Capturing the dynamics of facility allocation

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Introduction: a globalizing world

Recent developments such as the establishment of regional blocs like the European Union and NAFTA, the economic and political reforms in Eastern Europe and the rapid industrialization of the Asia Pacific region, illustrate the changing scene for companies nowadays. "Globalization" has become a buzzword in business; many observers consider it to be one of the big challenges for the 1990s and beyond[1,2]. Location-specific variables such as labour costs, labour productivity, energy prices, transportation rates, tariff and non-tariff barriers, taxation policies, and exchange rates tend to change rapidly. Such rapid changes alter the competitive advantage of countries and regions, resulting in shifting patterns of economic activities. These global shifts are by no means a new phenomenon. What is different in the 1990s is the sheer weight and speed of emerging competition, implying that cheap, educated labour-forces in industrializing countries are capable of operating sophisticated machinery[3]. In addition, developments in transportation and communications technologies have enabled multinational companies to monitor and co-ordinate their geographically dispersed subsidiaries, thus overcoming frictions of space and time[4].

The dynamics in the macro-economic environment poses both opportunities and threats at the micro-level of companies. This affects the "optimum" configuration of facilities in international networks. The essence of a globalization strategy at the company level is to allocate various parts of the value chain to those geographic locations where performance can be optimized. The focus in this optimization is usually on economic criteria or, to put it differently, driven by the logic of the bottom line[2]. Although maximizing profitability is of course a key issue in allocation decisions, more service-related criteria like quality and lead time reliability have become important as well. This need to consider multiple criteria implies that establishing proper allocation strategies has become a complex managerial issue indeed.

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Nowadays, large multinationals tend to have logistic networks with facilities in multiple countries and increasing volumes of border-crossing good flows.

The increasing complexity of managerial decision making on allocation issues has been met by scientific research in various disciplines. A review of the recent literature, presented in the next section, reveals that many contemporary models fail to incorporate dynamic elements. The main aim of this article is to fill this gap by presenting a dynamic allocation method to support managers in the (re)design of international facility networks. The results of a successful application of this method in a case study are also presented.

Strategic allocation issues for multinationals

Allocating facilities of multinational companies has been a popular research theme in the past decades, especially in disciplines like (business) economics and operations management. In this paper allocation is defined as determining the location, number, and capacity of manufacturing and/or distribution facilities of multinationals[5]. The focus is on strategic decisions concerning the (re)design of international networks, for example by establishing new plants abroad.

An important contribution of economic research in this field has been to establish explanatory forces for changing patterns in the international dispersion of economic activities[4,6]. In short, this type of research basically results in *ex post facto* explanations of allocation behaviour, whereas the main focus in this paper is to develop *ex ante* models to support managerial decision making.

The operations research literature contains numerous examples of such decision support models[7,8]. The objective function is usually defined in terms of cost minimization or profit maximization. These OR-models typically emphasize the mathematical formulation of allocation problems, without paying much attention to support the managerial processes involved. An interesting exception concerns a recent contribution by Billington and Davis[9] on facility strategy models at Hewlett-Packard. They describe a practical method to use mathematical programming models to support managers in developing multisite manufacturing strategies.

The literature on tools which focus more explicitly on *ex-ante* decision support is rather scarce. Recently, frameworks claiming to provide this support have been developed by Vos[5], Bartmess and Cerny[10] and MacCormack *et al.*[11]. The main contents of Vos's design method for international manufacturing and logistics will be described here, since it forms the basis for the remainder of the article. Comparisons with the two other frameworks are made whenever appropriate. Vos's design method is primarily based on three premisses:

(1) Focus support on the identification and design phases of strategic decision-making processes. Regarding the focus on identification and

design phases, field research by Mintzberg *et al.*[12] has shown that these are far more important than evaluation/choice activities.

(2) Active participation of decision makers in practical applications. Regarding management participation, managerial understanding on strategic issues can be enhanced by a proper diagnosis and the subsequent design of alternative courses of action. Previous research has also shown that participative business modelling techniques facilitate this increased managerial learning[13,14]. Bartmess and Cerny[10] and MacCormack *et al.*[11] are not so specific on the type of decision support provided by their frameworks.

(3) An integral chain approach as underlying conceptual model. Regarding the chain perspective, previous research demonstrated that an integral approach prevented sub-optimum allocation decisions and heavy organizational efforts on the wrong parts of the value chain[15]. Chain analysis is used to quantify the impact of changes in the location and/or capacity of facilities on supply, manufacturing, and distribution activities. This impact can be measured by determining the required input quantities (materials, labour, capital and energy) and the respective unit prices for alternative locations and capacity levels. In addition, factors in the international environment like taxes, barriers to trade, and exchange rates, will affect allocation strategies.

The final evaluation of alternative allocation strategies will primarily be based on economic considerations, like the estimated profitability over a period of "*n*" years. Bartmess and Cerny's[10] framework claims to have a broader scope, aiming to build a network of capabilities rather than just a network of facilities. Nevertheless, the final step in their framework also consists of a ROI-model to assess the bottom-line implications of alternative facility networks.

An attractive feature of Vos's design method is that several real-world case studies were executed. These cases all involved multinationals planning to redesign their existing networks. Subsequently, the value of the decision support provided was evaluated with the participating managers. This type of detailed empirical testing is lacking in the other two frameworks.

A drawback to all three frameworks is their static nature. which has been acknowledged in the recent literature[16,17] as well as by the participating managers in Vos's research. Still, one scarcely finds actual incorporation of dynamic elements in existing allocation models. Some mathematical models do incorporate dynamics by adding a subscript "t" to the variables. Given the relatively long time horizon required in strategic allocation issues, this indeed allows decision makers to capture developments over time. However, this is usually not sufficient to gain insight into crucial causal relations between key variables.

