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Cost modelling as decision support when locating manufacturing facilities

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Abstract: This paper presents a methodology for cost estimation in developing decision support for production location issues. The purpose is to provide a structured work procedure to be used by practitioners to derive the knowledge needed to make informed decisions on where to locate production. This paper present a special focus on how to integrate cost effects during the decision process. The result is a structure of cost estimation tools aligned to different steps in the work procedure. The cost models can facilitate both cost estimation for new production configurations and cost simulations to analyse the risks of wrong estimations and uncertainties in the input parameters. Future research aims to test the methodology in ongoing transfer projects to further understand difficulties in managing global production systems. Cost is usually estimated, in existing models and methods presented in the literature, on a too aggregated level to be suitable for decision support regarding production system design. The cost estimation methodology presented here provides new insights on cost driving factors related to the production system.

Key words: Cost analysis, Location decision, Production cost.

1. Introduction

To be competitive and increase profitability, many manufacturing companies have to enter the global arena in both sales and production (Aspelund and Butsko, 2010; Rusten and Bryson, 2010; Bell *et al.,* 2003). This need for internationalisation results in board decisions on manufacturing relocation in the form of both outsourcing and manufacturing of products at plants in new locations. In discussions of moving manufacturing activities, three distinct terms are used: relocating, offshoring, and outsourcing. Relocating refers to moving manufacturing activities within the company, between national or international sites (Kinkel *et al.,* 2007). Outsourcing refers to transferring manufacturing activities from internal control to external control, mainly to reduce the production cost by letting a subcontractor to produce the product at a lower cost than the contractee can (Nordigården, 2007). Offshoring refers to moving the manufacturing activities of a company abroad. Note that offshoring can refer to both manufacturing relocation and outsourcing (Kinkel *et al.,* 2007). This paper will concentrate on company relocation and the establishment of new processes and facilities within the company. The aim is to support companies in making informed decisions on production of key products and to facilitate the make or buy process.

A German survey conducted by Kinkel *et al.* (2007) compared the motives for offshoring with those for back-sourcing. The survey found that 87% of the studied companies considered production cost factors as the main drivers of offshoring, while 52% considered production costs as the main drivers for back-sourcing. The survey indicated that costs were a main reason for corporate offshoring and back-sourcing. Companies also back-sourced in order to supply particular sites and customers and to coordinate costs. In the case of offshoring, the ability to supply customers was a key factor, whereas coordination costs were of minor importance. The survey found that companies frequently overestimated the cost benefits of offshoring and did not completely understand the conditions at the new location. Platts and Song (2010) interviewed informants from several companies that had outsourced to China, finding that costs ended up 25–50% higher than quoted. Some studies find that relocation decisions are based on inadequate and uninformed consideration, often resulting in manufacturing activities eventually being repatriated to their original location (Whitten and Leidner, 2006;

Kinkel, 2009). The survey performed by Kinkel *et al.* (2007) indicated that approximately 20% of the 1450 surveyed German companies had conducted some sort of back-sourcing. As evident from the above studies, one important reason for relocation is cost. One possible conclusion from the above investigations is that companies could benefit from structured decision support which integrates various costs associated with relocating the production.

This paper will present a cost analysis methodology which can be integrated in a decision process for production location. The decision support was developed during a research project, aiming to facilitate manufacturing footprint decisions. The project, which aimed to develop a structured cost-based decision support for production relocation issues, was a three-year collaboration between five companies and two universities. The developed decision-support process, based on stage-gate principles and previously published in Andersson *et al.* (2013) and Bellgran *et al.* (2013). The work procedure aims to support the decision process preceding the realisation of a production location decision, and involves selecting and comparing various location alternatives. The user is guided through a series of activities in each step supported by a variety of tools and templates for analysing, for example, the costs and risks in each step. The process consists of five sequential phases representing the main activities in a location decision process:

1. *Initiation* - Establish motives and goals for changing the manufacturing footprint.
2. *Scoping* - Establish a project organization and plan for executing the relocation project and roughly estimate the costs and benefits.
3. *Pre-Study* - Analyse the current footprint and the requirements for and consequences of changing the footprint.
4. *Generation of alternatives* - Establish and analyse various location alternatives.
5. *Location selection* - Prepare to select the most suitable production location.

