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# Practitioner's Section

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## Flawless Start-up of Production Plants in Process Industries: The Link between Successful Project Performance and Optimal Future Operations

**Process plant start-up is a key element in the transition from the project phase to business operation. A proper start-up phase ensures safe and reliable process plant operations. When project start-up tasks are not properly considered, they can become activities performed at the end of a project with no clear acknowledgement of ownership. Failure to take start-up considerations into account in all project phases can have serious negative effects on net present value for a prolonged period of time over the total asset life cycle. To ensure project success, the start-up phase must be supported by those participating in both the project and business teams, and this starts with confirmation by top management that plant start-up is a fully-fledged project phase. This study presents the challenges that are most common within the process industry and can be solved or mitigated with adding proper actions and implementations into project management and execution processes. Providing a valuable contribution to the knowledge around start-up of new process plants, the study is based on experience based empirical observations and a comprehensive literature review.**

## 1 Introduction

There are many examples in which the projects of process plants and assets lack intentional goals for start-up and initial operations. Often the main performance indicators in projects include their scope, time, and budget, as established in policies and contracts. These performance indicators are focused solely on the project execution (Leitch, 2004). The most important goal of a project is its intended result. Owners, operators, and/or shareholders want revenues, as agreed, once the project has been delivered. To look beyond the project and examine the relative success of the operations or production phase after start-up, research (EY, 2014; Bagsarian, 2001; Lager, 2011) reveals unnecessarily long periods of underperformance or compromises in safety (Davies et al., 2009). Underperforming efficiency in the operational phase due to improperly executed projects requires innovative measures that promote improvements. Apart from underperformance, i.e., failure to reach on-specification (nameplate) operations, there is also the increased risk of harm to both humans and the environment when projects are not executed and delivered properly (Wallsgrove, 2015). Shortfalls with respect to process-plant start-up frequently result in prolonged periods of

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underperformance. In contrast, there are also examples of industries and companies that have given proper attention to start-up during all project phases.

This study describes and analyzes why commissioning and start-up are often underestimated and undervalued. Then, the fundamental measures and approaches are identified that will facilitate the success of commissioning and start-up in process-industry projects. Process industries are found in a wide range of industrial sectors, including petrochemicals and chemicals, food and beverages, mining and metals, mineral and materials, pharmaceuticals, paper, and steel (Lager, 2017). Although the oil and gas industry is often categorized as separate industries, in this study, the oil and gas industry is ranked as one sector of process industries. There are many differences among process industries, including distinct differences among production and operation processes with respect to production volumes, complexity, business model strategies, and low and high technologies. There are also commonalties among process industries, in that the production processes are often complex, capital intensive, hazardous, and under continuous production. These commonalities are factors that make a successful start-up important. For example, unplanned shutdowns in a continuous production process can be extremely costly and difficult to rectify.

Planning and execution of a plant start-up as an integrated project activity do not always occur. Often, only some level of commissioning activities are executed and start-up is left to the operations department with no substantive preparation. This study focuses on process-plant start-up as a project phase that must be fully developed and integrated.

The authors of multiple studies have specified the difficulties associated with project delivery, budget, and planning. Often these studies have focused on mega projects and suggest ways to address problems or improve project methods and approaches (O'Connor et al., 2016; Davies et al., 2009, Burke and Kirkham, 1993, Bush et al., 2000, EY, 2014). The transition from project to operating status, with start-up as a key element, requires that technical and business objectives be addressed during early phases of the project. As early as the project definition phase, planning and development of strategy and contractual requirements for transition to operations should be established.

Start-up is often carried out by the operations team with support from the commissioning team in accordance with a jointly prepared start-up plan. The start-up proceeds by ramping up and realizing the product qualities and production rates outlined in design documents and specifications. Commissioning is the heart of the start-up phase (Lewton, 2006). Failure to include or including only minimal commissioning and start-up activities in a project can have serious safety or environmental consequences. During the start-up and production period, flaws can emerge that can cause long periods of lost revenue or worse (Lawry and Pons, 2012; Killcross, 2012). Flawless production-plant start-up contributes to a smooth transition from the project organization to business operation. If commissioning and start-up are successful and production output is as anticipated, the project as a whole will be a success.

The objective of this study is twofold. First, it is important that process industries create a thorough understanding and awareness regarding the start-up phase of a project. Adequate acknowledgement by and the provision of knowledge about this phase within top management will ensure that the project start-up phase will be accepted by all stakeholders as a genuine project phase with its own related processes. Often, what has been lacking is a distribution of knowledge regarding the benefits of giving adequate consideration to project start-up among stakeholders. Apart from addressing the lack of necessary insights for improving the start-up experience in projects, acknowledgement and support by senior management must be promoted. The second objective of this study is to promote more research and data gathering to build reference models to facilitate the appropriate incorporation of start-up in projects. Examples include collecting reference data from executed projects and establishing models that support the provision of resources, budgets, and scheduling requirements for commissioning and start-up within process-industry projects. This can be an explicit task for researchers because companies themselves often do not carry out enough projects to collect enough data and insight.

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## 2 Research Methodology

This study addresses a knowledge gap within projects regarding commissioning and start-up. The research for this study was conducted through a mix of literature review and empirical observations by the author, who has been active for many decades in the commissioning and start-up of industrial plants. Interviews with informants were also conducted. The interviews involved commissioning and start-up management issues sustaining the empirical data. Several illustrative examples are presented to support various issues and topics. The illustrative examples are all drawn from the author's project experience. No detail references have been added on purpose. Because no permission has been requested and the author's intention is not to discredit the involved projects.

Start-up in process industries is a project area wherein many improvements can be made and a knowledge base established. Collaboration between those in academia and industry can facilitate these improvements.

## 3 Overview of Barriers and Difficulties in Plant Start-ups

Process plants often face many problems during initial start-up and initial operations. Studies show that it can take much more time to reach on-specification operations or production levels than anticipated, disregarding the risks related to safety and the environment. (YE, 2014; Bagsarian, 2001).

In process industries, there is a wide variety in how project commissioning and start-up is organized. Some organizations have such a substantial project portfolio that they are justified in having permanent project staff in-house, some of whom are responsible for commissioning and start-up. In contrast and more often, many organizations have no project staff or only a small core project team, whose members have no or only basic in-house commissioning and start-up knowledge (Lager, 2011). Although project magnitude influences the scope of a start-up, this does not imply that the start-up of a relatively small project is less important. Small projects can have a large impact on company performance.

There are a wide variety of reasons why problems occur at plant start-up such that on-specification operations are not realized. This paper presents the challenges that are most commonly experienced by process industries (Bagsarian, 2001; Killcross, 2012; Wallsgrove, 2015; Merrow, 2011), which can be solved or mitigated by the implementation of proper actions in project management and project execution tools. The proposed improvements and solutions are presented in section 2. These problem areas are presented in the following subsections under the headings:

1. Lack of knowledge among project stakeholders regarding commissioning and start-up
2. Contract deficiencies that affect start-up success
3. Late commencement of commissioning and start-up
4. Lack of recognition of the start-up phase and supportive actions
5. Understaffing during the start-up phase
6. Uniqueness of projects and technologies

### 3.1 Lack of knowledge among project stakeholders regarding commissioning and start-up

Lack of knowledge and insights regarding project commissioning, start-up, and operational readiness processes are often the reasons why plant start-ups are not properly prepared for and executed (Bagsarian, 2001). When insight is lacking, it is not easy to assess, with sufficient justification, the value of considering commissioning and start-up factors early in a project. The causes and likelihood of problems during commissioning and start-up are then misjudged (Lawry and Pons, 2012). The following barriers and difficulties regarding plant start-up presented here can be considered to result from a lack of knowledge about effective commissioning and start-up.

