Identification of significant life-cycle costs of intra-logistics systems as a basis for investment decisions

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Abstract
With regard to expensive operational costs, the research consensus indicates that the opportunity for influencing life-cycle costs is greatest during the planning phase. However, although research works exist in the field of plants and machines, a life-cycle costs structure analysis of intralogistics systems has not been executed. Transparency in the cost structure aims to reduce economic risks as early on as during the planning phase. Therefore, the investigations described in this paper give hints about the life-cycle costs structure of intralogistics systems. This allows us to answer the questions of which life-cycle costs exist and which of them are significant.

Keywords: cost structure, life-cycle, intralogistics

Purpose of this paper

Intralogistics systems secure the internal flow of materials and are a success factor for handling and production companies. The objective of analysing life-cycle costs (LCC) in general is to evaluate and economically compare system design alternatives with respect to the entire life-cycle, which are aimed at supporting investment decisions (Shokouhian *et al.*, 2011).

This is necessary because of the danger of operational costs being significantly higher than the investment itself (Fleischer *et al.*, 2007). By defining the fundamental aspects of construction and operation, research indicates that influencing LCCs are highest during the planning phase (Dunk, 2012).

There are several research works about the LCC structure in the field of plants and machines. They prove that the majority of LCC are generated during the operating phase. (Elmakis and Lisnianski, 2006) This is also alluded to in the field of intralogistics systems (Doha *et al.*, 2013).

However, an LCC structure analysis of intralogistics systems has not been executed so far. Transparency of the cost structure aims at detecting and reducing economic risks concerning the operating strategy or constructive aspects as early on as in the planning phase.

With the help of project cost calculations, this paper analyses the LCC structure of intralogistics systems. As a result, possible LCC types of intralogistics systems are detected and the significant ones are filtered out.

State of technique

The LCC calculation is performed by economically analysing the total costs incurred from the point of procurement until disposal and decommissioning. An essential goal in analysing and modelling LCC is to identify costs that significantly influence the total LCC. (Deutsches Institut für Normung e.V., 2005)

In the field of machines and plants, three main approaches for LCC calculations exist: The VDMA standard sheet 34160 and the regulations VDI 2884 as well as DIN EN 60300-3-3. It is important to emphasise here that solely the standard sheet provides a quantitative calculation model, whereas the named regulations can be evaluated as qualitative guidelines.

Because both the standard sheet and the regulations are concepts for production and manufacturing machines and plants, it can be stated that they are not usable in the field of intralogistics systems. This is due to the difference between the proceedings in intralogistics, which differ significantly from those of manufacturing machines and plants.

The proceedings in intralogistics systems can be clearly distinguished, as they comprise the manufacturing and manipulation of materials or goods. In other words, an object undergoes a change in condition. Otherwise, intralogistic processes are based on the conveying and storage operations of goods. Hence, requirements with regard to availability, networking technology and control are high. (Crostack and Schlueter, 2008)

However, isolated approaches do exist concerning a LCC model for intralogistics systems. It can be determined that in the field of intralogistics systems, planners of such systems know about LCC calculation, but this knowledge is rarely used. The LCC models available are solely delimited ones, especially in the fields of maintenance and spare parts (Dhillon, 2010; Ostwald and McLaren, 2004; Elsayed, 2012; Lad and Kulkarni, 2008; Jiang *et al.*, 2003) as well as energy consumption of stacker cranes and ascending conveyor technology (Ertl and Günthner, 2016; Dreier and Wehking, 2016).

Thus, it is fair to say that at this point, no overall standardised LCC calculation model of intralogistics systems, and thus LCC structure investigations, exists. As a result, there is no transparency within the LCC cost structure regarding intralogistics systems (Elmakis and Lisnianski, 2006).

Definition of the system boundary

With regard to the LCC calculation of intralogistics systems, in this paper focuses on automated material handling systems. A detailed overview of the conveyor and storage technology described is given in Figure 1 and described in the following.

The system boundary includes process-oriented automatic storage and retrieval of handling units (HU), in or from the automatic high-bay warehouse (HBW) or the mini-load system (MLS) from or to the transfer point of the automatic conveyor technology. As regards the pack conveyor technology, the personnel costs of the employee are considered in the analysis. The personnel costs of the employee who performs the uptake and release of HU are taken into account because the employee works directly on the conveyor technology and thus in a stationary workplace. Costs of forklifts, trucks, etc. are not considered, due to their non-automatic operation proceedings.