The last four steps of the work require different types of cost analysis at different levels of detail. The aim is to capture all costs affected by a change in location. The scoping phase (2) requires rough estimates of market potential, investment range, and project organisation. For this purpose, a rough business case design has been presented by Windmark and Andersson (2014). When analysing opportunities within the current manufacturing footprint (Phase 3) and different location alternatives (Phase 4), a more detailed cost analysis is required. Costs associated with production ramp-up, skills provision, and the impacts of moving products from an existing production site also need to be considered, motivating the development of several cost analysis tools for the different phases. The cost analysis methodology and tools presented here are connected to Phase 3 (P3) and Phase 4 (P4), as showed in the list below. Those marked with "*" are presented in this article, while the others are presented more as concepts:

- Current manufacturing cost analysis (P3)*
- Cost for supporting processes (P3, P4)*
- Cost impact of relocation (P3)
- Checklist of location factors (P3)*
- Scenario cost analyses of manufacturing (P4)*
- Installation and ramp-up cost analysis (P4)
- Costs for knowledge & skills provision (P4)

2. Parameters and Models

The following section reviews the literature on the parameters used when evaluating locations and designing decision supports. The purpose is to investigate the parameters, categories, functions, and stages included in existing location models and decision-support models.

2.1. Cost Parameters and Factors for Location Decisions

The importance of considering cost minimisation and other cost-driving factors is highlighted in Boloori *et al.* (2012). They have classified facility location models in logistics and production, demonstrating that 48 of the 66 reviewed papers had the minimisation of cost, time, distance, and risk as the main objectives. Numerous studies address the importance of cost awareness (MacCarthy and Atthirawong, 2003; Fang and Weng, 2010; Platts and Song, 2010), identifying the important cost groups as personnel costs, project costs, and investments, but no thorough analysis or decision support focuses on the cost influence of the combined financial impact of relocation.

McCarthy and Attirawong (2003) identified five major factors that may influence location decision: costs, infrastructure, labour characteristics, governmental and political situation, and economic factors. Kinkel *et al.*'s (2007) survey of German companies revealed that the main driving forces of offshoring in the investigated companies were access to low-cost production factors, access to markets, support of trade and distribution, proximity to customers, support of services, access to technologies, access to resources and materials, ability to counter-attack competitors, the search for strategic assets, tax incentives and benefits, and access to excellent infrastructure. Ellram *et al.* (2013) compiles a list of the driving factors of current global manufacturing location decisions; these factors include logistic costs, shipping time, supply chain response and recovery time, labour costs, labour productivity, environmental issues, currency stability, and theft of intellectual property.

2.2. Models and Processes for Location Decisions

Yang and Lee (1997) present a decision model based on an analytical hierarchy process (AHP) consisting of seven steps: (0) justifying and identifying the facilities, (1) identifying location factors, (2) developing priority weighting, (3) collecting data and ranking the potential locations, (4) analysing comparative results, (5) identifying preferred site(s), and (6) making final recommendations. The model acknowledges that often no location is "optimal" but that different sites can have different advantages so that, after some compromises, the best option can be found. The model focuses on the relationships between factors for each site, presenting relative rather than absolute preference information. One of the difficult steps in the model is that of developing adequate priority weighting, which can be facilitated by factual knowledge and actual cost information. The model only indicates the best alternative based on the inputs and not whether it is profitable to move manufacturing to the actual location.

Christodoulou *et al.* (2007) present a decision support for relocation, providing companies with strategies for gathering and evaluating data. It is a wide-ranging tool, focusing more on qualitative than quantitative parameters and thus lacking in-depth general manufacturing analysis and cost calculations and estimates.

A decision model for production location presented by Dogan (2012) combines Bayesian networks and total cost of ownership. Their literature study is extensive and cites several examples of relevant papers in the field. The model has four steps identifying: (1) supplier selection criteria, (2) factors, (3) cost elements, and (4) total costs. The model combines qualitative parameters such as labour skills and worker motivation with quantitative parameters such as wages, when estimating the labour costs.

Many production location models include costs, but often omit guidelines for making the needed estimates (Yang and Lee, 1997; Christodoulou *et al.,* 2007; Dogan, 2012). The present literature survey identifies a need for improved cost estimation when relocating and outsourcing, due to higher-than-expected final costs (Platts and Song, 2010). Costs have been demonstrated to be crucial when relocating, so a model based on cost estimation can be considered very useful. The literature survey identifies a gap in how cost estimates are integrated into current support frameworks. The location decision support tools found in the literature do not involve extensive cost analysis taking production performance into consideration and therefore do not closely quantify the cost impacts.

3. Method and motivation

The literature review indicates that cost is considered a key factor when locating production. Nevertheless, the literature overlooks how manufacturing costs are integrated into current decision support models for production location. The development of the location decision support presented here was motivated by industry statements on the need to integrate cost effects into the decision process. Research methods involving the industrial partners were selected because the research performed has a strong industrial motivation. The working process and its tools and templates were developed in parallel through interviews, literature studies, observations at companies, participation in case studies at companies, frequent discussions and workshops at the participating companies, and validations in the research group. During the workshops and interviews at the companies, the companies' requirements in terms of costs, risks, and strategic analyses were discussed. This resulted in a work procedure to support the decision making in a production location project; this procedure is a five-step stage-gate model together with a selection of cost-based tools and templates, all documented in a handbook (Andersson *et al.* (2013).