Commissioning and start-up are no easy tasks within a project. This phase commences in a relatively short period of time toward the end of a project. In a multi-disciplinary environment, equipment is put into service for the first time and budgeting the start-up activities correctly is key. Planning must be meticulous and equipment experts must be present at the right time. Personnel with sufficient knowledge and experience must have been recruited. During project execution, unexpected problems and difficulties can occur along with an increase in the level of uncertainty.

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### 3.2 Contract deficiencies that affect start-up success

The usual project terminology regarding completion, testing, verification, and start-up can be ambiguous and a source of confusion that can result in improperly executed activities. A lack of knowledge regarding definitions and terms leads to misinterpretation and failure to meet contractual agreements. This lack of knowledge and likelihood of misinterpretation can be found in standard contracts or contract configurations that have been copied from previous projects that do not correspond with the actual project. Appendix I provides a glossary of terms. Besides the project milestones related terminology there are contractual and legal term used to define completion milestones. For example contractual complete, primary acceptance and final acceptance. The contractual and legal terms can lead to confusion if they are not matching the project completion terminology.

## Illustrative example 1: Lack of commissioning and start-up knowledge

In a large project organization established to deliver an onshore natural gas plant, with a budget of approximately €800 million, the need for a commissioning manager was acknowledged. The company that initiated the project had no in-house project knowledge or resources for a large project. A project team was fully established with the exception of a commissioning start-up manager. Several interviews were conducted but no suitable candidate was identified by the project manager and his deputy. Only when a candidate himself argued that he could perform this task did the interviewers accept that this person was the right candidate. This example illustrates that there is often a lack of substantive knowledge regarding commissioning and start-up within a project team. This lack of understanding increases the number of project risks and related consequences.

## Illustrative example 2: Contract misalignment

A mega-cross-country project for a natural gas pipeline in Turkey was executed using an engineering, procurement, construction and commissioning (EPCM) contract set-up. The EPCM contract and related subcontracts were in place prior to recruiting the project commissioning manager. When the commissioning manager came onboard and reviewed the project contracts, he found four different contract definitions of Mechanical Completion. This meant that the related contract holders all had to be dealt with according to different definitions. This type of inconsistency can lead to mistakes and misunderstandings. This illustrates the need for the participation of a commissioning start-up specialist very early in the project to ensure the provision of proper contractual input regarding commissioning and start-up.

The project scopes outlined in contracts are often solely focused on the schedule and budget. With attention being given only to these internal project deliverables (Leitch, 2004), the time and cost associated with commissioning and start-up are inevitably underestimated.

In many cases, project-related contracts are already in place when the commissioning start-up manager comes on board. To be able to make the right decisions regarding the establishment of appropriate commissioning and start-up procedures, it is essential that the commissioning start-up manager read contracts as one of the first activities when joining a project.

Often, process-plant project contracts lack focus with respect to agreements about the connection between the project and operations. This lack of focus makes it unclear who is responsible for the transition between project, start-up and initial operations phase. Frequently, the project team will deem a project to be finished after testing and inspection and the operations department expects a fully functional installation. At first glance, this seems acceptable, but if the operational expenditure during the project stage has not been taken into account, this can have significant negative

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effects on production efficiency (Powell, 2012).

Since the term process industry covers a large group of industrial sectors, the variety of contract models is correspondingly large. Each sector has its own preferences regarding the preparation, presentation, and standards of contracts. Even within one sector of a process industry, there can be a variety of preferences regarding contract types. For example, the same sector in different geographical locations can have different preferences regarding contractual formats and types.

Typical project-related contracts are fixed-price contracts (Barnes, 1988), which are also referred to as lump-sum contracts. To avoid costly changes, a lump sum (fixed price) approach requires careful definitions of scope when setting up the contract. There are several lump-sum contract arrangements, a popular one being engineering procurement and construction (EPC) contracts. Unfortunately, many projects executed based on a lump-sum contract experience significant cost overruns (Merrow, 2011).

In EPC contracts, risk and control aspects are substantially the responsibility of the contractor, including the risk of any cost overruns, and the contractor must usually provide a performance guarantee. EPC contractors are necessarily focused on avoiding risk and safeguarding their profits from a project. This set-up creates a lack of integration and contributes to disagreements among stakeholders (Davies et al., 2009). To avoid negative contractual or legal consequences, EPC contractors will determine which tests in the contract are most relevant to them and which are related to applicable rules and regulations (McNair, 2004). This can lead to situations in which the EPC contractor or its sub-contractors avoid certain commissioning activities, which makes the start-up phase a more separate and uncertain project activity (O'Connor et al., 2016; Leight, 2004; Davies et al., 2009). An EPC contractor receives the largest contract price payment, approximately 85%, at construction completion. Within this large contractual payment is the contractor's profit for the project. The retainer for the portion of commissioning and start-up activities in the contract price payment are only in the range of 5 to 8 percent, which is not much of an incentive for the contractor to expend a lot of effort.

As the name suggests with turnkey contracts, the operational team must only turn the key and the plant is expected to operate as specified. This implies that turnkey contracts include commissioning, start-up, and initial operations. When implementing a turnkey contract, it is recommended that the turnkey contractor be an experienced and licensed operator of similar facilities with extensive experience in start-up. The reasons for selecting turnkey contracts include the following: when a company is on a tight schedule, when the project is considered to involve low-risk technology, when a company has no experience with the selected technology, and when the company has insufficient resources to execute start-up activities. The possibility of encountering problems is often overlooked when selecting a turnkey contract in relation to start-up and on-specification operations (Bagsarian, 2001).

Nowadays, other contract forms are being developed. For example, contract owners tend to use reimbursable contracts, which also apply effective definitions of commissioning and start-up activities.

Examples of how deficiencies in contractual agreements affect commissioning and start-up are as follows. When commissioning and start-up activities are not well defined and not properly communicated, the construction department may not be fully aware of upcoming activities. When construction is completed, temporary construction facilities, such as accommodation and office equipment, are dismantled and taken away, without taking into account that the commissioning and start-up personnel must make use of these facilities.

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## Illustrative example 3: Contract responsibilities

A natural gas plant project in the Netherlands had established construction contracts with prior involvement of the commissioning and start-up manager or subject matter expert. The electrical and instrumentation subcontractor of the EPC contractor succeeded in establishing a contractual agreement whereby the contract scope ended at construction completion. This implied that no test activities had been performed upon delivery of the construction work. As a consequence, the pre-commissioning inspection and checks were not included in the responsibilities of the electrical and instrumentation subcontractor, and had to be executed by the company project department. Since deficiencies identified at pre-commissioning can often be traced back to poor construction activities, they should be the contractual responsibility of the contractor. The establishment of a better contractual strategy and set-up regarding roles and responsibilities in the delivery and scope of a project will enhance project efficiency.

### 3.3 Late commencement of commissioning and start-up

There are a wide variety of times in which a project's commissioning activities may commence, including, for example, during engineering, construction or when construction is complete. Starting the commissioning process when construction kicks off is typical. To be successful, the importance of establishing the correction project construction sequence has been recognized (Mukherjee, 2005). If commissioning and start-up preparation commences at construction project phase, there is no commissioning and start-up influence in the engineering project phase, with all its negatives consequences. For example, better commissioning and start-up can be achieved by taking into account the application of an extra process connection or an extra valve during the engineering phase. During engineering of the control system, it is very useful to ensure that test and start-up scenarios are programmed, for example, such that one process system is ready for commissioning and start-up and another process system is separate from and safe with respect to construction activities.