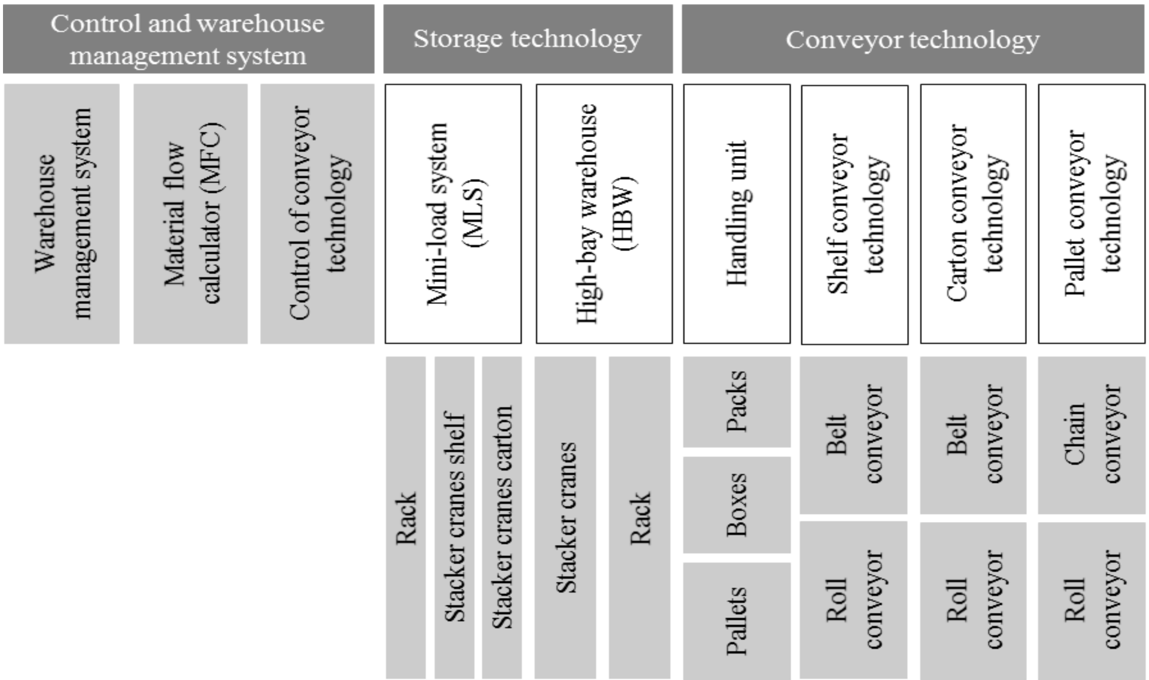

Figure 1 – System boundary

Methodology and approach

The first step was to identify the LCC types for intralogistics systems. With the help of norms and directives, as well as expert interviews, a list of possible LCC types was generated. The LCC types identified were clustered. Furthermore, they were temporally categorised in LCC phases:

- Concept and design phase
- Procurement and implementation phase
- Operation phase
- Disposal and decommissioning phase.

Secondly, the significant LCC types were tagged. With the help of project calculations, the significant ones were filtered out. The procedure of project calculations can be briefly outlined as in Table 1. The project calculations are based on a duration of 20 years including annual cost increases. The results of each project concerning the amount of LCC were compared and evaluated, as well as the significant LCC types identified. The methodology is described in detail in the following and can be split into two steps:

Identification of LCC types for intralogistics systems

First, the LCC types in the field of intralogistics are identified using four steps.

(1) With the help of norms and directives, possible LCC types were collected, resulting in a list of potential LCC types. This list was then summarised and selected.

(2) Then, the LCC types identified were classified into four phases (see Table 1).

(3) In step three, the consequential costs (warranty and liability) were added to the operational phase based on the *user-pays principle*. Consequential costs are visible during the entire life-cycle, but only caused temporarily during the operational phase. This is the reason that these costs are classified in the operational phase.

(4) In the last step, overheads (e.g. administration) that are generated during every life-cycle phase were included.

In each of the four steps, the LCC types are grouped together by similar wording or meaning. This ensures a comprehensive and practical overview of the possible LCC types.

Identification of the relevant LCC types regarding the total LCC

Second, the relevant LCC types are identified with the help of project calculations. These detected LCC types influence significantly the total LCC.

The project cost calculations are described in Table 1. Therein, several LCC types are calculated with the help of available data or with cost estimation methods based on concept and design data provided in the planning documents. The result of both cost calculation proceedings can then be added in order to determine the total LCC. The following table describes the project calculations differentiated into LCC type and calculation method (calculated by available data or by estimation):

Table 1: Determination of the total LCC (project cost calculations)

	LCC types	**Available data**	**Estimations**	**Source**	**Cost calculations method**
0. Concept and design phase	0.1 Project management, planning	x		Expenses incurred	Actual costs
	0.2 General procurement costs	x		Expenses incurred	Actual costs
	0.3 Administrative costs	x		Expenses incurred	Actual costs
	0.4 Monetary effects	x		Expenses incurred	Actual costs
1. Procurement and implementation phase	1.1 Acquisition price	x		Expenses incurred	Actual costs
	1.2 Installation costs	x		Expenses incurred	Actual costs
	1.3 Network infrastructure costs	x		Expenses incurred	Actual costs
	1.4 Extension costs	x		Expenses incurred	Actual costs
	1.5 Quality control, inspection	x		Expenses incurred	Actual costs
	1.6 Personnel training	x		Expenses incurred	Actual costs
	1.7 Administrative costs	x		Expenses incurred	Actual costs
	1.8 Monetary effects	x		Expenses incurred	Actual costs
2. Operation phase	2.1 Maintenance and inspection	x		Lump sum per year according to planning documents	Annual lump sum according to planning documents
	2.2 Repairs		x	Actual costs until 2014, then estimation	Estimation based on actual costs
	2.3 Unscheduled repairs		x	Actual costs until 2014, then estimation	Estimation based on actual costs
	2.4 Spare parts costs / storage		x	Actual costs until 2014, then estimation	Estimation based on actual costs
	2.5 Material costs	(x)	(x)	Lump sum or actual costs	Not relevant