The main purpose of this paper is to describe the cost tools developed in connection with phases P 3 and P 4. The literature presented above and a previous interview study (Windmark and Andersson, 2012) indicated that a wide range of parameters and factors are needed, suggesting that a location-decision support model must include extensive analyses. The developed tools were then presented to the participating companies during workshops and projects in which input was given to ensure industrial relevance and possible implementation. The paper presents economic estimates used in a decision-support process taking specific manufacturing considerations from a particular location into account and combining manufacturing performance with location-specific parameters. In addition, analyses of costs associated with other supporting activities in the supply chain are included in the model. The goal is to present a method for deciding if a new location provides more cost advantages than the current one or which of several alternative locations provides the most cost advantages. This paper proposes a structure for analysing production costs to be used when making location decisions.

4. Cost Estimations and Simulations Supporting Location Decisions

The costs affected by a change in manufacturing footprint depend on the organisational changes driven by the footprint change and by the costs of implementing them. When the production of a certain product is moved, individual sites might be subjected to changes in product ranges and capacity, causing increased costs for the remaining products manufactured at those sites. According to Simons *et al.* (2000), the work-process functions included in the most basic organisations are a marketing and sales unit, controller's department, information technology (IT) department, and production unit. Since the location analysis method presented here focuses on the design and performance of the production system, the cost of the production unit is broken down into manufacturing process costs and costs of the support functions necessary to deliver products to customers on time. Figure 1 illustrates the basic structure of the manufacturing system cost drivers used to develop the cost analysis tool structure in phases P 3 and P 4 of the process presented here.

The consolidated cost analysis assembled in phase P 5 of the work procedure includes the integrated impact of the cost drivers; (1) manufacturing processes, (2) production support functions, (3) impact on current location, (4) knowledge provision and (5) ramp-up and testing.

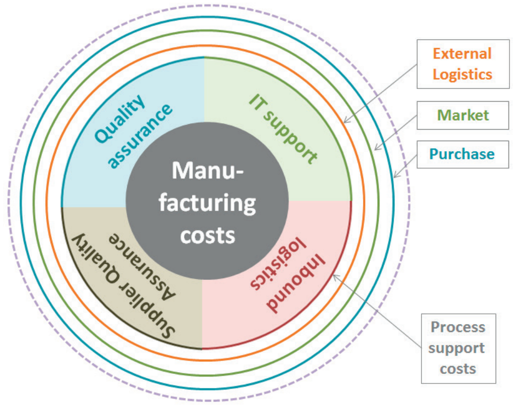

Figure 1. Cost structure of a manufacturing operation used for cost tool development.

The costs of knowledge provision in the new site, process testing, and ramp-up are cost drivers that must also be accounted for in a complete analysis. These costs can be regarded as generated before production starts and can be treated as investments in equipment and, in the end, be included in the process cost. In this paper, the cost analysis methods developed for manufacturing process costs and production support process costs are implemented in separate Excel tools. The concept of part cost is used, meaning that all costs are presented per unit. Different distribution keys (e.g., annual production volume) are therefore used to transform department and personnel costs when necessary.

A crucial factor when establishing a knowledge-based decision support is the quality of input data. Data acquisition can be a challenge for both existing and new production sites. To adopt a structured approach, Bjelkemyr *et al.* (2013) suggest categorising location parameters based on the various functions of a corporate organisation:

1. *Sales and marketing*: market price, market share, costs of the marketing and sales division, etc.
2. *Sourcing and purchasing:* raw material price, costs of purchasing division, etc.
3. *Legal and finance:* interest rates, tax levels, costs of regulation investigations, etc.
4. *Facilities and IT:* building costs, hardware & software costs, infrastructure costs, etc.
5. *Human resources:* salary costs, insurance costs, moving costs, pensions, etc.

6. *R&D*: additional personnel and office costs, moving costs, etc.
7. *Operations*: salary costs, equipment investments, performance, energy costs, etc.
8. *Installation and ramp-up*: travel, living, and personnel costs; testing costs, installation costs, etc.

The last item on the list is an activity, rather than a corporate function, often necessary when establishing a new manufacturing unit and changing locations.

Based on the above categories, we propose a checklist to provide the various cost analysis tools with the required input data. The checklist serves as a gross list of input data and is aligned with the data requirements of the cost analysis tools. A trade-off always exists between the effort spent acquiring information about the production system and the possibility of making well-informed decisions; the purpose of the checklist is to provide insight into important cost-driving factors and parameters. The checklist contains a total of 69 quantitative parameters structured in the eight categories listed above. In addition to the estimated or measured values, the checklist also contains a column for estimating the quality (or risk of making an erroneous estimate) of each input data item. The quality of the estimated data is also dependent on whom or what corporate function responsible for data acquisition. The checklist should therefore be specified with the support of employees of the various functions associated with the location project, and include information about who is responsible for gathering data. As the location project proceeds and the amount of information increases, the checklist can be updated to improve the quality of the input data.