In summary, various recent publications on strategic allocation issues claim that existing models in this field can be improved by incorporating dynamics and "soft" variables. Still, there is hardly any empirical evidence on the practical applicability of such extended models in terms of *ex ante* decision support. The purpose of this paper is to bridge this gap between management theory and management practice.

Towards a dynamic allocation method

Extension of existing design method

Vos's original method for the (re)design of international facility networks[5], briefly described in the previous section, has been extended by incorporating a system dynamics component in the design phase. It is beyond the scope of this article to discuss this extension in full detail. Previous research has sufficiently demonstrated the applicability of system dynamics in modelling supply chains[18-20].

In essence, the extension offers several advantages:

- First of all, the dynamic behaviour of all variables can be incorporated. These variables can be endogenous (e.g. production costs, product quality) or exogenous (e.g. market demand, exchange rates, transport costs).
- It becomes possible to model explicitly an incremental implementation strategy for relocation, thus improving the fit with reality. Moreover, the implementation stage tends to be a critical period for the eventual success of allocation strategies.
- Another advantage is that system dynamics models allow decision makers to obtain additional insight into critical cause-effect relationships. Active management participation in model building, using graphical (causal) models, is essential in facilitating this learning process[5,20].
- A practical advantage of most system dynamics software packages is that they allow for a rapid execution of various scenario analyses. Such analyses are always necessary to assess inherent risks and uncertainties in the global business environment, but often such assessments prove to be technically cumbersome.
- Finally, the system dynamics modelling "toolkit" contains various techniques for incorporating "soft" variables, such as employee skills and the impact of expatriate management on foreign plant performance. Such variables can be difficult to quantify but are crucial for a proper assessment of alternative allocation strategies. Very few allocation models explicitly incorporate soft variables[11].

Tools to support dynamic modelling

Various tools and techniques are available to provide support in strategic decision-making processes[20]. The tools described in this section (causal diagramming, stocks and flows diagramming, graphical functions, and dynamic simulation models) are primarily intended to show how the benefits of dynamic modelling can be operationalized to extend Vos's design method. Examples of the case study to be presented in the next section are used to illustrate the applicability of these tools in studies on strategic facility allocation issues.

Causal diagramming. The main purpose of causal diagramming is to identify the causal links that exist between the relevant variables. Often, these causal links lead to circular connections, to so-called feedback loops. This "feedback thinking" lies at the heart of system dynamics modelling and is fundamentally different from so-called "linear thinking"[21]. Figure 1 shows some key causal relations that determine the economic feasibility of plant locations in less-developed countries.

