTPs based on a detailed background and awareness of the actual on-the-ground status and work details. The sense of ownership that the foreman gain by developing the WTPs can keep them committed to the best practices and standards they developed by themselves.

2. The proposed control model enables all stakeholders to contribute to the monitoring of the work status on the different levels in real time. Consequently, constraints are overcome quickly and more efficiently while the practitioners are provided with the advantage of proactivity rather remaining be caught in the reactivity mode.
3. The proposed control model recommends the conduction of a Critical Chain Method rather than a Critical Path Method for creating the execution plan. This provides the project with the ability to absorb any time slippage that occurs. Besides, it allows an increased safety for the scheduling while using limited resources of the project.
4. The proposed control model allows real time monitoring of all the project's levels. This enforces better integration and coordination between the entire project's execution team as well as improves the project's capability to absorb any unforeseen issues.
5. The proposed control model encourages to have everything on site when it is needed, to assure the optimum allocation and levelling of resources on site – which is usually a challenge in EPC projects. This can be realized by integrating the pull approach as recommended by the proposed model and consequently decreasing work in process, reducing inventories, and enhancing the utilization of the equipment on site.
6. The proposed control model recommends adapting the lessons learned to the best practice of the project, which are then used for the execution of the remaining WTPs. This provides the model with a "mistake-proofing" advance and thus prevents the occurrence of repeatable mistakes and consequent wasted time and resources.
7. The proposed control model entails the digitalization of the monitoring and control process of EPC projects. This makes the task of real time reporting more efficient and effortless and saves many resources that are normally allocated for the reporting process.

From the above-mentioned facts, it is certainly clear that the proposed control model brings many advantages and benefits for controlling EPC projects compared to other conventional control systems.

8. Conclusion

This research shows that the construction industry is in a pressing need for the continuous development of the control systems used for managing the EPC projects particularly mega and capital projects with high complexity and large scope of work. EPC projects are in crucial need of proactive control systems that guarantee on time delivery while maintaining the required quality and minimizing the waste of resources. The prolonged failures of EPC projects that are mostly triggered by ineffective conventional control systems are threatening the profitability of the construction industry especially in the wake of massive investments taking place in the industry.

This paper responds to the industry's demand of developing proactive and waste minimizing control systems that enable executers to control their projects efficiently. The supply gap of efficient controls systems is being filled by the contribution of this research. It proposes the application of lean principles in EPC control systems to allow real-time project control and monitoring, that can flexibly absorb unforeseen challenges. This is achieved by developing a lean based project control model.

This model mainly proposes the application of an integrated breakdown structure of the project's main elements – work scope, organization, and cost –. This helps drawing the boarders of the responsibilities within the project and provides a structured view on the project to enable an efficient control. Besides, it provides the executers with ownership and organizational involvement. Moreover, the model proposes the gathering and documentation of lessons learned as well as adapting them in the company's best practices for the purpose of continuous improvement and prevention of reoccurring challenging. Furthermore, the model proposes an efficient lifecycle of the project WTPs to assure continuity of the workflow as well as to guarantee optimum utilization of resources and thus an increased productivity. Besides, the model proposes sustaining a so called 'pull' flow system that optimizes utilization of resources and minimizing the inventory. Furthermore, it proposes a proactive and real time control and monitoring of the project by using color coded visual panels that reflect the actual work status at the different project levels. The center piece of the proposed lean model is a digital control tool that facilitates bottom to top reporting. This achieved by the means of a user-friendly mobile application that is linked to a smart database, which channels the actual work status to the visual panels. The real time reported work status gets also reflected on the execution project schedule. Consequently, project stakeholders enjoy a proactive mode of control and are able to undertake necessary improvement actions to sustain a noninterrupted workflow.

This paper recommends some tools for measuring the performance of the proposed control model: workflow steadiness indicator, constraints analysis, percent plan complete and resources utilization indicator. These indicators can provide practitioners with an estimation of the proposed system performance.

All In all, the proposed lean control model proves to have advantages over other conventional systems. It allows a real time monitoring, proactive control and “mistake-proofing” of projects.

9. Limitation and Recommendations

As any other research, this one has some limitation too. Firstly, this research is built on the idea that a project's success or failure highly depends on the control system used in it. While this reflects a big part of reality, the success or failure of projects might be also caused by other internal or external factors. A recent example for this is the "bad" performance of current Oil & Gas EPC projects caused by the work restrictions due to the global corona pandemic. It is recommended for future research to investigate other factors that have an impact on EPC project's success and failure.

Moreover, the best way for evaluating the efficiency of a control system is implementing it in reality and observing its performance. The proposed control model has not been applied yet in practice to an EPC project. Therefore, some modifications or advancements might be considered when the proposed control model is applied in practice. The application of the proposed model in practice would most probably uncover lesson learned and best practices as well as advancement possibilities for its implementation. It is therefore recommended for future research to study lesson learned, best practices and advancement possibilities of the proposed model once its applied in an EPC project.

Finally, measuring the performance of the proposed model is based on the author's expectations built from his professional experience and deep research in the field. When the proposed model is applied in practice, some better measuring methods for its efficiency and performance might occur. It is therefore recommended for future research to review the performance measuring methods of the proposed model and modify it if needed once the proposed model is applied in practice.

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