Apart from failure to incorporate design interference with respect to commissioning and start-up input, commencing too late also has consequences for the budget allotted for commissioning and start-up. Often, the allocated budget is not sufficient (Wallsgrove, 2015) when commissioning and start-up activities are scheduled to begin too late in the project.

The literature regarding the plant commissioning and start-up costs of process industries indicates that these costs range from 5 to 20 percent (Leitch, 2004; Mukherjee, 2005; Sheridan, 2015) of the overall capital cost of a project, when properly and thoroughly budgeted. This is a substantial amount of the overall capital expenditure, and this percentage depends on a wide variety of factors, such as the type and size of the project.

### 3.4 Lack of recognition of the start-up phase and supportive actions

Senior managers, directors, business leaders, and stakeholders all need to understand, recognize, and support project methods that ensure flawless project delivery and operations (O'Conner et al., 2016; Merrow, 2011). Lack of support regarding start-up and related project methods can occur during the construction phase if there have been no agreements made with respect to the preparation of commissioning and start-up. *Taking into account the early commissioning and start-up of utilities is often considered by the external construction contractor to be a barrier to completing the construction.* Given that construction management has more influence on resource and budgetary decisions, it can be difficult to persuade related contractors to adapt to commissioning and start-up methods if these have not been or were poorly incorporated into the contractual agreements (Killcross, 2012). A singular focus on project performance means that budget and schedule concerns can provoke nearsighted behavior. Many of the problems that occur during start-up can be related to earlier project phases and activities such as contract negotiations, engineering contractor performance, procurement specifications and pricing, construction workmanship, financial restraints, and operating group performance (Wallsgrove, 2015).

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### 3.5 Understaffing during the start-up phase

When a project's start-up preparation and execution is not properly acknowledged, there will be inefficiency in the use of human resources during both the commissioning and start-up phases, with negative consequences (Lawry and Pons, 2012). Both the correct amount of resources and the right personnel (Bagsarian, 2001) are important. Without a sufficient number of people involved in start-up, the workload of those involved becomes too severe, which can lead to fatigue, reduced effectiveness, and the increased probability of errors (Wallsgrove, 2015). The right people for the job implies personnel with commissioning and start-up experience.

Depending on the geographical location, one current issue is the difficulty in finding a technically skilled workforce (EY, 2014). Inexperience of the operational staff is one of the reasons that achieving an effective start-up and reaching specified production rates is difficult. An important aspect of the commissioning and start-up activities is the provision of training for operational personnel. The integration of operational staff and of staff from other departments in the business organization within a project team can also be difficult (Sparks, 2018). This is because, to a large extent, company departments work independently of each other. And those working in business organizations are typically already fully occupied.

During a project and in particular at start-up, staff from the operations department are often necessarily put into the position of doing tasks that they are not and cannot be fully qualified to perform and have seldom or never performed in the past. Their inexperience adversely affects start-up. As such, operations staff should have important input during the design process and planning for start-up (Wallsgrove, 2015).

### 3.6 Uniqueness of projects and technologies

The uniqueness of projects (Davies et al., 2009) means that often project execution cannot be managed using standardized methods for commissioning and start-up. To address this issue, there must be a good evaluation of a wide range of variables when developing a strategy and plan. Variables that influence the project approach include, for example, geographical location, company experience, organizational culture, and the use of new technology. Even if a project is a virtual copy of an existing plant or facility, there are variations to be taken into account. These include the likelihood that the project will be executed by different people and that companies may fall into the trap of copying previous project mistakes (Wallsgrove, 2015).

The characteristics of a project can have a large impact on the start-up duration and time taken to reach nameplate capacity (Bagsarian, 2001). Examples include when a project is a copy of previous projects or involves new technology (Bush et al., 2000).

The use of new technology in a project contributes significantly to the time needed to start up a process plant (Davies et al., 2009). If the impact of a new technology is disregarded in a project, the commissioning and start-up effort will become tedious (Lager, 2011). Besides the burden experienced during start-up, new technology can also be problematic in remote areas and harsh climates that make operation and maintenance more difficult (Powell, 2012). In addition to new technology, poorly selected or inadequately designed technology will further contribute to a problematic start-up that will then require an extended period of time to reach on-specification operations. Frequently, senior management is unaware of the impact of new technology (Wallsgrove, 2015) on the start-up, ramp-up, and operational performance.

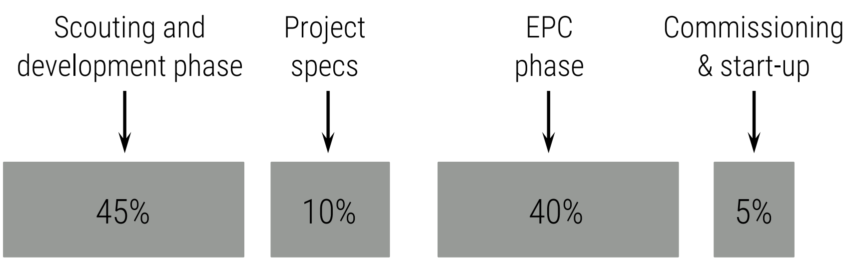


Figure 1 Flaws introduction in project phases (source: Sasol Ltd., 2008).

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## Illustrative example 4: Underestimating the influence of new technology

In a greenfield natural gas plant project in the Netherlands, the incorporated equipment included a substantial amount of new technology. The public relations department proudly announced that the development of the plant involved state-of-the-art technology, since the use of new technology by a project is viewed as positive. However, project stakeholders were unaware of the implications of introducing new technology in the project and faced multiple start-up problems, and it took a long time to reach on-specification operations. Introducing a new technology into a project means that more time is needed to obtain stable and on-specification operations. When this influence is recognized early in the project preparations, the related difficulties can be mitigated by adequate budgeting and the development of a realistic schedule. Alternatively, in the definition and selection phase of a project, the choice can be made to implement more proven technology if the economic advantages of the new technology are drastically reduced by costly start-up.

## 4 Proposed Improved Plant Start-up Work Process: The Right Way

Having assessed the main reasons for lack of adherence to a properly established start-up as a project phase, in the following sections, we present factors that improve the success of the start-up phase. Through better understanding and preparation, the problems that often occur during start-up and operational underperformance can be mitigated. Innovations in the project start-up phase and initial operations can enhance the financial returns of the operations phase (O'Conner et al., 2016; Powell, 2012; Burke and Kirkham, 1993). In addition to focusing on the organizational and technical aspects of commissioning and start-up, attention must also be paid to the preparations of the operations phase, including reviews of the project operability, maintainability, and availability (Powell, 2012). Issues related to the business organization should also be in place prior to start-up. The business-related scope to be addressed and implemented includes, among other things, operational and environmental permits, health safety and environmental procedures, infrastructure, finance, human resources, and information technology.

Start-up execution can be successful by understanding, preparing for, and acknowledging that this phase will involve time and money (Bendiksen and Young, 2015). When start-up and commissioning are considered throughout the project life-cycle, this helps to prevent or mitigate flaws that will only emerge during the execution of start-up and commissioning. More than 50% of flaws are introduced in the development and specification phases of a project (see Figure 1). If these flaws are not recognized and solved during the early stages in which the flaws first occur, the project will suffer delays and cost overruns (Sasol Ltd, 2008).

The challenges in achieving a flawless start-up and on-specification operations are multiple and ambiguous. To achieve success in planning start-up, safety, and expected revenues, the preparation and execution of start-up should encompass the key concepts presented in the following sections.