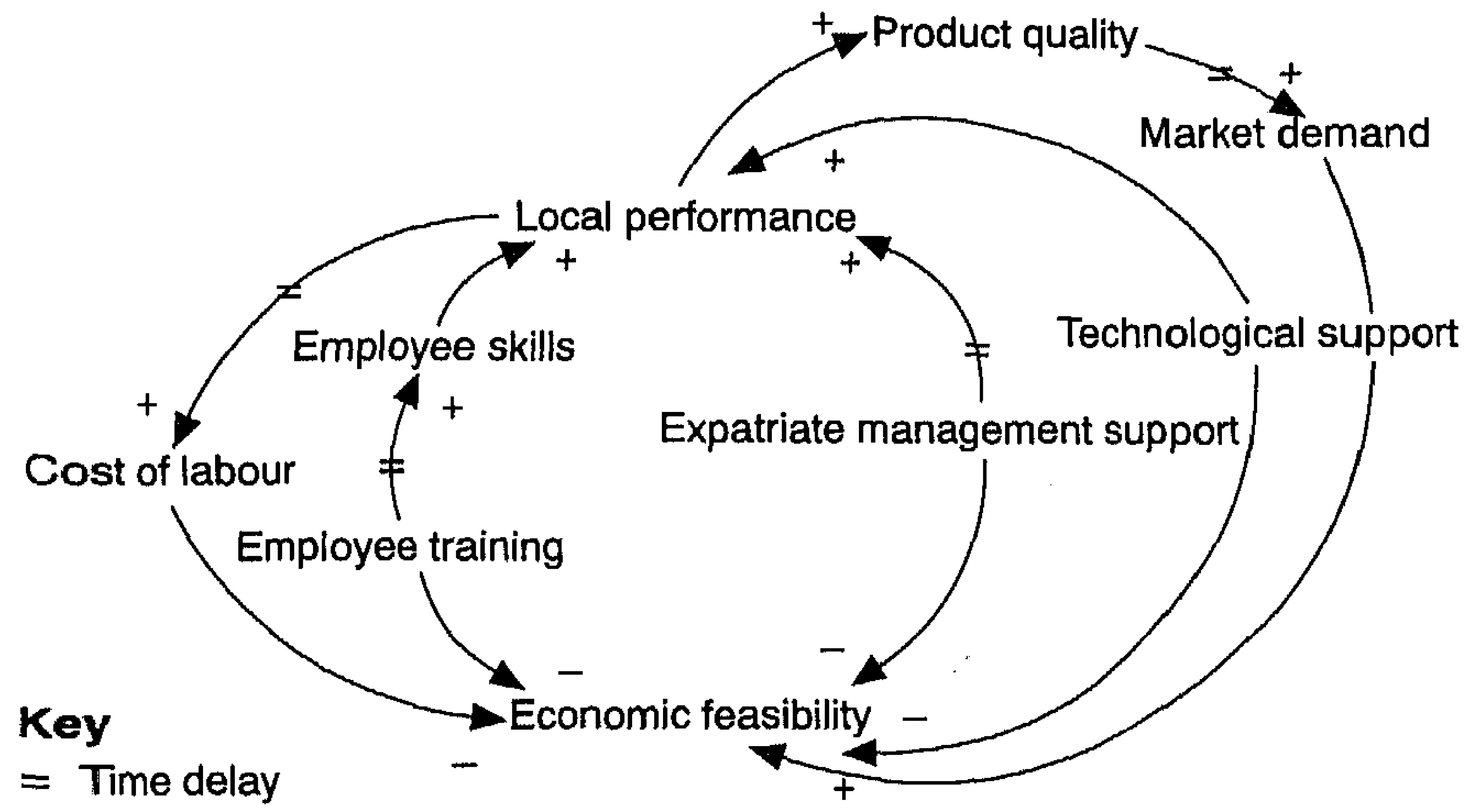

Figure 1. Examples of key causal relations in allocation issues

In Figure 1 it can be seen that several interrelated trade-offs have to be made, also involving "soft" variables. Simply focusing on prevailing low wage rates will cause disappointing results if other aspects like logistics, local productivity, co-ordination, and quality issues are ignored[5,10,15]. Explanatory factors for a lower performance in less developed countries can broadly be classified into three categories: organization, technical system, and human skills. Some specific measures to increase local performance are respectively to appoint expatriate managers, technology transfer, and training of employees. Such measures do have a negative effect on the economic feasibility in the short run, but the time delays depicted in Figure 1 imply that benefits due to performance improvement can be expected in the long run.

Stocks and flows diagramming. Stocks and flows diagrams are used to model the relations between various variables in a continuous system. A distinction is made between flows of resources and the mechanisms that regulate these flows. An interesting feature is that this technique can be applied to model multiple resource flows such as materials, orders, money, and personnel. Figure 2 shows an example of a stock and flows diagram for material and personnel flows in a production system.

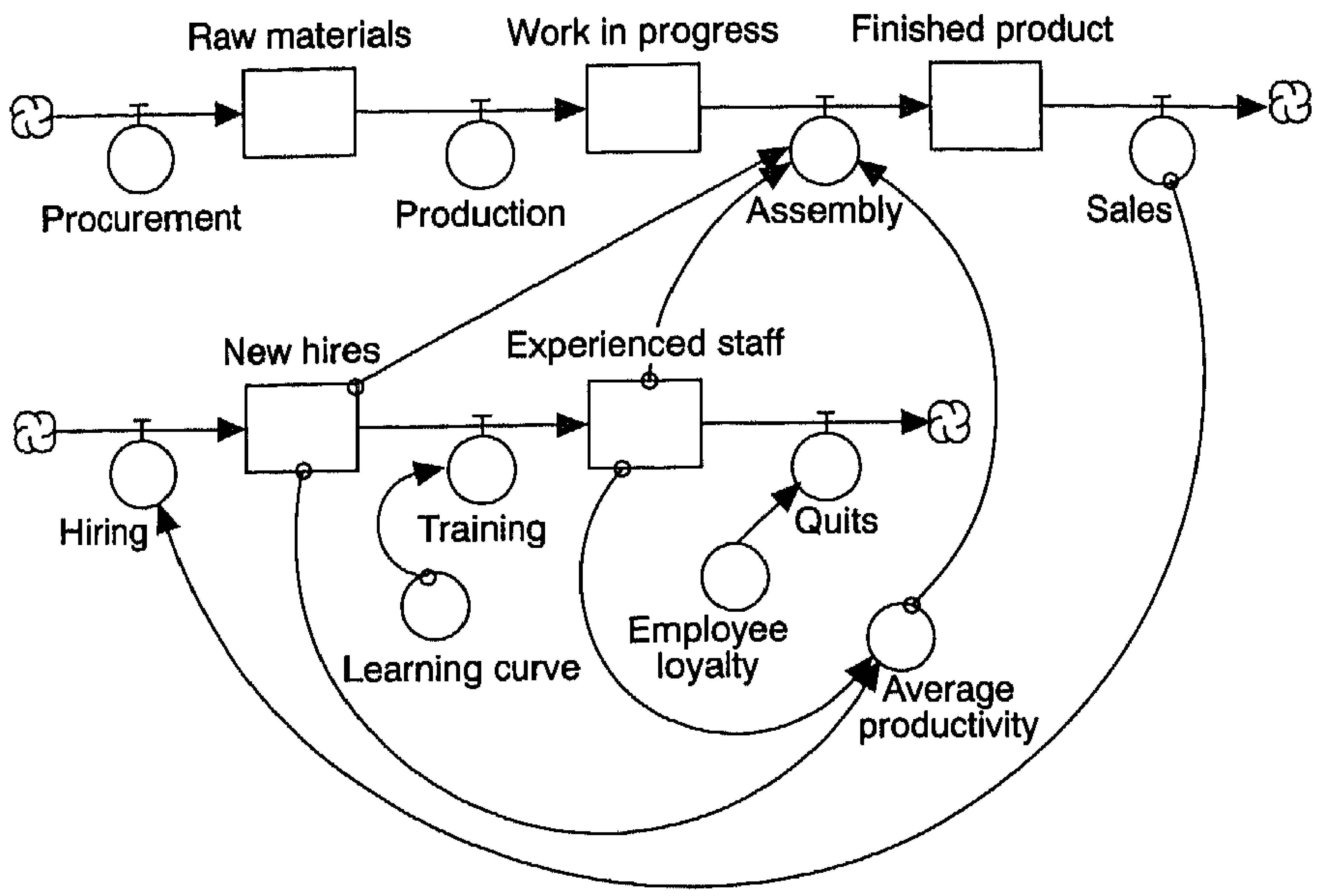

Figure 2.
Stocks and flows diagram of some material and personnel flows in case study

