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Real option framework for equipment wise expansion of modular plants applied to the design of a continuous multiproduct plant

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ABSTRACT

As market demand forecasts will become more uncertain in the future it is necessary to develop new methods for plant design. New technologies allow combining the flexibility of a batch plant with the efficiency of a continuous production. To gain even more economic benefit intensified equipment is often designed as a module. The usage of equipment modules allows an easily and efficient increase of capacity. In this way a plant expansion close to the market is possible.

Consideration of stepwise plant expansion is often limited to the copying of complete production lines. This approach results in high additional investment costs due to the loss of economy of scale. To overcome the limitations set by economy of scale, an equipment wise expansion strategy should be applied. By debottlenecking the capacity limits of the plant it is possible to adapt plant capacity very close to the changing environment and reduce the additional costs. Therefore, design of a modular plant must be combined with suitable economic evaluation methods for uncertain demand forecasts.

In this work a framework for such a design based on predefined and standardized modules will be presented. The framework consists of two stages. The first stage is the selection of possible modular setups and suitable expansion strategies. Next these setups are evaluated in a real option analysis to investigate the economic performance in an uncertain market. The approach will be used to evaluate a multiproduct continuous plant. The main finding is that the economy of the modular plant depends under the given boundary conditions on the equipment item with the highest proportion on total investment costs and a high cost degression exponent.

Keywords: Flexibility; Modularization; Plant expansion; Real option analysis; Modular plant; Stepwise expansion

1. Introduction

The handling of uncertainty in market demand is one of the major challenges for chemical plant design. In the fields of fine chemicals and pharmaceuticals this uncertainty is mainly caused by different factors. Product life cycles are getting shorter caused by predatory competition. In addition customers ask for more specialized products so that product diversity is increasing. Furthermore, economic pressure from Asia is increasing and market volatilities are increasing. All these points result in nearly unforeseeable market situation and make the decision for tapping into new markets or establishing new products. On the one hand entering volatile markets might lead to significant economic losses. On the other hand these markets are also an opportunity.

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To face these challenges, one of the upcoming trends in chemical engineering is to use small scale continuous plants. This development is supported by the progress in the field of micro apparatuses and process intensification (Bieringer et al., 2013). The usage of continuous microstructured reactors for example can reduce or even avoid the need of solvents for exothermic reactions due to the improved heat transfer (Hessel et al., 2013).

Besides the development of new intensified equipment it needs for planning methods that allow for a designing a plant if market development is uncertain. Thereby, the usage of continuous multiproduct plants in combination with stepwise plant expansion for fine chemicals and pharmaceuticals is a promising approach. This approach allows for high flexibility concerning different demands and a reduced investment risk. It is possible to react on e.g. changing prices and demands in future by either expanding or reducing capacity or by simply waiting with a decision.

The problem of plant expansion is already addressed in different publications. One example is the evaluation method developed by Oldenburg et al. (2007) which gives an indication if a stepwise expansion of a given plant design is economically beneficial. The analysis used in this method is based on a plant degression exponent which is a measure for economy of scale (Oldenburg et al., 2007). If stepwise expansion is an option, a MINLP model can be used to optimize plant expansion steps as described in Wiesner et al. (2008). Another optimization method for investment strategies in uncertain markets can be found in Coleman and York (1964).

In most cases stepwise expansion is limited to copying complete production lines. Thus, the main drawback of a stepwise plant expansion is the increase in investment costs. Building multiple smaller production lines instead of one large scale plant leads to a reduction of economy of scale as specific costs for a larger apparatus are usually lower than for multiple smaller units. Furthermore, costs for e.g. sensors, regulators and valves will also be significantly higher if multiple units are installed. Operating costs will also be affected by the higher number of units as e.g. additional workers are needed to operate and control the higher number of equipment items. Thus, economy of scale is the limiting factor for stepwise plant expansion. In other words, the increase in flexibility has to be measured against additional investment and operating costs.