### 4.1 Acknowledgement by project stakeholders

First and most importantly, prior to implementing strategic project plans, insights regarding the realization of a sound commissioning and start-up phase must be shared with the company top management for their acknowledgement, support, and understanding (O'Conner et al., 2016; Bush et al., 2000). Implementing better strategies and methods with respect to start-up must be recognized as providing added value and must be supported by the top management (Busch et al., 2000, Leitch, 2004, Merrow, 2011). If start-up interventions and efforts throughout all project phases are not recognized or understood, they may be considered by top management to represent extra and unnecessary effort and investment. As such, it is important to obtain expert input on this topic in the early stages of a project. In organizations where process plant start-ups often occur, it is recommended that references be gathered of successful and unsuccessful projects to convey the importance of an adequate focus on start-up. In addition to acknowledgement from senior management, it is important that all other

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stakeholders be informed and trained accordingly.

### 4.2 Determine start-up strategies and select the start-up management team

Continuity and attention to commissioning and start-up throughout the project are paramount for keeping the determined project philosophies and goals clear and alive (Burke and Kirkham, 1993). The main focus of start-up is on the successful end result. Paying attention to start-up and taking into account the efficiency of a project start-up is not a new concept—Baloff (1966) presented a study of this subject more than fifty years ago.

All stakeholder and project disciplines involved should have one common project goal in mind across all project phases, i.e., start-up and operational readiness. Operational readiness, a project process common in the oil and gas industry, relates to the readiness process and includes technical operations and operational business that ensures proper preparation of the process plant business organization for on-specification operations (Powell, 2012).

In the project definition and feasibility phase, it is important that commissioning and start-up strategies be presented, discussed, and selected. In this early phase, decisions are made regarding the scope of contracts and the related budget and preliminary duration period. Budgets and duration periods in the early project phase can be determined in various ways. In early project phases, acceptable margins are often used for the budget and schedule. When sufficient attention is given to start-up, the chance of meeting the business goals within the anticipated period becomes more realistic (Leicht, 2004).

An innovative approach to achieving a flawless start-up requires that project start-up be given strong attention not only at the last minute but throughout the project life cycle (see Figure 2).

If the focus of a project is start-up and operations driven and the work processes are driven by the commissioning and start-up manager, much responsibility lies with the person who executes this role. Therefore, the necessary knowledge, experience, and qualifications must be carefully defined. A commissioning start-up manager must have a multitude of skills; he or she must be a leader, communicator, decision maker, and problem solver. This person must have multi-disciplinary technical knowledge and experience. Sound business and project insight and experience are also required. To indicate the versatility required and the amount of work involved, Appendix II presents a comprehensive summary of the activities associated with ensuring commissioning, start-up, and operational readiness for each project phase with regard to large projects and mega-projects (Horsely, 1997; Bendiksen and Yong, 2015; Killcross, 2012; Tuin, 2019). From the activities listed in Appendix II, it is clear that preparation is crucial to ensure that the start-up of a process plant occurs without any flaws or problems.

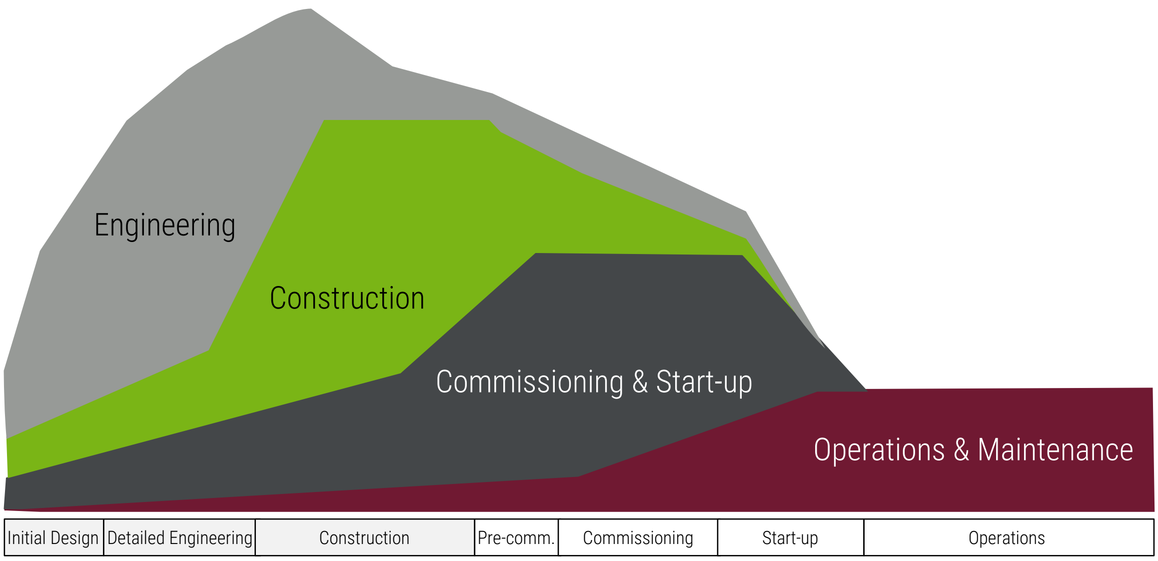


Figure 2 Start-up involvement throughout all project stages (source: Sasol Ltd., 2008).

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## Illustrative example 5: Conflicting interests amongst project stakeholders

In a new oil and gas production facility offshore in Qatar, a vendor representative was asked to perform commissioning activities. The vendor delivered process equipment to a construction company, who built the production facility in the Middle East. The construction company was responsible for delivering the offshore oil and gas facility to the operator within a specified period, which was fast approaching. The vendor representative performed the inspections, found that the installation was not ready for commissioning, and proposed necessary measures to reach readiness for commissioning. The vendor representative was then persuaded by the construction company to establish lenient acceptance criteria for the current state and to proceed with commissioning test activities. This case illustrates the underestimation of the requirements related to thorough testing. The primary focus of the construction contractor was the completion of the main scope of the construction and not on project commissioning. A different contractual approach would involve and ensure the interest of contractors in cooperating to achieve a flawless start-up.

Companies who include start-up and operational readiness as part of their project execution, according to the list in Appendix II, will have a good likelihood of success in process-plant start-up and reaching on-specification operations in the shortest possible time (Tuin, 2019). Ownership of the start-up and readiness factors that affect operational activities depends on the parameters of various project and business teams. Examples include project size, scope, and related in-house knowledge of the business organization. Large organizations can more easily assemble project teams that can work continuously on a project. Operational organizations must have flexibility to adapt to the changes that come with a new plant or installation (Biery, 2015).

### 4.3 Define the contractual terms with a strong attention to start-up

Contractual set-up and execution are significant factors in achieving a successful plant start-up and reaching on-specifications operations. Different types of projects demand different contract approaches to commissioning and start-up (Lawry and Pons, 2012).

To devote more attention to successful project delivery and its subsequent flawless start-up and on-specification operations, there must be full cooperation and integration among contractors and other project stakeholders (Davies et al., 2009). Rather than trying to predict and establish all risks in the contractual agreements, it is recommended that risks be shared with the contractors and their genuine cooperation be obtained. The approach involving cooperation, integration, and risk-sharing calls for a matching contract strategy (Davies et al., 2009; Leitch, 2004). This type of contract set-up could be a mix of fixed-price and reimbursable or cost-plus incentives agreements that reflect the performance and innovations established by the contractors. The contract and outsourcing strategies and plans must be established in the early project phases (Powell, 2012). To secure safe and efficient preparation and execution, clear terms and definitions must also be used in contractual documents regarding the requirements for checkout, handover and acceptance, commissioning, and start-up (Lawry and Pons, 2012). An even better contract strategy might be for the plant owner or operator to take responsibility for start-up, with assistance from the contractors.