A supply chain consists of various processes in which raw materials are transformed into finished products. Each process has different characteristics, making it more or less attractive for a relocation to less developed countries. An important success factor is the labour productivity in such countries. As shown in Figure 2, one of the factors influencing average productivity is the mix between new and experienced employees. Training of new employees will increase their productivity, but also their attractiveness on the labour market. In combination with a low level of loyalty to the employer, this is likely to result in a high percentage of labour turnover, which in turn has a negative impact on the average labour productivity.

Graphical functions. Strategic business modelling exercises are often plagued by a limited availability of data, particularly when dealing with soft variables. Graphical functions can be useful to overcome this lack of data by drawing a plausible relation between two variables. Drawing such a relation typically requires an iterative procedure with participating managers. Eventually, a curving of the relation that is acceptable to everyone will be developed. An example of such a graphical function is shown in Figure 3.

Training of employees is likely to have a positive effect on performance (see Figure 1). The ability to learn new skills to a great extent determines the magnitude of this effect. An S-shaped growth curve, rather typical for learning processes, is used in Figure 3 to model the impact of this "soft" variable. The steepness of this curve can, for example, be influenced by expatriate management support and by varying the intensity of training programmes. A steeper curve implies enhanced performance on indicators like labour

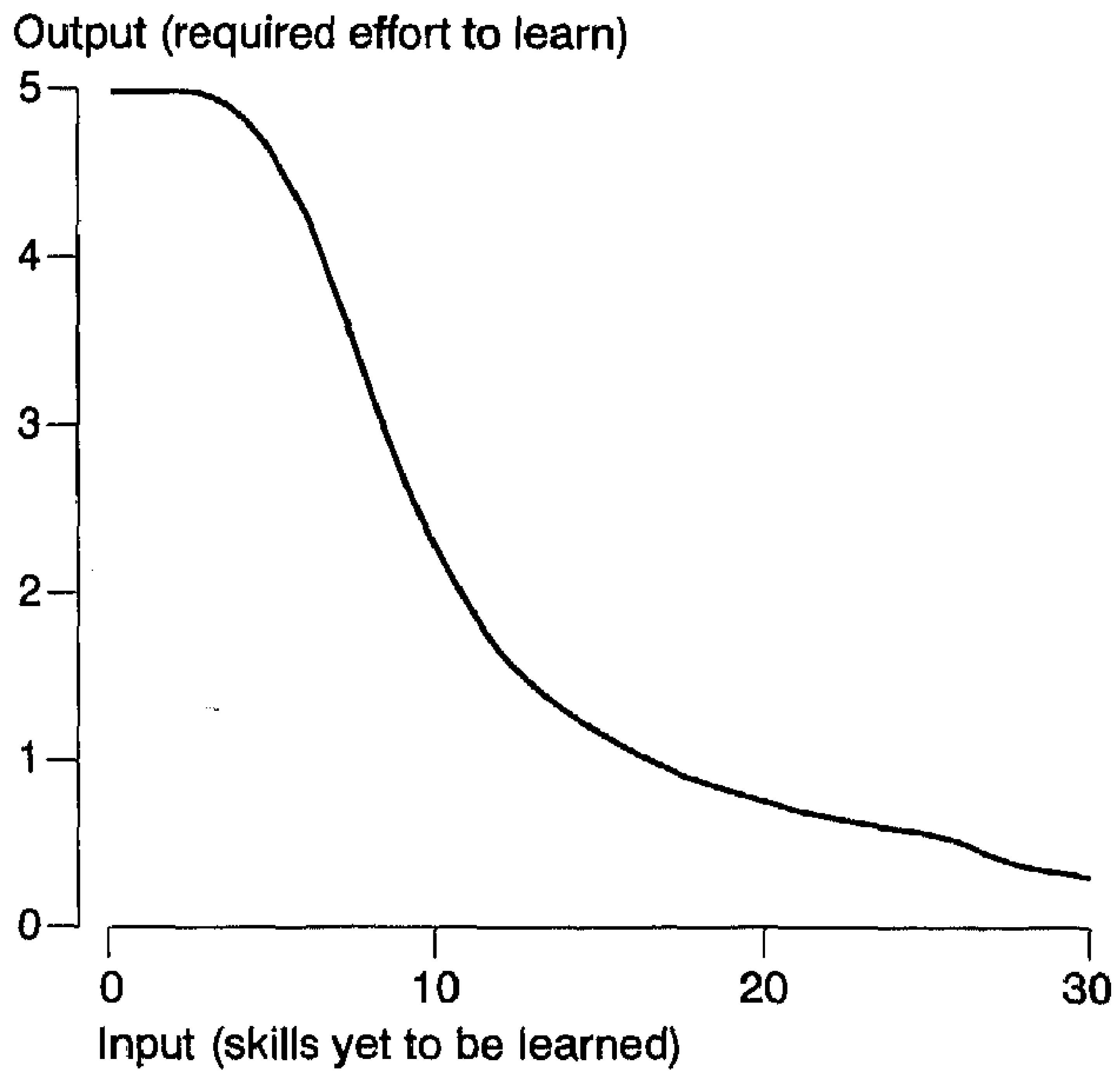

Figure 3. Graphical function for the relation between learning ability and performance

productivity and reliable product quality. The latter is a necessary condition to supply Western export markets.

