17th European Symposium on Computer Aided Process Engineering – ESCAPE17
V. Plesu and P.S. Agachi (Editors)

A method for quick evaluation of stepwise plant expansion scenarios in the chemical industry

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Abstract

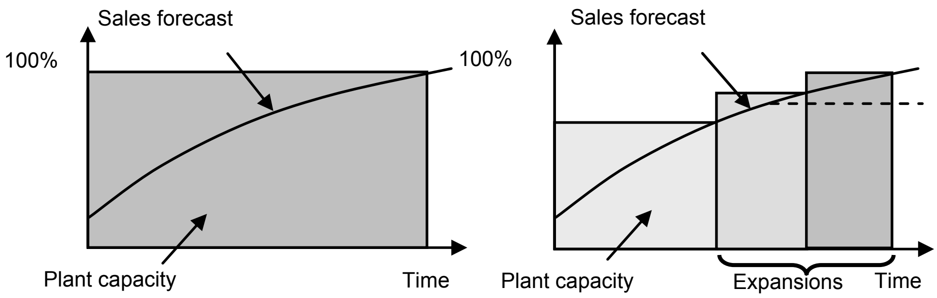
The profitability of investment projects for chemical production plants is affected by the installed plant capacity in relation to the actual sales of the materials produced in the plant. Especially for markets with large predicted growth rates, it can be beneficial to gradually increase the installed production capacity rather than building a large capacity at once. Whether this is the case, however, depends on various factors such as the product sales forecast and the technology, cost structure and economy of scale of the required production equipment. We propose a method which enables a quick comparison of possible stepwise plant expansion scenarios versus building a full capacity plant.

Keywords: stepwise plant expansion, process modules, plant life-cycle costs

1. Introduction

BASF has to deal with differently growing markets for its products. To minimize the life-cycle costs of a process plant, it may be advantageous to gradually increase the installed plant capacity rather than installing the full capacity at once (cf. Fig. 1). There are two reasons why a stepwise plant expansion can be economically attractive: (i) the present value of the overall investment costs is minimized and (ii) the risk of an under-utilized plant (i.e. the sales forecast is not reached) is reduced. The latter point is illustrated in the right half of Fig. 1, where a deviation of the actual sales demand from the forecast is shown by a dashed line. In such a situation, a subset of the planned expansion steps – here the last expansion step – could be avoided to save the respective portion of investment costs.

Figure 1: Installation of the full plant capacity at once vs. stepwise plant expansion. The dimensionless name plate capacity of the plant is represented as 100% on the ordinate, the dotted line indicates a deviation of actual sales figures from the sales forecast.



In many cases, however, it is not at all obvious whether a stepwise plant expansion policy is economically attractive or not. A fundamental reason is that there exists a natural tradeoff between the economy of scale of chemical process plants and the discounting effect of an investment (see e.g. [1]). The economy-of-scale effect can be nicely captured by a simple relationship that is frequently used for rough plant cost estimates during the early project phase:

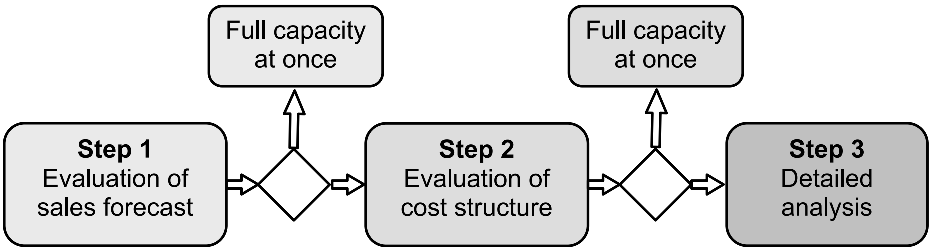
$$\frac{C_2}{C_1} = \left(\frac{Q_2}{Q_1}\right)^{CEX} \tag{1}$$

Based on a known cost C_1 of an investment of capacity Q_1 and so-called cost-capacity exponent CEX, the cost C_2 of a new capacity Q_2 can be calculated using Eq. (1). According to [2], Eq. (1) is often referred to as the 6/10-th or 7/10-th rule, since a typical first guess for values of CEX is 0.6 for pieces of equipment and 0.7 for complete plants. However, depending on the case considered, the cost-capacity exponent can vary within a range of 0.2 to 1.0. In some rare cases, values below 0.2 or above 1.0 are also found [3]. In either case, Eq. (1) can be employed as a rather simple but very useful way to roughly measure the impact of the economy of scale for a particular investment project. While small values of the CEX show that the economy of scale will play a dominant role, values close to 1.0 indicate that the opposite will hold true.