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## Illustrative example 6: Contract innovation

In an EPCM contract for a natural gas mega-project in Turkey, commissioning, start-up, and operational readiness were incorporated under the term "operations assurance." This contractual set-up could suggest that the operations assurance team was not fully independent with regard to inspections and testing, which could result in potential problems during start-up and initial operations. A better solution was implemented by transferring the operations assurance team to the owner's operational organization. Although extensive meetings and negotiations were needed to establish this adaptation, this is an example of good cooperation and innovation within a contractual set-up.

### 4.4 Project cohesion and intra- and inter-organizational integration

A truly integrated project team (Lawry and Pons, 2012), led by, for example, an interface coordinator, can contribute significantly to a successful project start-up. True integration and cooperation can ensure that vital knowledge is conveyed to the project stakeholders (Burke and Kirkham, 1993). In addition to integrating all the stakeholders in a project, the commissioning, start-up, and operational readiness must be integrated and consistent in every project phase (Annandale, 1990). An inventory of different interfaces should be established and consolidated to ensure the efficient execution of activities. Important interfaces include those between the operator/owner, engineering team, procurement and construction, vendors and specialists, and regulators and statutory bodies. Equally important within a project are the interfaces between various disciplines. A mechanism that establishes a holistic project goal can facilitate the realization of this envisioned integration.

Commissioning, start-up, and operational readiness activities must be planned, scheduled, and budgeted in close cooperation with all stakeholders and with due consideration to the recognized interfaces to ensure the efficient execution of activities (Tuin, 2015). In addition to the integration of start-up considerations throughout all project stages, commissioning and start-up leadership of a project will help to keep the attention focused on achieving a flawless start-up (O'Connor et al., 2016). Establishing a common goal between the client and contractors is important for a successful integration (Leitch, 2004). Early involvement of construction contractors in the detailed design phase adds value by the contractors' experience and knowledge of specific subjects relevant to the project (Davies et al., 2009).

In addition to integrating commissioning and start-up into every phase of a project, the involvement of the production team during all stages of the project adds value to the design due to their operational experience and knowledge (Kirsilå et al., 20007). Involving operations personnel in the design phase can lead to better commissioning and start-up plans and procedures. During the construction phase, operational personnel can contribute to construction quality by performing regular inspections. In addition to providing formal training, the involvement of operational personnel in all stages of a project ensures the provision of a level of confidence, insight, and knowledge that cannot be obtained during any other period of the plant life cycle (Horsley, 1997; Wallsgrove, 2015; Bush et al., 2000; Killcross, 2012). Training and participation of the production team during project stages can yield valuable insights for start-up and during plant operations. On-the-job training of operational staff consists of performing inspections, participating in testing, preparing operational procedures, participating in safety studies, and reviewing designs.

Many publications relating to plant start-up report integration aspects as a success factor, while acknowledging that implementing and benefitting from this success factor can be challenging. Project organizations are set up in different ways than company organizations, and this topic is addressed in section 2.5.

Typically, when a project phase is completed, the corresponding contract is terminated and the people involved leave the project, taking their relevant knowledge with them. This means that information is being lost or can be misinterpreted in other project phases. Problems related to a lack of personnel continuity become perfectly clear when commissioning and start-up activities are introduced too late in the project.

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To contribute to a highly successful start-up, integration, as a success factor (Burke and Kirkham, 1993; Bush et al., 2000), requires effort from the project leaders and a focus on common project goals (Sparks, 2018).

## 4.5 Planning and budgeting

Having a sound organization alone does not ensure successful commissioning and start-up. To be fruitful, substantial and meticulous planning is also required (Accenture, 2012). Project progress must be checked frequently, as problems arise and are solved, to keep the actual status matched with the planned schedule. If schedule flexibility is taken into account, encountered problems can be accommodated and addressed. A key element in achieving efficient plant start-up is commencing plans for plant start-up at the project's front end (Sheridan, 2015). Prior to plant start-up, it is recommended that as much of the equipment as possible is run to identify any problems early so that they can be adequately solved (Burke and Kirkham, 1993). This requires innovative thinking by the commissioning start-up manager. For example, natural gas equipment could be run with nitrogen or chemical systems could be tested with water.

Commissioning and start-up can be commenced when all construction activities are complete and all necessary documentation is in place. This method is referred to as the ***traditional commissioning*** method (Burke and Kirkham, 1993), which can be used with a small or uncomplicated project, or when no contractual agreements are made regarding staggered construction delivery at the system level. When no contractual arrangements are made regarding the method of systems commissioning but these arrangements are attempted, confusion may arise and even dangerous situations. The systems commissioning method or systemization is based on the concept that to efficiently complete a project; the installation must be divided into practical commissionable portions that are addressed in the correct sequence (Tuin, 2015). Systemization of the installation or plant is an important consideration during planning. With systemization, the sequencing of delivery and completion is determined most efficiently. Therefore, it is important to change from area planning to system planning when the construction process is 60 % to 70 % complete (Burke and Kirkham, 1993). This approach allows for the early start-up of plant utilities that must be live prior to the start-up of other process systems. Another advantage of the system commissioning approach is that the construction teams are still active on-site during the commissioning activities and can be deployed to rectify problems as they occur.

In terms of efficiency, it is recommended that multiple points be established in the schedule for inspecting the construction quality for flaws, defects, and omissions by each discipline. Rather than a punch list action, scheduled milestones can be used to determine whether the construction contractors should be paid at construction completion. A second effect of early and frequent inspections during construction is that the commissioning and operations teams are frequently present on site and the contractors get the message that the client is serious about error-free delivery.

The "ready for start-up" (RFSU) milestone is a critical stage in a project, when the facility is checked and all testing and inspections are confirmed as having been completed. This means that all necessary safety precautions are in place, all start-up requirements have been met, and the operator and start-up team are prepared and ready; technical, statutory, regulatory, and compliance requirements are in place and it is considered safe to commence the first-time start-up process.

Estimating the duration of the commissioning and start-up phase involves consideration of all components and details, which require time and resources. All these components and details must be properly identified and reflected in the schedule. The systemization of commissioning activities contributes significantly to project efficiency. It is important to determine and include vendor assistance in the schedule. To create a manageable schedule, the commissioning activities must be broken down into logical steps and systems, and the planned schedule must be compared with the actual progress on a regular basis to identify and solve any problems to prevent delays.

Table 1 presents a method for predicting the time needed for commissioning and start-up, for which the duration must be aligned with the resources available (Tuin, 2015). This formula is based on data gathered from previous projects. Time prediction models can be an excellent tool in early project phases for determining the impact of commissioning and start-up on project duration and resources. In this formula, it is estimated that in a basic case, the time allotted for commissioning and start-up is 15 % of the total

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Table 1 Formula: prediction of commissioning and start-up duration (source: Sasol Ltd., 2008).

| TIME= A x (0.15+B+C+D+N x E) |
|---|
| **A = Construction time** |
| **B = Process factor** |
| 0.15 for radically new process |
| 0.05 for relative new process |
| -0.01 for familiar process |
| **C = Equipment factor** |
| 0.15 for radically new |
| 0.08 for very new |
| 0.05 for relatively new |
| -0.01 for familiar equipment |
| **D = Workforce factor** |
| 0.15 for workforce in short supply |
| 0.05 for workforce scarce |
| -0.01 for surplus workforce |
| **N = Number of dependent process units** (e.g. utilities considered as unit) |
| **E = Dependency factor** |
| 0.25 for interdependent process units |
| 0.10 for moderately dependent |
| -0.02 for independent plants |

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Table 2 Formula: prediction of commissioning and start-up cost (source: Sasol Ltd., 2008).

| COST= A x (0.10+B+C+D+NxE) |
|---|
| **A = Total indicated cost of project** |
| **B = Process factor** |
| 0.05 for radically new process |
| 0.02 for relative new process |
| -0.02 for familiar process |
| **C = Equipment factor** |
| 0.07 for radically new |
| 0.04 for very new |
| 0.02 for relatively new |
| -0.03 for familiar equipment |
| **D = Workforce factor** |
| 0.04 for workforce in short supply |
| 0.02 for workforce scarce |
| -0.01 for surplus workforce |
| **N = Number of dependent process units** (e.g. utilities considered as unit) |
| **E = Dependency factor** |
| 0.04 for interdependent units |
| 0.02 for moderately dependent |
| -0.02 for independent plants |

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construction time. The application of new technology, i.e., radically new equipment or a new process, will have a huge influence on the project duration. Merrow (2011) reported that the influence of new technology on the duration of a project start-up will vary with the type of project. A small project can be managed and changes incorporated relatively easily, which means that the impact of a new technology on the start-up period is manageable. When a new technology is heavily applied in large projects, the start-up time can be five times that when proven technology is used (Merrow, 2011).