In every process design an economical evaluation is carried out to identify the best alternatives. One of the most widespread methods for economic evaluation is discounted cash flow (DCF) calculation. In this method the net present value (NPV) which is the sum of all discounted future cash flows is the decisive parameter (Park, 2010). A positive NPV is a minimum requirement for an investment decision. The disadvantage of this method is that the height of NPV is directly linked with a discount rate. In this discount rate risk for e.g. changing demands or prices are included (Park, 2010). This makes the determination of a suitable discount rate extremely difficult and the project might be overvalued or undervalued (Mun, 2006a). Furthermore, the opportunity to react on changing demands or prices is difficult to include (Park, 2010; Mun, 2006a). Thus, the results of the NPV calculation are only suitable for investments with low uncertainties.

If uncertainty in e.g. market demand is high the option to react on uncertainty has to be taken into consideration in the analysis. The ability to change investment decisions if conditions estimated in market forecast change is called managerial flexibility (Trigeorgis, 1996). Managerial flexibility allows a company to shift time and size of an investment achieving an optimal adaptation to market conditions (Trigeorgis, 1996). To integrate managerial flexibility into economic analysis, NPV calculation has to be extended.

Management opportunities to react on changing risks can be modeled with the help of real option analysis (ROA) (Brach, 2003). The idea of ROA is based on option price theory for stocks (Mun, 2006a). In contrast to option price theory, investments in assets like plants, machines or other operating resources are evaluated. As these investments are real the decision to buy them or not is called a real option (Brach, 2003).

While in stock market only the price of the stock is uncertain, in industrial projects uncertainty is influenced by factors like volatility of product, energy or raw material prices or uncertainties in market demand (Park, 2010; Brach, 2003). Often these influencing factors are linked so that an estimation of volatility is very complex. The uncertainty for the different factors can be derived from historical data. If these data is not meaningful or not available it is possible to estimate volatility from e.g. Monte Carlo simulation (Mun, 2006a). A detailed description how volatility can be estimated is given in Mun (2006a).

The idea of the real option approach has been used in multiple publications to investigate expansion scenarios of plants in various industrial sectors. Pederson and Zou (2009) used ROA to investigate the impact of market price risk on investment decision for Ethanol plants. In their work they could show how the decision for or against an expansion of a plant is influenced by volatility of feedstock and product prices (Pederson and Zou, 2009). In Jaina et al. (2013) the flexibility of modular designed small and medium nuclear reactors is investigated with the help of ROA. Sharma et al. (2013) developed a method for the optimization of investment decisions in production of cellulosic ethanol and biosuccinic acid. They presented a stochastic integer programming model based on ROA taking uncertainty in product demand and price into account (Sharma et al., 2013). Lier et al. (2012) applied ROA in the investigation of a stepwise expansion of a modular plant. To describe multiple expansion stages they used the method of a sequential compound option. This method was already used by e.g. Herath and Park (2002) for economic investigation of projects with multiple stages. Lier et al. (2012) identified uncertainty and the ratio between investment costs and project value as two of the main drivers for stepwise expansion. This finding shows also the impact of the process design on the achievable economic result. Nevertheless, their investigation was also limited to the copying of complete production lines.

The aim of this paper is to show how to integrate ROA in the design and selection of a modular setup. Modular setups differ in number and size of the modules that are used to realize the different unit operations in the process. The modules that are used within the design are predefined and available in fixed sizes only. This approach allows adding modules specifically to the setup to increase capacity by eliminating capacity bottlenecks. The advantage of this approach compared to copying complete production lines is that flexibility in capacity expansion is higher and investment costs are lower as the installation of overcapacity can be controlled. Therefore process simulation is required in order to determine process bottlenecks and to calculate the additional apparatuses needed for the expansion. This implies that the operating window of each unit operation in the process is known. Furthermore, the change in OPEX and CAPEX must be estimated in process simulation. In most cases plants for specialties and