In order to decide about a potential stepwise capacity expansion, economy of scale is only one influence factor. Additionally, the sales forecast has to be analyzed. Intuitively, a forecast which only slowly increases over the prediction horizon does not support a gradual capacity expansion, whereas a significant market growth rate renders the economic benefit of such a strategy more likely. Certainly, the decision for a full-capacity-at-once or a stepwise strategy is very important and has to be taken at an early stage in the project workflow. Due to the large variety of products and production technologies of BASF's chemical process plants, a case-by-case evaluation of candidate projects based on economical criteria is required to be able to identify an optimal or at least close to optimal way of installing the plant capacity.

The method proposed in this contribution helps to quickly distinguish between projects that can or cannot (at least potentially) benefit from a stepwise plant expansion policy. This method has been developed to serve as a value-driven decision support tool in the early stage of our investment projects. It is embedded into a procedure consisting of three sequential steps as depicted in Fig. 2. In each step, a comparison is drawn between building a full capacity plant and a gradual increase of plant capacity for a particular investment project.

Figure 2: Three-step procedure for identifying candidate projects.



In the subsequent section, the proposed procedure is presented. Note that a detailed discussion of the third step – the detailed analysis – and the question how to cope with effects of *uncertain* sales forecast data is beyond the scope of this paper. In Section 3, the method is illustrated by means of a case study. The findings of this work are summarized in Section 4.

2. A method for identifying candidate projects for a stepwise expansion

By analyzing the sales forecast in the first step, a rough estimate is made whether it makes sense at all to consider stepwise plant expansion scenarios and if it is worth going further into depth in the subsequent steps. The result of this step is condensed into one single indicator that serves as a link to the second step of the proposed procedure, the check for technical feasibility. Here, the cost structure of the investment project and key process modules are identified. If in these two steps it is found that a stepwise plant expansion scenario is economically attractive and technically feasible, a detailed workout of a stepwise plant expansion will become part of the engineering project in the third step. A fundamental advantage of the work flow illustrated in Fig. 2 is that a first quick estimate is obtained with very low effort based on already existing project data.

2.1. Step 1: Evaluation of the sales forecast

To assess the economical value of different plant expansion scenarios the discounted overall investment costs are calculated. The present value of the investment cost (*PI*) is determined by reducing its value by an appropriate discount rate for each time the respective cash flow is to be valued. For our considerations, these calculations also take into account investment-related expenditures minus revenues originating from tax depreciation whereas revenues from product sales are not considered.
Based on a given sales forecast, a so-called *break-even cost-capacity exponent* (*BE-CEX*) can be determined which defines the minimum *CEX* for which a stepwise plant expansion can be economically interesting at all. Thus, the *BE-CEX* defines a benchmark for the cost characteristic – in terms of the economy of scale – of the plant technology under consideration. In the following, it is shown how the *BE-CEX* can be computed.

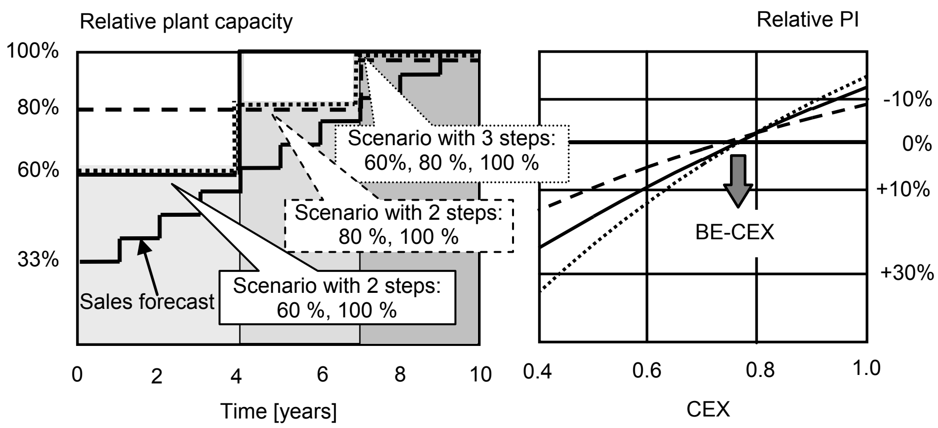


Figure 3: Typical plant expansion scenarios for a given linear and monotonically increasing sales forecast curve and corresponding relative *PI*.