Figure 2 shows the various cost categories in the production system included in the analysis in phase P 3 and P 4. The analysis in these two phases is based on the same methodology, but in phase P 3 the current manufacturing site (if there is one) is analysed, while in phase P 4 the selected alternative locations are investigated.

It is a challenge to estimate investments, operator costs, and production performance for facilities not yet realised. To overcome the risk of over- or underestimating input parameters, scenario simulation is a powerful methodology. This enables the analysis of both the best- and worst-case scenarios as well as the sensitivity analysis of individual cost drivers. The following sections present the methodology for analysing manufacturing and support costs and use the scenario capability to analyse various fictive location scenarios.

4.1. Phase 3: Current Footprint

In phase P 3 – current footprint, the decision support encourages the analysis of the existing organisation, systems, and products. To achieve this, cost models have been integrated into two tools, one focusing on the manufacturing process and one on the supporting activities.

Manufacturing cost estimation

The foundation of the cost analysis structure is a performance-driven manufacturing part cost model designed for production development (Ståhl *et al.,* 2007). The model outcome is the cost per part in a manufacturing process. A special feature of this model is that production performance, in terms of quality, availability, and production speed rate losses, are taken into consideration and directly connected to the costs integrated in the cost model. Other factors central to the model are the set-up time, cycle time, and batch size. Several processes are often involved in manufacturing the products. This cost model is based on the principles of activity-based costing (Cooper and Kaplan, 1998), making it possible to allocate costs to particular activities and to visualize the cost drivers in an organisation, so that the economics of operations can be understood and improved.

The process part cost is influenced by five cost categories (see Figure 3), each consisting of several cost drivers that together constitute the total

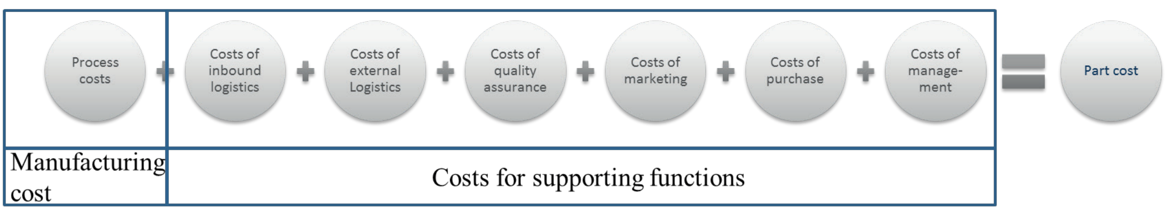

Figure 2. Costs affecting the final part cost.

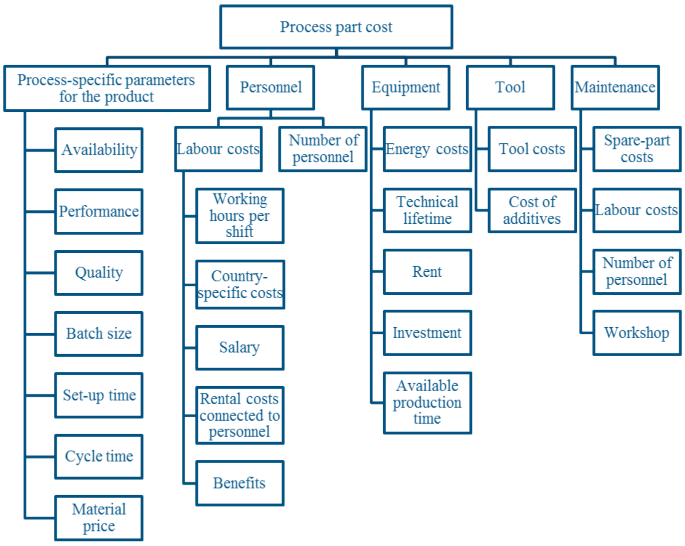

Figure 3. Factors and parameters affecting the process part costs.

production part cost. The maintenance costs can be seen as costs connected either to a specific product or to general equipment not connected to specific manufactured products.

Since a product is usually machined and assembled in a series of steps, and the total production cost comprises the accumulated costs of all processing steps, the cost model is applied to each individual step. In the first step, the material cost corresponds to the purchased raw material. In the second step, the material cost corresponds to the manufacturing costs in the first step and any additional raw materials used in this step. This procedure is repeated throughout the manufacturing chain to yield the total manufacturing cost for the finished part. With this methodology, the cost of poor quality can be determined after each process step, visualising the cost effects of quality defects occurring early or late in the manufacturing chain.

When calculating hourly equipment and personnel costs, the available production time must be established, since it is the basis on which costs are allocated. Available production time is all the time when personnel is paid and/or equipment is in operation. E.g. a 24 hour operation 7 days a week gives an available production time of 8760 hours per year. If production downtime occurs, the total time is unaffected. Instead, the performance parameters connected to availability and equipment utilisation are affected.

