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Lead time estimation for modular production plants

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ABSTRACT

Modular plant design is an approach for making chemical production more flexible and more efficient. Different approaches for modular plant design have been developed, for example in the CoPIRIDE or F^3 factory project. They have in common, that lead time reductions for modular equipment are expected e.g. by utilizing design repetition or parallelization of pre-assembly of modules. To support the decision for or against a modular concept, besides cost effects possible lead time changes compared to conventional concepts should be anticipated in early economic evaluations already. In this article, a lead time estimation method will be presented that correlates project costs and project durations and can be applied to modular and non-modular plants enabling comparative studies. An example from a previous paper was used to investigate the impact of modularization on lead time. It includes modular production lines and a non-modular backbone facility that provides energy and utility supply. A range of investment sizes (FCI of 3–95 mio. €) was investigated and compared with a conventional reference plant. Total lead time reduction was in the range from 2.6 to 5.5 month depending on investment size. For a more significant impact on the lead time the modularization approach needs to be modified by also applying modular design to the backbone facility. In this case depending on investment size total lead time reduction would be between 3.9 and 18.7 months representing a very significant reduction of 23%–60% compared to the lead time of the conventionally designed reference plant. This is considered as the maximum expectable lead time reduction that can be achieved through modular plant design. This reduction would represent a major potential for speeding up construction of chemical plants.

1. Introduction

Future development of global chemical market is characterized by diversification and fragmentation (Lier et al., 2015). Technological improvements and new fields of application make customers ask for more tailor-made products, which leads to an increasing number of products, decreased production volumes, delocalized product demand and shorter product life cycles. This in turn leads to more volatile markets and an increasing demand for a flexible production (Buchholz, 2010). Additionally, there is increasing pressure on product prices and a trend of increasing raw material prices in the long term. To keep up with this future development, future chemical production will also need to be more efficient.

Fulfillment of both, increased flexibility and efficiency is hardly possible applying existing production concepts. In a simplified view the existing production concepts can be described by the benchmarks

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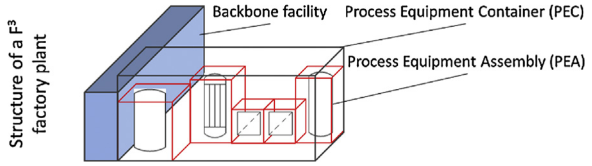

Fig. 1 – Scheme of the modular design of the F^3 factory concept.

of the large-scale commodities production plant and the small-scale specialties production plant (Bramsiepe, 2014).

Traditionally, the main economic driver of the continuously operated large-scale commodities production plant is the economy of scale together with high process efficiency. However, this concept usually offers a low degree of product and capacity flexibility (Buchholz, 2010). The small scale specialties production concept, e.g. a multi-purpose batch plant, offers a higher degree of flexibility regarding capacity and product portfolio. Here, the ability to quickly react to seasonal or new market requirements including innovations are main economic drivers (Rauch, 1998). The disadvantage of this concept is the comparably low efficiency due to a lack of material and heat integration (Rauch, 1998).

A solution proposed to combine the advantages of both production concepts are production plants that use a modular design (Buchholz, 2010). Several approaches to describe modularization are available. While Jameson (2007) describes a module as just being a mobile unit, a more detailed description has been developed by Burdorf et al. (2004), Kampczyk et al. (2004) and Schmidt-Traub et al. (1999). In their definition a module corresponds to a main equipment item including its local pipe installation. A module description that also includes standardization of modules has been developed in several research activities in the recent years. European research projects to be considered are for example CoPIRIDE (Löb, 2013) or F^3 factory (Buchholz, 2010; Buchholz, 2013), further relevant projects have been listed by Lier et al. (2015).

The concept used as a reference for modular design in this paper was used in the F^3 factory concept. F^3 stands for flexible, fast and future production plants and describes a modular and continuous operating mode. The overall F^3 factory plant is made up from two modular structures, PEAs (Process Equipment Assembly) and PECs (Process Equipment Container), both equipped with standardized interfaces. The structure is schematically illustrated in Fig. 1.