Dynamic simulation models. The tools described in this section are important building blocks of system dynamics simulation models. The main aim in these models is to reproduce the behaviour of a (real-life) network of interconnected flows over time. In mathematical terms, such continuous systems are represented by linear and non-linear differential equations. In most available software packages, these equations are created simultaneously with the creation of stocks and flows diagrams[20].

System dynamics models usually comprise a large number of interrelated variables. It has become common practice to summarize the values of key variables in a so-called control panel. The dozens of other model variables are kept out of sight. This presentation technique allows managers to monitor patterns in a system's behaviour without being bothered by too much detail.

Management participation

The importance of managerial involvement in applications of Vos's (extended) design method has already been emphasized earlier in this article. Still, the extent of this participation has not yet been operationalized. Figure 4 shows some important roles of participating managers in various phases of the design method.

At the outset of a study, it is important to arrive at a proper problem definition. Participating managers should explicitly state their perception of opportunities, problems, and/or crises evoking decision making. Management's main participative role is in the design phase. In the static part, their expertise

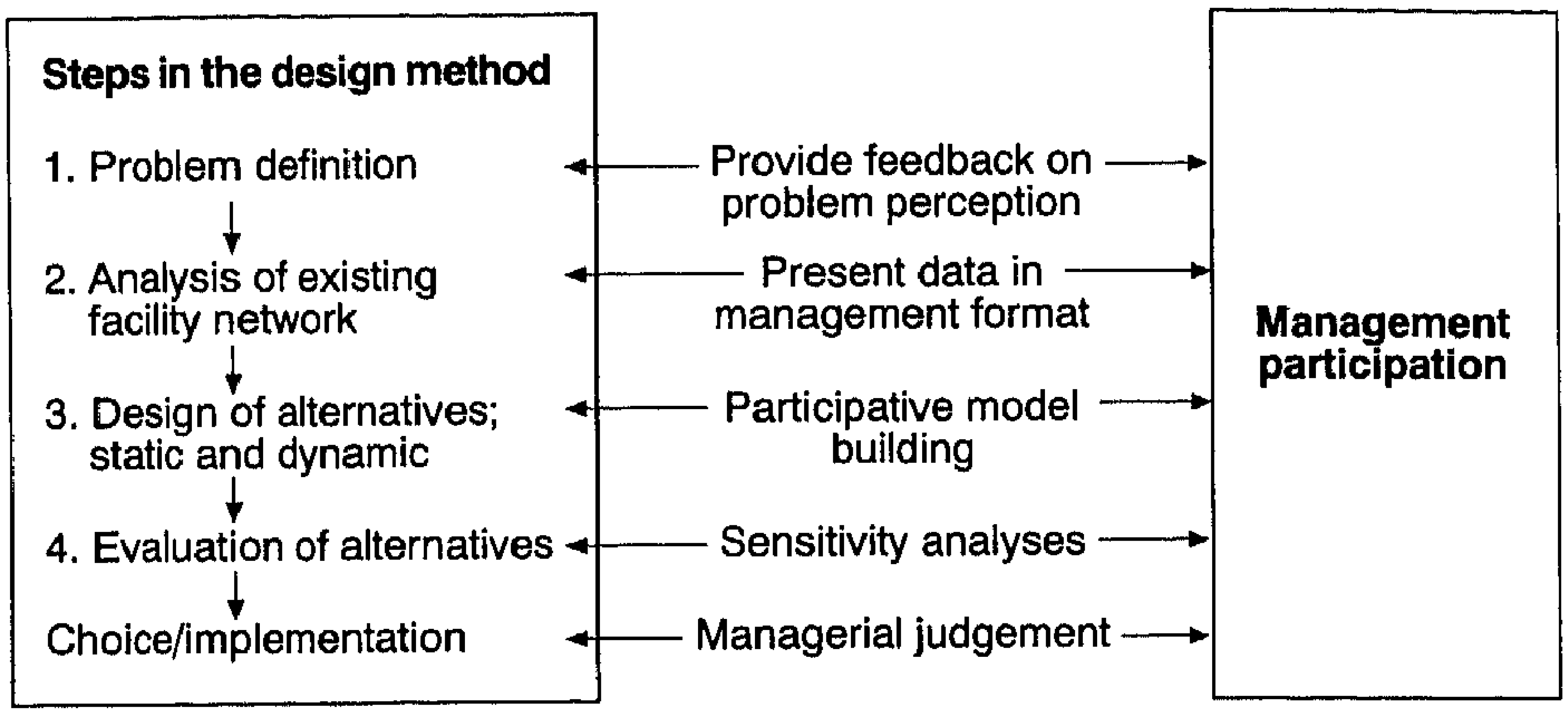

Figure 4. Management participation in various phases of Vos's design method

is required to construct so-called model plants for alternative locations and/or annual capacity levels[5]. At least one of the participating managers should be actively involved in the subsequent building of the system dynamics model. This facilitates the communication of results to other members of the management team, needed to actually contribute to enhanced understanding of strategic allocation issues. Structured discussions should evoke managers to come with their main "what-if" questions, thus providing the input for sensitivity analyses.

Finally, it is unlikely that ultimate decisions will solely be based on results of this rational-analytical approach. Decision makers have to make a subjective trade-off between estimated profitability and perceived risks and uncertainties. Stated differently, the rather factual evaluation of alternatives is supplemented with managerial experience and intuition[5,12].