The *BE-CEX* is derived using the fact that the *PI* depends on (i) a particular plant expansion scenario defined by a finite number of plant expansion steps, $i=1,\ldots,n$, the corresponding points in time t_i when the plant capacity Q_i is to be increased and on (ii) the investment costs C_i of each individual expansion. The investment costs C_i can be determined using cost estimation relations (cf. Eq. (1) and e.g. [2,3]) once the corresponding capacities Q_i are fixed.

A set of alternative plant expansion scenarios can be determined for a given product sales forecast. This is illustrated in the left half of Fig. 3 showing the increasing relative plant capacity (100%: name plate capacity) over a certain period of time, e.g. 10 years. The bold line at 0% in Fig. 3, right, indicates the *PI* of a plant for which the name plate capacity is installed in one single step as a function of the *CEX*. As expected, the *PI* of this particular scenario is independent of the *CEX*. This is, however, not the case for the three expansion scenarios. For large values of the *CEX*, these stepwise expansion scenarios are more attractive – measured by a negative relative *PI*. The opposite is true for small values of the *CEX*. As can be seen in Fig. 3, the break-even point defining equal economic attractiveness is found at the intersection of the relative *PI* curves for the different expansion scenarios with the 0%-line.

Interestingly, the three curves intersect at points located very close to each other leading to a distinct *BE-CEX* value. This observation can be made for all possible linear and monotonically increasing sales forecast profiles leading to the conclusion that the *BE-CEX* can be determined for a given sales forecast.

If the *BE-CEX* is close to 1, a stepwise strategy can be immediately ruled out, because this means that at least parts of the plant equipment with a significant contribution to the overall investment would require a *CEX* larger than 1 for a economically feasible stepwise expansion – a very unlikely case.

On the other hand, if the *BE-CEX* is significantly smaller than 1, say 0.78 as in the above example, one has to take a closer look on the cost structure and plant technology. This is done in Step 2 of the procedure.

2.2. Step 2: Investigation of the cost structure and plant technology

Entering Step 2, we already know that from a sales forecast perspective a stepwise expansion looks reasonable. In Step 2, we have to figure out whether the plant technology is suitable for that. Again, we are interested in a quick check. For this purpose, the structure of the cost estimate is analyzed as follows: The plant is disaggregated into process modules such as reactor, separation train, storage, packaging etc. Then, for each of these modules we determine its *CEX* and its portion of the overall investment cost. Thus, we obtain a compilation of all process modules, each with a separate investment cost contribution and a corresponding *CEX* and compare it with the *BE-CEX*. If there is no process module with *CEX* > *BE-CEX* and a significant share of the overall investment cost, we conclude that the plant technology does not support a stepwise expansion. Otherwise, we proceed to Step 3.

2.3. Step 3: Detailed analysis

Up to this point, the proposed method allows quick decisions requiring only a limited amount of input data. For the detailed analysis, however, this is not possible anymore. Rather, a thorough investigation of the plant technology is required in order to elaborate a specific expansion strategy, i.e. which piece of equipment has to be installed with which capacity at what time. This always depends on the individual project and, therefore, will not further be elaborated in this contribution. Here, one option is to apply a model-based approach using elements from the work presented in [4].

3. Case study

To illustrate the method, we take a brief look at a real life case study. The project deals with a polymerization process. From the sales forecast, a *BE-CEX* of 0.7 has been determined. Hence, we further proceed to Step 2. The plant can be segregated in three process modules: 12.5% of the overall investment are utility and infrastructure, with a *CEX* << *BE-CEX*. Another 12.5% of the investment are for the reactor unit. Here, we find *BE-CEX* < *CEX* < 1. The largest portion of the investment, about 75% is required for the extruder unit. *BE-CEX* < *CEX* ~ 1 in this case. Thus, after Step 2 a stepwise capacity expansion still is a feasible option. In this project, after the detailed analysis indeed a stepwise capacity expansion policy has been elaborated which proved to be economically advantageous compared to the installation of the full name plate capacity in one single step.

4. Conclusions

The production capacity to be installed is an important decision to be taken at the beginning of investment projects in the chemical industry. It has been shown that installing the full name plate capacity in one go is not necessarily the most attractive option. The optimal decision depends on the sales forecast as well as the plant technology in terms of economy of scale. In this contribution, a method has been proposed, which allows a quick evaluation of stepwise plant expansion scenarios.

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