Personnel costs are highly dependent on where the production is located and are often one of the main reasons for a relocation decision (Brouwer *et al.,* 2004; Windmark and Andersson, 2012), as the location determines remuneration, employer contributions, and whether personnel receive free meals and free housing. Other factors affecting personnel costs are the daily working hours and the policies on employees' standard of living.

Figure 4 shows the design of the Excel tool for the manufacturing cost analysis. In the right-hand column, general input data and data on equipment and maintenance are specified. The equipment cost per hour and the manufacturing cost per part are calculated, based on the input specified in the white cells. In the left-hand column, factors connected to the actual products are taken into consideration. Here the production performance parameters of availability, performance, and quality, are the three constituents of the Overall Equipment Efficiency (OEE) measure, because they are associated with a specific product. These parameters are often regarded as equipment specific, but analysis made by Stål *et al.* (2012) shows that OEE can vary between products manufactured using the same equipment.

Estimating costs of supporting processes

Relocating or setting up a new production facility will likely affect the costs of various production-support functions. Here we regard support functions as those required to ensure that products reach customers on time, as follows: *IT support, marketing, purchasing, quality assurance, internal/inbound logistics, external logistics, management, and additional costs* (to capture other costs not connected to the specified

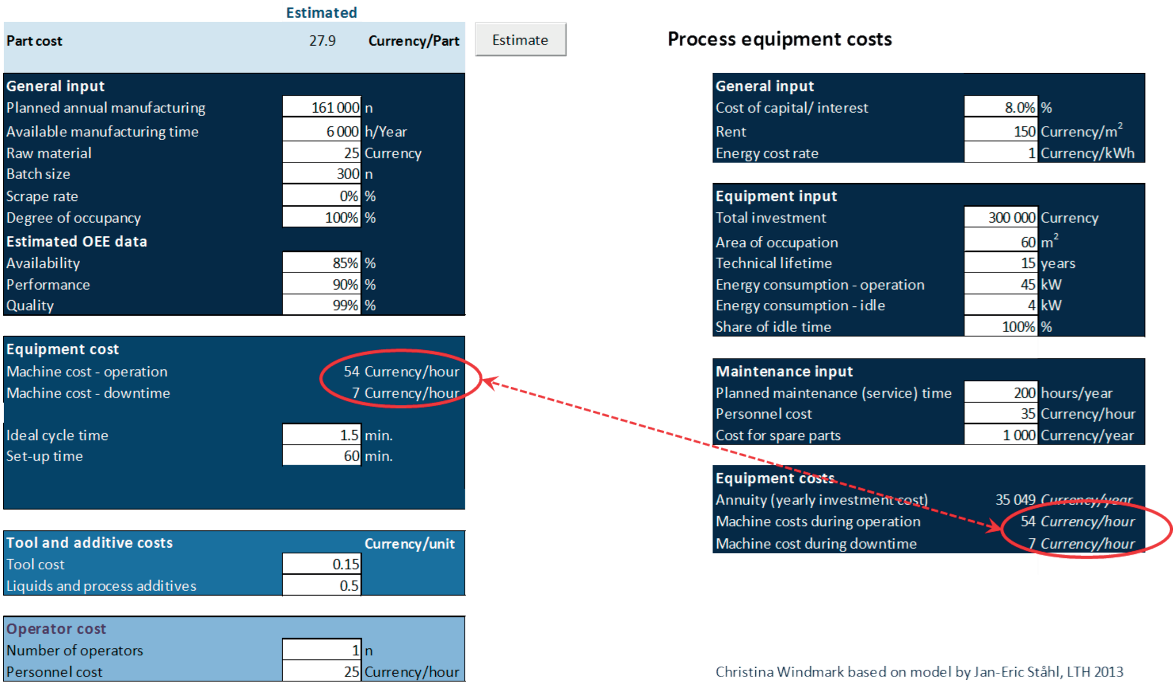

Figure 4. A tool for estimating process part cost.

functions). These were identified and discussed together with the five industrial partners.

Table 1 shows parameters for different support functions that are considered in estimating the cost of each function. The purpose is to estimate the cost per part incurred by the support functions necessary for production systems operation, in order to capture costs likely to be affected by a change in location. Opening a new plant could entail the opening of a new purchasing department or the expansion of an existing one. The new location could also require new marketing units for the local market. The logistics cost will also depend on where the plant is located, which will affect the plant design and hence the internal logistics configuration. A local IT-support unit might be needed and the cost of local management should also be included. The support cost for management includes both financial personnel and managers connected with production. A new location would also require new local suppliers, were costs for identifying and quality

Table 1. Input costs and parameters in the economic tool for process support costs.