Case study: to relocate or not to relocate

The strategic allocation issue of the client company

The client company was a mid-sized company in the Dutch metalworking industry. Its annual turnover in 1994 was about US$15 million, mainly supplying sanitary-ware products to the construction sector. The company realized over 95 per cent of its sales in The Netherlands. This "local for local" strategy is a rather common characteristic for this industry in Europe.

The client company's management team was considering to establish a plant in China, primarily to increase its cost competitiveness. Low costs were regarded as a critical success factor for this manufacturer of a relatively small range of standardized products, utilizing mature technologies. A secondary motive for choosing China as a potential location was to become involved as a supplier for the rapidly growing local building industry. A combination of these motives was expected to result in a gradual implementation of a relocation strategy, as shown in Figure 5. Initially, a Chinese plant would sell its products on the local market, gradually starting exports to Europe, provided that reliable

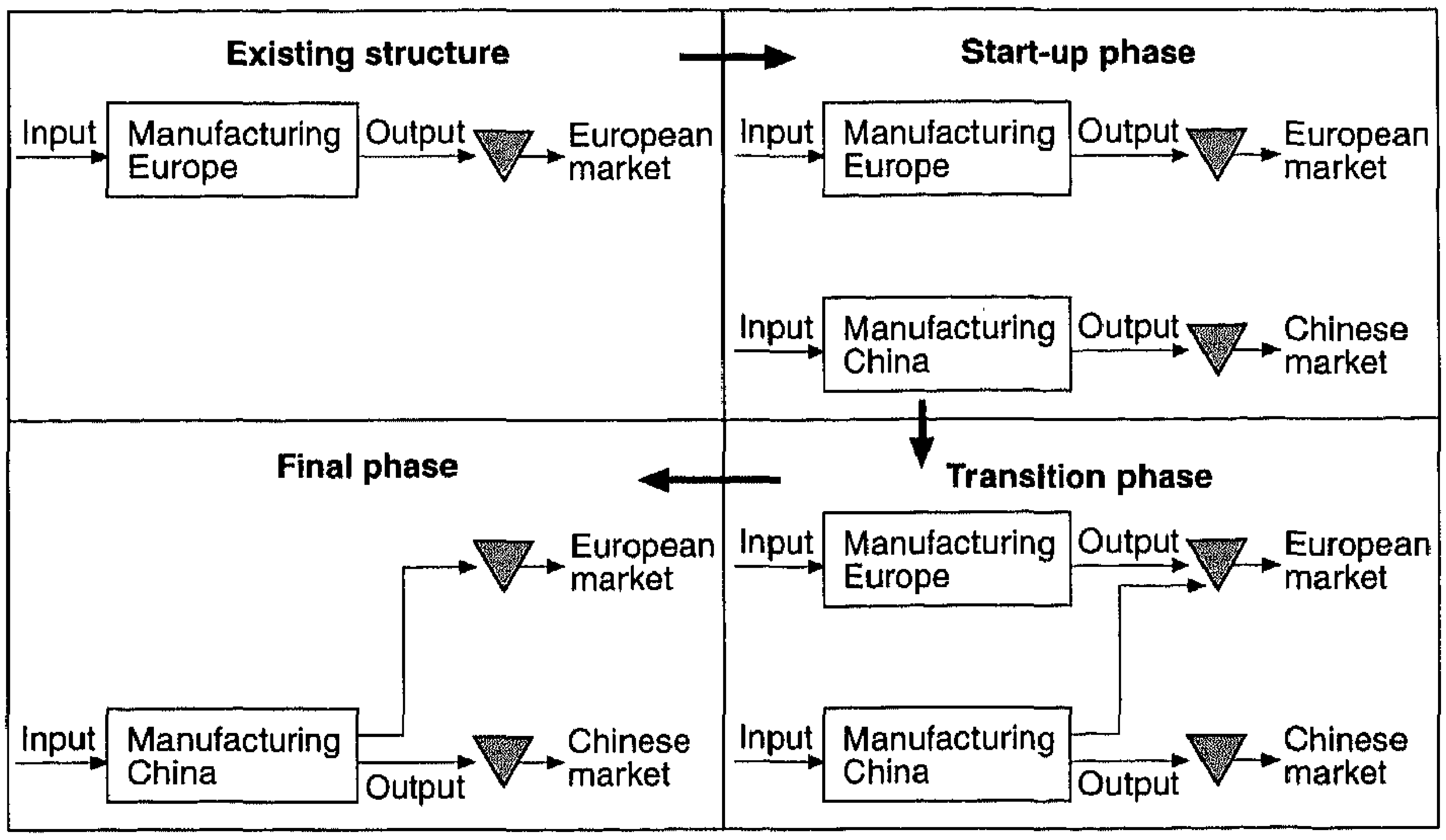

Figure 5. Gradual implementation of a potential relocation to China

product quality and lead-times could be achieved. In the final phase, all manufacturing activities might be relocated to China. The remaining European organization would be responsible for activities like sales, distribution, and after-sales service.

Project synopsis

Vos's design method extended with the tools described in the previous section, was applied to provide support in this strategic decision-making process. In this way, the participating managers should be able to evaluate the bottom-line benefits, and the underlying causes, of a potential relocation to less developed countries.

The research team for this project consisted of three persons. Each of these three focused on a particular aspect of the modelling process. In the terminology of Akkermans[20], the first author acted as an expert coach with specific knowledge on international allocation issues. The process coach role, facilitating and monitoring the model building process, was the second author's main responsibility. The third team member acted as model coach, responsible for data collection and analysis and the actual programming of the simulation model. The client company was also represented by three persons. The manufacturing manager was mainly involved in the static part of the analysis, the controller provided the required access to financial data. The general manager was the project sponsor and the main problem owner.