When organizations undergo frequent process start-ups, and to a large extent the project members are staff of the business organization, it is recommended that process-related parameters from previously executed projects be identified to enable the development of specific models and thereby obtain a tailor-made commissioning and start-up duration model for a particular organization. The process of gathering the required data and building the model requires a significant amount of time and professional dedication.

Budgeting accuracy heavily depends on how well the project has been defined during the preparation and planning phase. Effective estimations of the commissioning and start-up costs is a task that requires great insight and experience. An average of 5 % to 20 % (Killcross, 2012; Bendiksen and Young, 2015; Leitch, 2004; Wallsgrove, 2015) of the overall capital cost of large to mega-projects is allocated to commissioning and start-up. The most significant cost items in this total comprise feedstock during start-up and related off-specification production, manpower, managing the impact of a new technology, equipment, and chemical and utility consumption (Wallsgrove, 2015).

Start-up budgets for process plants can be estimated based on calculations of a percentage of the total indicated cost of a project, with the addition of weight factors for various project parameters. Table 2 presents a commissioning and start-up cost model, the formula for which is based on data gathered from previous projects. The start-up cost model predicts the associated budget at an early project stage. The model assumes that the basic cost for commissioning and start-up is 10 % of the total project cost. The weight factors presented do not include margins for mistakes, problems, or other issues that would increase costs. New technology and new process, in the formula, has a substantial impact in the commissioning and start-up cost. The prediction can be used in the early project stages to support, for example, feasibility studies. As the project progresses, the budget estimates should be refined by entering the actual costs. For example, the rates for commissioning and start-up personnel can be determined and obtained.

In each project phase, operation and maintenance (O&M) requirements must be assessed to ensure that they have been implemented (Dvir, 2005). These requirements should take into account project cost as well as life-cycle operating costs (OPEX) to ensure the financial sustainability during operations (Biery, 2015).

## 4.6 Organization for a flawless start-up

Early involvement and preparation by the commissioning start-up manager is imperative to ensure that fundamental decisions and related budget and planning for start-up and operations are taken into account. Good definition and preparation improves the performance and increases the ultimate value of a project.

Establishing appropriate personnel plans for the commissioning and start-up team is a task that must be started early in the project (Burke and Kirkham, 1993). If not planned early, difficulties will arise regarding budget and availability of the resources needed when it is time to execute start-up (Lager, 2011). Vendor resources must be booked far in advance (Mukkerjee, 2005) to ensure the availability of the field engineer or specialist when needed. Also important is establishing agreement about the availability of construction personnel during testing for tasks such as removing or installing mechanical process isolations. The level of experience of commissioning and start-up team members is also a key factor that can determine the success of plant start-up (Burke and Kirkham, 1993). Recruiting experienced and qualified people is a lengthy process that must be planned carefully well in advance. A measure that also ensures continuity within the project is the engagement of engineers from the design phase during commissioning.

Lager (2012) described different start-up organizations with different levels of interference from the operator or owner, with the start-up organizations varying with respect to the size and type of project. Start-up is often led by the operations team since operational licenses are provided to the operations department.

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An O&M team must be established or involved early enough in the project to be able to participate in design reviews and receive necessary training (Lager, 2011). The involvement and training of O&M personnel during a project adds great value to the plant operation (Kirsilå et al., 2007).

In organizations that have a permanent commissioning and start-up manager, there is the opportunity to develop tailor-made models that can help to determine project resources, budgets, and duration with respect to start-up and operational readiness.

# 5 Management Implications and Suggested Further Research

## 5.1 Management implications

High operational costs due to troublesome operations and unscheduled maintenance activities can be prevented if the importance of the commissioning and start-up phase is acknowledged and proper preparations are made. Flawless project delivery and project start-up can only be achieved via a structured work process to establish the required policies, standards, business processes, and procedures.

One of the most important aspects is to secure support from top management. Serious attention to the start-up phase and operational readiness must be given and supported by top management, followed by communicating this project approach to all project stakeholders. In addition, it is recommended that in the initiation phase of a project, a decision step should be incorporated regarding the strategy to be selected for start-up and how its execution and delivery will occur. Awareness of the importance of start-up among top management and project stakeholders as one of the measures for increasing start-up success sounds very plausible, but is more difficult to establish than introducing methods for project start-up.

Although the scope and magnitude of start-up activities and resources depend on the project size and the business organization, the fixed core issues that apply to success at start-up are commencement at the front-end loading phase, integration and focus on start-up throughout all project phases, intensive active involvement of the business organization in the project, and use of the appropriate type of contract with the additional focus on flawless start-up and operational readiness. Controlling the commissioning and start-up progress of a project from one phase to the next, as presented in appendix II, can be managed by gate reviews and audits (powell, 2012).

## 5.2 Conclusions and suggested further research

Members of the process industries face increasing pressure regarding project cost control and increasingly onerous environmental rules and regulations. Therefore, a project approach that envisions a flawless start-up and on-specification operations is paramount. In this light, it is surprising to learn that the importance of plant start-up and the transition from project to operations are often underestimated. These factors require more attention, understanding, promotion, and implementation. In general, project stakeholders understand and acknowledge that preparations are important and essential to project success. The deficiencies related to plant start-up and the transition from project to operations is so underexposed that it is actually a shame. Of vital importance is early involvement of a commissioning and start-up representative. In the conceptual phase of a project, there must be funded plans for determining how to transform a project flawlessly into an on-specification operating plant. Ownership of the commissioning and start-up within a project is correspondingly important. Is this responsibility left to a contractor with only minor interest and little incentive regarding commissioning and start-up? For the plant owner, the whole operation's business is at stake!

Cross sectional cooperation and knowledge sharing within process industries is rare (Lager, 2017). One of the reasons for this failure to share knowledge and lack of cooperation is the attitude of those in process industries that whatever a particular company is processing is unique and difficult rather than viewing the commonalities of technical and business processes for their improvement, innovation, and learning opportunities. The positive aspect of two very different process-industry sectors cooperating is that there is no competition aspect to restrain the parties in sharing valuable information to improve their business performance.

Better and more intensive cooperation among practitioners and researchers regarding process-industry plant start-ups can establish a platform from which innovation and knowledge can be shared, complex problems solved,

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and knowledge and insight gained toward improved management tools and methodologies (lager 2017).

Further research may consist of data gathering and analysis regarding the efficiency of project start-ups in process industries with respect to budget, duration, resources, and preparation. This will contribute to improved insights, greater understanding, and better project performance. Large organizations with substantial project portfolios could build their own knowledge bases to better understand and improve their own plant start-ups. Organizations that are unable to perform independent data gathering could benefit by obtaining support from and collaborating with scientific institutions that can provide industry-specific data, research, and tools for supporting better process-plant start-ups.