	Annual production	Annual production product	Personnel costs	Rental costs	Computers	Equipment costs	Maintenance	Licensing costs	Travel costs	Education costs	Advertising	Insurance costs	Number of parts in delivery	Delay costs	Transportation costs (transport)	Transportation costs (personnel)	Duty/delivery	Tied capital (shipping)/part	Tied capital (storage)/part	Planning personnel cost	Rent cost planning personnel	Additional costs	Inbound logistics costs
IT support	x	x	x	x	x	x	x	x		x												x	
Marketing	x	x	x	x	x			x	x	x	x											x	
Purchasing	x	x	x	x	x			x	x	x												x	
Management	x	x	x	x	x			x	x	x												x	
Quality assurance	x	x	x	x	x	x	x	x		x												x	
External logistics	x	x			x			x				x	x	x	x	x	x	x	x	x	x	x	
Inbound logistics																			x				x

assuring these could vary substantially, depending on the maturity in the region.

The personnel costs comprise wage costs and additional costs for facility, equipment and travels. If personnel are relocated, living costs should also be included. These are separated into individual cost drivers to allow analysis of the impact of each of them on the total cost. The annual costs of these functions and the annual production volume are specified to determine the estimated part cost. Cost models for inbound logistics have previously been developed by Windmark and Andersson (2015) and are therefore not considered in detail here. The external logistic costs vary considerably depending on the product, business contract, and type of logistics transportation. Due to the wide range of possible cost estimates, the users can choose to use either the predetermined parameters or a fixed cost per part based on their own estimates. The predetermined parameters are of four types: (1) costs of insurance and delay, (2) costs connected to product transportation, (3) costs connected to inventory and storage outside the manufacturing plant, and (4) costs connected to planning the external logistics. Burns *et al.* (1985) present an extensive cost model for calculating transportation costs which is close in comparison to the input factors for external logistics in Table 1.

4.2. Phase P4: Generating Alternatives

In phase P4, various location alternatives are compared. In some cases, the estimation of costs and productivity for new locations is made problematic by data collection difficulties. Due to the high risk of inaccurate data, the tools used in this phase are constructed to allow for scenario analysis. This makes it possible to analyse both the impact of different factors on the total cost and the cost range of the produced product. The cost analysis methodology used in phase P3 can be reused in this phase for estimating the cost of alternative production systems and for estimating the production costs of the remaining production in existing plants.

When a well-functioning performance measurement system is not in place, the OEE data is recommended to be estimated based on experience. In the case of location comparison, gathering data for the various alternatives can be challenging. When configuring a new production cell or line, many estimates are needed, for example, of machine costs. To be able to design the production system and its capacity, a thorough analysis of the potential market is necessary. Decisions on whether to buy new or use existing equipment is also required together with estimates of the required number of annual operation hours to meet the market demands. The available production time depends on market demand and operators' daily working hours (Latino *et al.,* 2013).

The level of education and skills in a country or region are also important when deciding what process technology to use (Brynjolfsson and Hitt, 2000). If new equipment will be used, it´s recommended to acquire information on equipment performance to be able to analyse different cost scenarios in in phase P4. If the company already has experience from similar equipment, the estimates could be more accurate than if the technology is new to the company.

Scenario analyses of three fictive cases

In the following sub-section, three fictive production alternatives are analysed to illustrate how economic tools can be used for location decision support. The cases involve both a scenario on improvements by investing in a current production facility and an analysis of a new location in an attractive area for Swedish companies to relocate. The main objective is to reduce costs. The three cases are: (1) *Sweden – current*: An existing assembly line, (2) *Sweden – new*: Same assembly line as the current one but with additional investments to reduce cycle time, improve performance parameters, and increase the level of automation, (3) *China:* A new assembly line close in configuration to the current assembly line but involving more manual work.

In the three cases, raw material is obtained from each location's region, captured by using differentiated cost levels for the raw material. Due to greater distance from the design department and the fact that new suppliers are needed, the quality rate is estimated to be lower for the production site in China. The personnel costs include assembler wages, employer contributions, and technician salaries. The ingoing parameters needed to perform the scenario analyses are shown in Tables 2 and 3. To simplify the estimation and simulation, the occupancy level is set to 100%.

From the data above, the following part costs are calculated:

Sweden – current	21.6 €/part
Sweden – new	18.2 €/part
China	15.9 €/part

To reduce the risk of erroneous estimates, various best- or worst-case scenarios can be simulated to

Table 2. Data concerning equipment costs in the assembly line.

	Process equipment costs											
	Cost of capital (interest) (%)	Rent (€/m2/year)	Energy cost rate (€/kWh)	Total investment (€)	Area of occupation (m2)	Technical lifetime (years)	Energy consumption – operation (kW/h)	Energy consumption – idle (kW/h)	Share of idle time (%)	Planned maintenance (service) time (h)	Personnel costs (maintenance) (€/h)	Cost of spare parts (€)
Sweden – current	8	100	0.08	400,000	450	15	18	12	100	110	25.5	2000
Sweden – new	8	100	0.08	500,000	450	15	24	12	100	100	25.5	2000
China	8	50	0.10	350,000	600	15	18	12	100	150	5	2000

Table 3. Data concerning general input, performance parameters, tools, and personnel costs in the assembly line.