Total project duration was about ten months. The main project aim was not merely to "solve" the China issue, but rather to develop a tool to support future strategic allocation decisions. Various workshops were organized throughout the project, particularly to support the modelling process. In these workshops management assumptions about the anticipated consequences of a relocation were systematically made explicit, challenged, and further refined.

Static analysis: production function comparison

A cost comparison was made between the existing Dutch situation and a situation in which all production activities would be relocated to China. This limitation to the final phase of a relocation (see Figure 5) was one of the reasons to label this part of the analysis as static. Two other reasons were the use of current cost figures, without taking anticipated changes into account, and a fixed annual capacity of 500,000 pieces, being the present output of the Dutch plant.

Due to these restrictions, the results of this static analysis were merely useful to obtain some initial insight into the potential benefits of a relocation to China. This was achieved by establishing a production function for a Chinese plant. This implied determining the required quantities of input materials and of the production factors labour, capital and energy, given a certain volume of finished products. Since these inputs are far from homogeneous categories, this production function should be as detailed as possible[5]. Important subjects in the production function analysis were technology selection and estimates of the Chinese productivity level. Subsequently, a cost function was obtained by multiplying the required quantities of the various inputs with the respective local unit prices. The initial data on relevant Chinese unit prices were based on desk research, verified during a field trip to China.

The results of the static analysis revealed that the estimated Chinese cost advantage would be very small, less than 5 per cent, given the current output level. This rather surprising result was mainly caused by the relatively high costs associated with the remaining Dutch organization (see Figure 5). Thus, the present scale of the client company appeared to be too small to justify a cost-driven relocation. Additional calculations demonstrated that the company's strategy to increase its turnover in Europe would indeed enhance the attractiveness of investing in China. The estimated Chinese cost advantage, using current cost data, would increase up to 25 per cent for a European turnover of US$100 million. These findings reconfirmed the general manager's intuitive ideas at the start of this project.

Dynamic analysis: system dynamics modelling

Building the system dynamics model was basically a joint effort of the model coach and the controller, with regular feedback from the other members of the project team. Causal diagrams, stocks and flows diagrams, and graphical functions, like the ones shown in the previous section, were used in this modelling process. The resulting system dynamics model looked rather complex, incorporating a considerable number of relevant causal relations and linking physical, personnel, and financial flows. Validation of such a complex model is always essential if it is to be used by a company's management team to support strategic decision-making processes. One relatively straightforward test in this case was to use the detailed data of the static production function analysis as input for the system dynamics model. A comparison of the calculated profitability in both models yielded a difference of less than 5 per cent.

Some important simulation results regarding the cumulative profitability in five scenarios are shown in Figure 6. The time frame has been limited to a period of seven years. Beyond this period it is impossible to predict the value of certain variables in the highly volatile Chinese environment. The base run (line 1 in Figure 6) reflected the most likely scenario, as perceived by the project team. This base scenario was deliberately kept on the safe side. Rather pessimistic estimates were made of Chinese price increases (e.g. for wages, housing and materials), productivity improvements and of the time period during which expatriates would be required. Obviously, this had a negative effect on the financial feasibility of an investment in China. However, reported experiences with establishing and operating manufacturing plants in China provided support for this cautious approach[22-24].