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## Appendix I – Brief Glossary of Terms Commonly Used In Commissioning and Start-up of Process Plants

When dealing with the issues involved in project definition and execution a major source of difficulty is the lack of a common language and a set of widely accepted definitions of the key concepts. Therefor it is important to define the terms being used in this study.

**Area (construction) planning**: Construction activities in logical order per area per discipline.

**Business readiness**: Process of managing change within the enterprise, for example after a project a company has a new system, or process that has an effect on the organization. Business readiness is used to proactively plan and manage the steps that need to occur to ensure the business impacted by the upcoming changes will be ready (Powel, 2012).

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**Commissioning**: Actual plant commissioning demonstrates that systems operate correctly and in accordance with operational characteristics that comply with the vendor purchase orders, engineering, procurement and construction contracts, and other contracts. This demonstration includes all functions, including test runs of individual units and their associated auxiliary and safety systems, and ensures that the systems are safe and operable (Tuin, 2015).

**Commissioning start-up manager**: Specialist with knowledge in managing the development of all project commissioning and start-up standards and practices and related business aspects to ensure successful commercialization and implementation of a project. The commissioning start-up manager is held accountable for ensuring the provision of sufficient commissioning and start-up resources for all projects to effectively mobilize project operations and ensures that teams work towards the timely completion and handover of safe, and operable and maintainable plants.

**Construction**: Project phase starts with the receipt of the first purchased component on site and ends with the last functional system having achieved the mechanical complete status.

**Completion**: Status of a project (phase) at which all relevant criteria have been reached and can move into a next stage. For example, construction complete is reached when the following conditions are simultaneously met: all components of the systems are erected, installed, assembled, hooked up, flushed, cleaned, preserved and aligned according to construction drawings and specifications.

**Emergency shutdown test**: Test verifying emergency shut down functions of a plant. Testing the shutdown function by triggering a process value that stops process operations and isolating from incoming connections or currents to reduce the possibility of an unwanted event quickly.

**EPC**: A contracting arrangement by an engineering and construction contractor that will carry out the detailed engineering design of the project, procure all the equipment and materials necessary, and then construct to deliver a functioning facility or asset to the clients. The main EPC contractor can sub-contract specific disciplines.

**EPCM**: Engineering, Procurement, Construction Management is a type of contract different from an EPC contract in that the contractor is not directly involved in the construction but is responsible for administering the construction contracts.

**Flawless commissioning and start-up**: Focused and systematic approach to influence successful commissioning, start-up and first cycle operation. Its objective is to achieve trouble-free start-up and sustained operational performance for the total project (Powel, 2012)

**Flawless project delivery**: Promoting and ensuring that good methods are in place to stop the occurring of flaws and the concept of doing activities right first time within a project. It is the adoption of processes and actions by which risks to this objective will be identified, assessed and addressed during engineering, procurement and site implementation in a proactive manner (Powel, 2012).

**Handover**: Transfer of responsibility regarding the care, custody, and control for the project. An example is handover to owner at the final stage of project after the plant is constructed, inspected and tested. The handover activity includes all relative constructed facilities as well as project documentation as specified in the contract. The plant handed over should be in safe condition. There can be several handover moments within a project, from engineering to construction, form construction to commissioning and form commissioning to plant operational team (depending on project set-up). At Lump-sum Turnkey Type (LSTK) Contracts where there is only one handover - a single handover to Operations, namely Handover of running Plant after successful completion and acceptance of Performance Test Runs.

**Lump sum contract**: Contract under which a customer agrees to pay a contractor a specified amount that will cover entire project phases as specified in the contract. This contract does not allow for changes in the contract. Any additions require a change order.

**Mechanical completion**: Widely used term with various definitions. Often it is a contractual milestone related to construction complete, but also used as a project term to mark completion of systems. It would be better to avoid the term mechanical completion and use for example the phrase Construction Completions, since this presents more accurate the actual moment and its importance.

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**Nameplate operations**: Operations level of a process plant with production targets output as per specified in the design. Also referred to as the plant is at full production or as on-specifications operations.

**Operations assurance**: Process used in the performance of projects to measure progress towards achieving the state of "readiness to operate". The process also includes an assurance component that gives an ongoing, real-time indication of the likelihood that the project will achieve that state by the time of handover to the owner/operator.

**Operational readiness**: Process of preparing the operational staff of an asset under construction and their supporting organizations to be fully ready to assume ownership of the asset at the point of delivery/handover, and to be able to take responsibility for performing the safe and efficient operation of that asset (Powel, 2012).

**Pre-commissioning**: Test activities carried out on a single discipline basis (such as electrical, instrumentation and piping) and requires materials, equipment or systems to be energized, but does not require the introduction of process fluids.

**Process plant start-up**: Project phase that starts with the receipt of the first feedstock and ends with the plant having achieved fully operational status; regarding capacity and design specifications. The objective of start-up is to verify that the facility operation is in accordance with the design requirements as defined in the project specifications. Typical start-up activities include the basic tuning of control systems and verification of start-up and shutdown sequences.

**Ramp-up**: After start-up, the process is brought to its design parameters and sustained operation. Flawless project delivery is characterized by a smooth start-up and steady ramp-up. Ramp-up in the process industries must not be confused with ramp-up in the manufacturing industries.

**Ready for start-up**: Status in the project that all the compiled functional systems have reached the condition of commissioned, documents are as-built, agreed spare parts are handed over to client including preservation records, and the operations organisation is able to operate and take care, custody and control of the unit for processing feed stocks, diligently complying with all relevant codes, regulations, guidelines, licence prescriptions, and applicable operating procedures and standards.

**Reimbursable contracts**: Contract under which allowable and reasonable costs incurred by a contractor in the performance of a contract are reimbursed in accordance with the terms of the contract.

**Shutdown**: A stoppage of a production process. Shutdowns are not always planned. A planned shutdown is also referred to as turnaround.

**System Planning**: Planning approach based on the completion of systems in a logical order.

**Systems commissioning** (Systemization): A system is a composite assembly of equipment, instruments, electrical supplies, etc., which can be defined as having a singular purpose. It is a section of the assets for which a clear function can be identified, and to a significant extent can be commissioned and brought into operation either in isolation or with primary support e.g. power from adjacent systems. Advantage of a system commissioning approach is it can already commence when simultaneously construction activities are still executed. This has a time saving effect within large multi discipline projects.

**Staggered construction delivery**: Deliver construction completion on a system level that goes together with systems commissioning.

**Traditional commissioning**: The opposite of systems commissioning. Testing and inspection that commences after construction is totally completed (Burke and Kirkham, 1993). This could be a good approach towards commissioning and start-up in small project, in projects where there are no contractual agreements on systemization or where the risks are too high when implementing systems commissioning.

**Turnkey contract**: A contract in which a contractor is given full responsibility to plan, build, test and start-up the industrial plant. In the process industries this often difficult since the contractor must have operational knowledge and often license to be able to operate the plant.

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# Appendix II - Overview of Activities Related To Commissioning and Start-up of Process Plants

Once a project strategy adopts integrated commissioning and start-up in all project phases, the strategy must be translated into methods and tools. Per project phase commissioning and start-up processes, tasks, actions, and involvement are presented. This comprehensive list is to demonstrate the amount of activities when process plant commissioning and start-up is thoroughly managed and executed. The presented activities are executed, managed or inspected by the commissioning start-up manager or the commissioning start-up team. Implementing all activities throughout the project phases could be a substantial transformation towards project execution method and therefore could take considerable amount of time. Depending on projects characteristics, presented activities could be clustered or altered as required. The presented project phases progress and readiness can be controlled though assessments or audits referred to as project gate review.