	General input					Performance parameters					Tools		Personnel	
	Planned annual production (units)	Available production time (h)	Raw material (€/part)	Batch size	Occupancy level (%)	Quality rate (%)	Speed performance (%)	Availability (not including set-up) (%)	Ideal cycle time (min)	Set-up time (min)	Tool cost (€/part)	Cost of liquids and process additives (€/part)	Personnel costs (€/personnel)	Number of operators
Sweden – current	100,000	3600	15	1 200	100	95	93	85	2	40	0	0.02	25	3
Sweden – new	100,000	3600	15	1 200	100	98	93	90	1.5	40	0	0.02	25	3
China	100,000	3600	12	1 200	100	90	93	80	2	40	0	0.02	4	7

provide information on how sensitive the results are to changes in different parameter values. Figure 5 shows examples, of how the total part costs are influenced by the changes in quality rate and the downtime rate in all three scenarios. The diagram shows that the impact of downtime differs depending on the equipment setup. The influence of other isolated parameters or the combined effect of changes in more than one parameter can be simulated as well. A typical location scenario could be a change in automation level that would increase the equipment cost and at the same time reduce the operator cost.

Boston Consulting Group (2011) shows that the wage costs in China are increasing at much faster rates than in the USA. The annual wage cost increase by 2% for Sweden and 10% for China was used as the base for this scenario analysis.

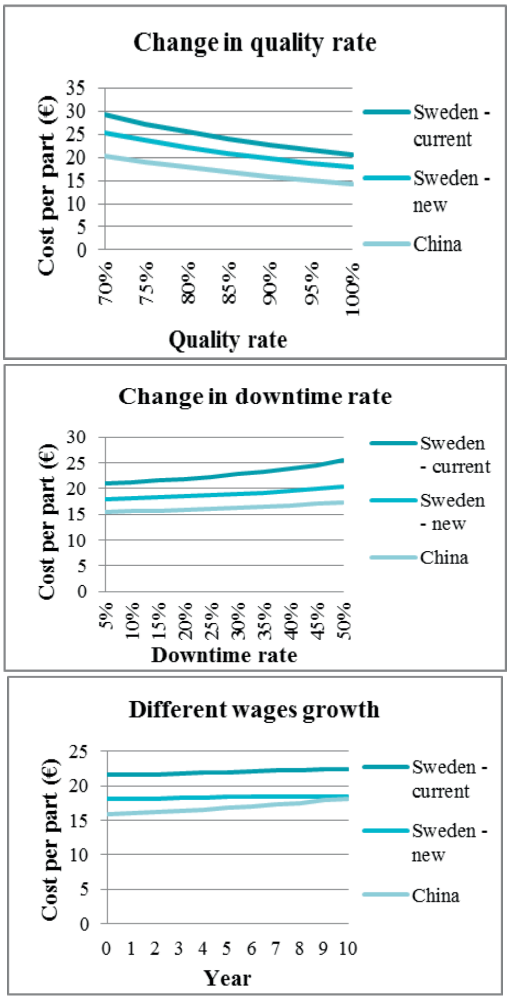

Figure 5. Simulated part costs when the quality rate, downtime rate, and personnel cost vary.

The result in Figure 5 shows that the quality rate has a greater effect on the final cost than does the downtime rate. A conclusion is that it is more critical to estimate the quality in a correct way. With different salary growth rates, the cost of the part produced in China will approach the level of the "Sweden – new" case. These simulations only consider the costs of assembly, while the support functions such as logistics and IT are not included.

A relocation of production is likely to cause changes in more than one parameter; therefore scenarios involving a set of changes for the new location in China are performed.

Scenario: The quality rate in China is estimated to decrease from 90% to 80%. The assembler wage costs are estimated to increase by 10% annually. For the other parameters, the conditions are as stated in Tables 2 and 3.

The results of the simulations, shown in Figure 6, indicate that the manufacturing part cost at the new site in China will exceed the one at the improved Swedish assembly line after approximately six years.

The above simulations include only the process part cost and not the costs connected to the manufacturing support functions. Including these costs might considerably change the outcome. When comparing only the process costs between China and Sweden, the relocation to China appears to be preferable, but if the risks of overestimated performance and underestimated wage growth are included, it is not obviously the best location.