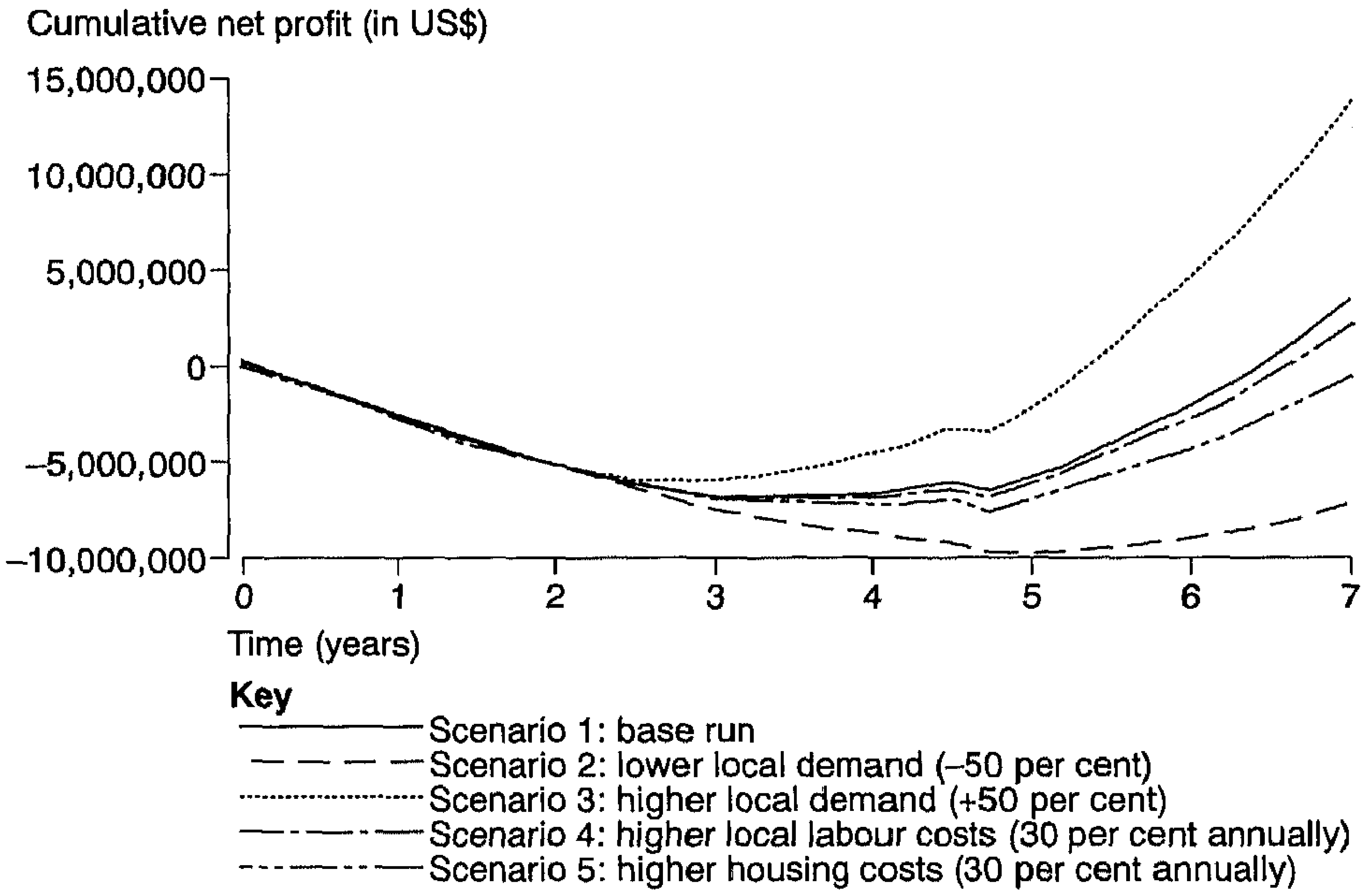

Figure 6. Cumulative profitability of a Chinese plant for five scenarios

The results of this base case were not very promising in terms of profitability, mainly due to relatively low utilization rates in the start-up phase and to relatively high costs for expatriate management support. Building on this, sensitivity analyses were made to quantify the consequences of changing certain assumptions. The main uncertainty perceived by the client company's managers concerned market demand in China: What happens with profitability if our Chinese sales volume is substantially lower (e.g. 50 per cent) than assumed in the base scenario? And what if Chinese sales are substantially higher? As might have been expected, financial performance indeed proved to be very sensitive to demand fluctuations (see Figure 6).

The financial results were far less sensitive to increases in wages and lease prices of buildings. The latter findings were important since the field research in China indicated that it was quite plausible for wages and lease prices to increase more rapidly than assumed in the base case. Lines 4 and 5 in Figure 6 reveal that the impact of annual price increases in these categories of 30 per cent instead of 10 per cent for the next seven years would be rather limited. One explanation for this finding was that a large part of labour costs consisted of compensation for expatriate management, which is not sensitive to changes in local wage levels.

Managerial implications

As will be obvious from looking at Figure 6, the management team decided not to establish a plant in China. The present turnover of the client company was too small to justity a cost-driven relocation. In addition, the start-up phase in China would require substantial efforts, thus costs, to assure satisfactory performance levels. Establishing a plant in China might still have been attractive for more strategic, market-oriented motives. However, market share would have to be built up from scratch, whereas other, bigger competitors had already established themselves in China. A thorough market analysis, not included in this project, would be required prior to a market-driven investment decision, especially given the sensitivity to lower sales volumes.

This "no go" decision also illustrates the importance of managerial judgement in decisions on strategic allocation issues. The perceived risks and uncertainties associated with investing in China were too high. Nevertheless, the participating managers were very positive in an evaluation of the process. The participative modelling approach greatly enhanced their understanding of the trade-offs involved in the (re)design of international facility configurations. Management indicated that they intended to use the system dynamics model to investigate the potential for a gradual relocation to Eastern Europe. A sister company established a joint-venture with a local partner several years ago. Substantial efforts in terms of management and technological support had already been made. It was anticipated that the start-up of an additional manufacturing unit in this existing Eastern European joint venture would be considerably easier compared with starting from scratch in China.

Conclusions

It can be argued that one case study is not enough to arrive at general conclusions regarding the value and applicability of the proposed dynamic allocation method. Still, experiences with system dynamics modelling techniques in other strategic decision-making processes have yielded valuable results for the participating managers as well[20]. Positive feedback was also obtained from the managers participating in the practical applications of Vos's original design method[5].

Therefore, it is plausible to translate the results presented in this article into three tentative messages for the field of operations management (OM). First, recent advances in both software and new facilitation-oriented approaches to modelling, can increase managerial acceptance and use of system dynamics techniques for OM issues. The system dynamics model developed in the case study was tested for only one specific problem (relocation to China), but due to the participative approach it can also be applied to support future allocation decisions. In this sense, the case results have definitely contributed to increased organizational learning for the client company.

Second, static analyses of complex facility allocation issues do not do full justice to the inherent dynamic nature of these issues. In this case study, particularly the variables market demand forecasts and the time to realize a satisfactory local performance level were found to be critical success factors. Estimated changes in required quantities and unit prices of the various inputs should be taken into account as well.

And finally, "soft" variables are important in assessing the performance of foreign plants. In the case company's relocation problem, training of Chinese employees in combination with a relatively low level of employee loyalty resulted in a substantial labour turnover in the course of time. This dynamic behaviour in turn reduced the anticipated positive impact of training on the Chinese plant performance. This study thus demonstrated that it is feasible and indeed essential to incorporate "soft" variables as employee skills, employee loyalty, and the impact of expatriates on local performance into predominantly quantitative analyses of strategic allocation issues.

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