In this concept, modular equipment fulfilling a full unit operation (the PEAs) can be placed into standard containers which represent the modular superstructure (the PECs) and are connected to a shared backbone facility that provides housing and basic supply with utilities and energy. Aiming for high process efficiency highly automated, continuously operated processes using process intensified technologies and material and heat integration can be implemented (Seifert et al., 2014; Bramsiepe et al., 2012).

However, process intensified technologies are often limited in throughput. Especially when parallelization or numbering up is required to prepare technically relevant production capacities, loss of economy of scale can compensate improved conversion cost.

An economic evaluation is necessary to determine whether the modular approach provides economic advantages over conventional production concepts.

For such economic evaluation it is not sufficient to incorporate investment costs and conversion costs only. There are further economic aspects like supply chain costs, personnel costs, site-specific costs, and others that are affected by implementation of a modular plant design and need to be considered (Sievers et al., 2017).

One of the most important effects on the economy is the increase of plant flexibility. The structural flexibility obtained by the modular design poses the chance to build processes quickly and in multiple small scale units (Buchholz, 2010). From lab to production scale a small factor applies, reducing scale-up issues. Potentially, existing modules can already be used for product development and production of sample amounts while production capacity can later be increase by numbering up. Such integration of product and process development, leading to a reduction of development periods was shown e.g. by Brodhagen et al. (2012). Another feature that can be exploited using modularization is standardization. Standardized modules and standardized simulation models can be used for faster process development by selecting modules from a module database rather than designing them individually. For example, in two studies (fine chemicals and pharma product) Grundemann et al. (2012) showed that the time-to-market can be reduced by implementing pre-designed, continuously operated micro-structure units.

Moreover, pre-construction of modules in an off-site workshop under ideal spatial conditions and the presence of all necessary tools and expertise may lead to a reduction of field work but requires a high degree of logistics planning, additional accommodation for workers at the site and can potentially be dependent on weather conditions. Nevertheless, construction expenses and time may be reduced.

The reduction of engineering and construction effort helps to decrease lead times and thus the time to market, which can substantially improve the economy by generating earlier sales. As could be shown by Bramsiepe et al. (2012) and Seifert et al. (2012), a lead time reduction from three to one year by means of modular setup implementation can result in a net present value improvement of more than 25 percent, which offers the opportunity to compensate loss of economy of scale. The generation of earlier sales also results in a shorter pay-back period, reducing the investment risk. This in turn allows to go for projects that otherwise were too risky, creating an increased degree of business flexibility.

It becomes clear that lead time is a central element for economic evaluation and comparison of modular and conventional production concepts. There are different project phases, which constitute the lead time. An example of a typical differentiation of lead time phases is given, for example, by Bramsiepe et al. (2011).

The first economic evaluation that already includes a lead time estimate is conducted during a feasibility study in the process concept phase (Navarette, 2009). This evaluation aims at choosing one of the process alternatives developed, e.g. a modular vs. a conventional approach. *Bramsiepe* (Bramsiepe, 2014) found that for conventional plants in this phase only a rough estimate is conducted for lead time estimation because "*especially during early process design only few information about the process under investigation are available so that the decision pro or contra a process alternative has to be made based on practical knowledge instead of detailed calculations*". For example, in this phase Mosberger (2012) propose to estimate two to two-and-a-half years from process design freeze to start-up plus half a year to one year until minimum capacity is reached that corresponds the break-even point.

Even rough lead time estimates need to be established on a common and comparable basis to get meaningful results. Thus, comparing modular and conventional design requires that the same methodological approach is applied and the same database is used for the lead time estimate of both approaches. Of course above mentioned expectable lead time reductions for modular plants need to be considered in such comparison. This means existing rough lead time estimates for conventional plants need to be adjusted and for plants with modular design a new estimate is required.

2. Approach

For lead time estimation, first, the phases of an engineering project have to be defined. After that a calculation method has to be developed that allows determining the duration of each of the phases.

For further considerations, it is assumed that there is a relationship between the duration of a project and the investment sum as for any given project, accruing costs and the project duration can be expressed as a relation, i.e. different durations will yield different costs (Khosrowshahi, 2002).

As a starting point for the lead time calculation thus, the fixed capital investment (FCI) must be calculated first. The starting parameters used for calculating phase durations are the expenses that accumulate by the engineering activities