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Table A1 1. Concept, Feasibility and Basic Engineering Phase (own representation).

| 1. Concept, Feasibility and Basic Engineering Phase |
|---|
| ■ Recruit or appoint commissioning start-up manager in this early phase. |
| ■ Determine and formulate commissioning start-up in project strategy. |
| ■ Clarify and communicate the contracting strategy including key contractual requirements |
| ■ Develop the philosophy regarding commissioning and start-up, containing commissioning and start-up approach and organisation. |
| ■ Set up commissioning and start-up preliminary budgeting and schedule, including pre-production budget. |
| ■ Provide basic engineering input and review including: |
| ■ *Defining the sequence of Commissioning & start-up of systems in the process plant.* |
| ■ *Listing early need requirements regarding utilities, resources, and spare parts.* |
| ■ *Determining long lead items.* |
| ■ Provide input in operations and maintenance philosophy and strategy from which the needed requirements are determined. |
| ■ Contribute to basis for design and invitation to tender, regarding commissioning and start-up scope and deliverables. |
| ■ Develop the training philosophy and strategy regarding commissioning and start-up and operations and maintenance. |
| ■ Review equipment arrangement in respective to commissioning requirements. Providing the need for temporary jump-overs, bypasses, etc. |
| ■ Conduct interviews and appoint lead commissioning engineers for detail engineering phase. |

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Table A2 2. Detailed Design Phase (own representation).

| 2. Detailed Design Phase |
|---|
| - Improve commissioning and start-up budget and schedule based on project detailing. |
| - Build commissioning and start-up organisation and implement roles and responsibilities. |
| - Set up commissioning and start-up plans regarding preparation and execution and set-up commissioning and start-up schedules. |
| - Commissioning start-up management documents includes: |
|   - *Commissioning start-up execution plan (Commissioning Manual).* |
|   - *Pre-commissioning, commissioning and plant start-up sequence.* |
|   - *Defining the transfer of care, custody & control (legal responsibility) at predetermined level of Completion in the project. Such as ready for commissioning and ready for start-up in the handover management plan.* |
| - Developing procedures for pre-commissioning and commissioning, including: |
|   - *Pre-commissioning specific documents, such as test and inspection procedures.* |
|   - *Commissioning specific documents, such as test and inspection procedures.* |
|   - *List spare parts, special tools and consumables to be ordered for commissioning activities.* |
|   - *What systems or equipment need preservation until start-up and how.* |
|   - *Flange management, assuring flange connections are leak tight.* |
|   - *Interface management, stating what interfaces need to me managed by who and how.* |
|   - *Roles and responsibilities subdivision between commissioning and engineering, construction and operations.* |
| - Set-up the framework and communicate handover management within the project and to operations. Describing what is handed over to whom. |
| - Safety and risk reviews and management. |
|   - *Contribute to the project risk reviews.* |
|   - *Develop mitigation plans related to commissioning and start-up risks.* |
|   - *Develop HSE commissioning and start-up plan.* |
|   - *Develop and communicate list with necessary Inhibit and overrides.* |
|   - *Contribute to set-up Permit to work system in test and start-up phase.* |
|   - *Develop and communicate list with process isolation.* |
|   - *Build test plan and procedures for emergency shutdown, and Emergency Response plans.* |
|   - *Procedure for dealing with management of change during commissioning and start-up.* |

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Continuation Table A2 2. Detailed Design Phase (own representation).

| 2. Detailed Design Phase |
| --- |
| ■ Provide design input and contribute to design reviews. |
| ■ Develop completion management system. |
| ■ Implement training plan and execution. |
| ■ Continue to conduct interviews and appoint commissioning team members, including operations & maintenance personnel who form part of integrated team. |
| ■ Develop pre-start-up safety review and readiness review. |
| ■ Develop and agree procedures for simulations operations. |
| ■ Develop process tie-in strategy, to establish safe commissioning and sequential start-up. |
| ■ Develop and communicate the plant ramp-up plan. |

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Table A3 3. Construction Phase (own representation).

| 3. Construction Phase |
| --- |
| ■ Populate the remainder of commissioning start-up organization structure. |
| ■ Finalise detailed commissioning plans and schedules. |
| ■ Commissioning start-up team attending risk reviews, giving operational and commissioning input. |
| ■ Implement handover meetings with stakeholders. |
| ■ Finalise mass balances (steam, utilities, power, etc.), to be used during plant tests and solving problems during commissioning and start-up. |
| ■ Implementation completions management system, containing the following items: |
| ■ *Tracking of progress of completion, tests and inspections.* |
| ■ *Check-out of plant is built in accordance to specifications (Punching workflow).* |
| ■ *Handover control.* |
| ■ *Handover/completion audits.* |
| ■ *Implementing various reporting documents and levels.* |
| ■ Implement systems planning approach at ±70% construction completion. |
| ■ Conduct pre-commissioning activities. |
| ■ *Perform check-outs/walk downs.* |
| ■ *Manage and check Flushing/cleaning.* |
| ■ *Manage and check tightness testing.* |
| ■ Construction verification and acceptance of systems handover. |
| ■ Determine an implement reporting requirements for management regarding completion. |
| ■ Executing training for operations and maintenance staff. |
| ■ Handover or turnover (depending how defined in project) from construction to commissioning. |

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Table A4 4. Commissioning and Start-up Phase (own representation).

| 4. Commissioning and Start-up Phase |
|---|
| ■ Mobilizing Vendor support. |
| ■ Execute inspections, for example; opening up Towers, Distillation Columns, Boilers and, Pumps. |
| ■ Conduct commissioning and start-up risk reviews. |
| ■ Conduct commissioning activities per system, area, unit, etc. depending on requirements. |
| ■ Test runs and functional testing without feedstock (Dry runs) - cold and hot water runs. |
| ■ Conduct final leak testing. Can be prior to process medium during function tests. Pressurise facilities on air, water, nitrogen and conduct simulated operating runs. |
| ■ Simultaneous operations (SIMOPS) construction, pre-commissioning, commissioning and start-up in progress. |
| ■ Acceptance and handover from commissioning to start-up. |
| ■ Execute pre-start-up safety review and readiness review. |
| ■ Transfer end-of-job (EOJ) documentation including all statutory documentation. |
| ■ Conduct business readiness review. |
| ■ Close-out all outstanding punch items. |
| ■ Acceptance of clearance for operations. |
| ■ Demobilisation of commissioning team. |

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Table A5 5. Ramp-up and Operations (own representation).

| 5. Ramp-up and Operations |
|---|
| ■ Reaching and executing plant and business start-up. |
| ■ Implement plant insurances for operations. |
| ■ Terminate construction all risks (CAR) insurance policies. |
| ■ Provide operations & maintenance support. |
| ■ Plant optimisation and problem solving. |
| ■ Verify alarm management system. Number of active alarms can be excessive during start-up and needs to be minimised within acceptable and manageable levels to allow Console Operator to control without distraction of unnecessary and nuisance alarms |
| ■ Implement any start-up modifications For example; temporary jump-overs, strainers etc. Will require a separate budget and each modification treated as a mini project with related HSE precautions. |
| ■ Verify operations competency declarations. |
| ■ Conduct performance testing. |
|     ■ *Hydraulic efficiency – major equipment test runs.* |
|     ■ *Process guarantees.* |
| ■ Verify environmental performance. |
| ■ Obtain steady state operations. |
| ■ Handover |
| ■ Collect, and discuss lessons learned to be turned into improvements. |
| ■ Close-out of the project. |