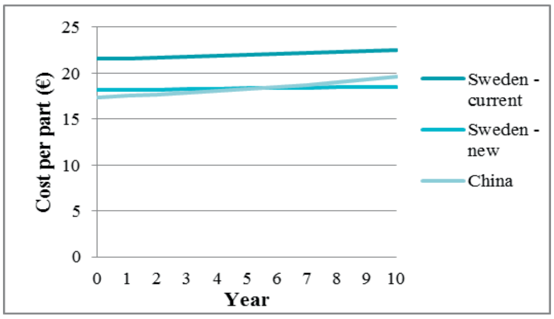

Figure 6. Quality rate in the assembly line in China is estimated to be 80% and the wage growth 10%.

In addition to the quantitative risk, illustrated by the simulations above, qualitative factors, such as access to skilled personnel, infrastructure reliability, and quality and delivery reliability of incoming goods, could have a substantial impact on the success of production relocation.

5. Results and Discussion

Decisions on relocation and outsourcing require a clear understanding of the driving forces for changing the manufacturing footprint. For example, previous studies (Kinkel *et al.,* 2007; Aspelund and Butsko, 2010; Windmark and Andersson, 2012) have demonstrated that costs and strategic factors such as distance from key customers and markets are highly important for companies considering changes in the manufacturing footprint. Even if relocation decisions are mainly based on strategic motives, an analysis of costs and benefits should always (and is usually) performed and considered in the decision process.

The motivation for the research presented here are both the gap found in the literature on cost analysis methodology in production relocation and the industrial practitioners view of lacking a structure to develop decision support in production relocation issues.

The development of a work procedure to facilitate the development of a structured decision support for production relocation, were performed in close collaboration with five industrial partners. The research methods used during the development work were interviews, case studies, workshops and group validation. The research limitation is that the development is based on a limited set of empirical data. A broader constellation of case study companies would have the opportunity to capture a broader set of parameters influencing location. A research limitation is also the selected scope of operational focus. This will incur a risk of limiting the consideration of e.g. sustainability factors. In the cost tools it is possible to simulate currency fluctuation, but this have not been included in the scenario analysis presented here.

The involved companies differed in size and in experience regarding location projects, which contributed to different needs for support in the location process. This group of industrial partners included both companies with international operations and those planning to establish such operations; this motivated the development of a wide-ranging modularised decision support, enabling users to select parts of the procedure or tools to complement their already established work procedures.

This paper presents a methodology for estimating costs in the process of developing a comprehensive support for production location decisions. The principle for cost calculations is based on a cost model presented by Ståhl *et al.* (2007), integrating technical performance parameters with financial parameters. A feature of this cost model is the inclusion of equipment performance (Overall Equipment Efficiency), parameters that substantially affect costs (see Figure 4). The structure of the cost model (see Figure 3) incurs the possibility of scenario simulation of different production setups, making the model suitable for analysis of different alternative in a relocation decision process.

To capture the total costs of relocation, an array of parameters needs to be considered. Figure 4 show the set of parameters needed to estimate the part cost for operations including equipment, facility and employees. The additional costs concerning support functions such as quality assurance, market etc. were identified together with the industrial partners, see Table 1. Tools for estimating support costs were developed. Models for estimating inbound logistics costs are presented in Windmark and Andersson (2014, 2015).

The use of the cost analysis methodology is demonstrated by the scenario simulations presented in section 4.2. These analyses show (see Figure 5) that production costs are influenced by performance (downtime and quality rates), indicating that theses parameters should not be neglected when analysing location alternatives. Figure 5 also shows that wage cost fluctuations can change the costs and benefits completely. This indicates that analyses of future potential changes in wage costs, currency and market stability should be made prior to a location decision.

The success of using the presented methodology is highly dependent on the availability of data for the parameters included in the cost models. The models are fairly comprehensive and the work needed to gather the necessary input data could be time consuming. However, in view of the huge investments needed to establish a new production location, we argue that the workload is justified to be able to make decisions on a thorough analysis of costs and benefits. As companies constantly increase the quality and availability of data and the data is digitally available to a greater extent, the effort needed for developing comprehensive decision supports, is likely to decrease. A challenge is however to retrieve data to estimate costs for a new location. These efforts can however be supported by experiences from an existing production system.

The methodology presented here only includes quantitative parameters, and would require additional concern of strategic non-quantifiable parameters, e.g. legal, cultural, social, political, and economic factors prior to a decision. In addition, proximity to suppliers, markets/customers, parent company facilities, and competitors must be taken into consideration (MacCarthy and Atthirawong, 2003).

Other cost drivers important in production relocation, not included in the cost analyses here, are costs of knowledge provision, process testing and ramp-up at a new site. These costs could be viewed as the costs generated before the production starts and can be treated as the investment costs and be included in the process costs. It is also important to analyse the cost impact on a current site if the location project results in production relocation. Further development of the cost analysis method will include these cost drivers. The aim for the future is also to test the work methodology and tools in ongoing transfer projects to further understand and grasp issues and difficulties in managing global production systems.

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