2. Operation phase	2.6 Energy costs		x	Energy data according to technical specification sheets in the planning documents	Annual cost increase of 1.5 %; costs in the year of implementation amount to 50 % of energy costs of the first year; estimation based on (Ertl and Günthner, 2016) (stacker cranes) and on (Habenicht, 2015) (conveyor technology)
	2.7 Personnel costs		x	Cost data according to technical specifications	52 weeks per year and €20 per hour with an annual cost increase of 1.5 %
	2.8 Tooling costs	(x)	(x)	Lump sum or actual costs	Not relevant
	2.9 Set-up costs	(x)	(x)	Lump sum or actual costs	Not relevant
	2.10 Cleaning, waste disposal*	(x)	(x)	Lump sum or actual costs	Not relevant
	2.11 Support services	x		Lump sum or actual costs	Not relevant
	2.12 Insurance		x	Assumption	1/20 of 3 % of procurement and implementation costs
	2.13 Occupancy costs	(x)	(x)	Lump sum or actual costs	Not relevant
	2.14 Software costs	(x)	(x)	Lump sum or actual costs	Not relevant
	2.15 Warranty and liability	(x)	(x)	Lump sum or actual costs	Not relevant
	2.16 Administrative costs		x	Assumption	1/20 of 5 % of concept, design, procurement and implementation costs
	2.17 Monetary effects		x	Assumption	3 % of annual operating costs
3. Disposal and decommissioning	3.1 Disposal	(x)	(x)	Lump sum or actual costs	Not relevant
	3.2 Decommissioning	(x)	(x)	Lump sum or actual costs	Not relevant
	3.3 Renovation	(x)	(x)	Lump sum or actual costs	Not relevant
	3.4 Administrative costs	(x)	(x)	Lump sum or actual costs	Not relevant
	3.5 Monetary effects	(x)	(x)	Lump sum or actual costs	Not relevant

* of material costs
(x) if required or if data is available

The phase of disposal and decommissioning is not considered because it is the investment and operational costs that are of the most interest during the planning phase. The LCC types designated as 'not relevant' in Table 1 can be classified as such due to their few and low-cost positions derived from the planning documents and data available.

In order to proceed with the project LCC calculations, three intralogistics projects (A, B and C) are consulted. The projects, as well as the framework conditions regarding the calculations, are described briefly in the following table.

Table 2: Framework conditions for project LCC calculations

General framework conditions: **Energy costs**: €0.10/kWh and annual cost increase of 1.5 % from base year; costs in the year of implementation amount to 50 % of energy costs of the first year **Insurance costs:** 3 % per annum of the investment distributed over 20 years **Administrative overheads:** 5 % p.a. of concept and design as well as procurement and implementation costs distributed over 20 years **Monetary effects:** 3 % p.a. of operating costs **52 weeks/year and €20/h for employees in the repacking area** **Period under review:** 20 years + year of procurement = 21 years	
Project	
A	- MLS with approx. 38,500 storage positions - Carton and shelf conveyor technology - Industry sector: Building technology
B	- HBW and MLS with approx. 200,000 storage positions - Pallet, carton and shelf conveyor technology - Industry sector: Consumer goods
C	- HBW and MLS with approx. 10,000 storage positions - Pallet, carton and shelf conveyor technology - Industry sector: Consumer goods

The LCC calculation comprises a period under review of 21 years including the year of procurement. Table 1 describes the LCC types and the specific calculation method. Then, the LCC types are added up to 21 years in order to calculate the total LCC and to describe the proportion of certain LCC types within the total, in order to determine the relevant LCCs. In order to compare results despite the different projects with their different specifications, the total LCC were discounted to the period $t = 0$.

The LCC types 2.2 (repairs), 2.3 (unscheduled repairs) and 2.4 (spare parts) are estimated based on available cost data from the point of implementation until the end of 2014. In the field of cost estimation methods, a range of different approaches is possible. To choose an appropriate cost estimation method, the framework conditions and required data was first determined and evaluated (see Table 3).

Concerning Table 3, only the second-order exponential smoothing fulfils the requirements given. The second-order exponential smoothing stands out in particular due to the consideration of random fluctuations and trend-affected rows. As a result, second-order exponential smoothing was used for estimating the LCC types 2.2 to 2.4.

As a result, it was assumed that fluctuations or a seasonal cost trend exist (Günther and Tempelmeier, 2009, p. 152). The most important advantage of this cost estimation method is the easy and standardised process and the consideration of random fluctuations in past costs. The cost elements 2.2 to 2.4 based on the actual costs show such a fluctuate to such an extent that the use of exponential smoothing must be verified.

Table 3: Choice of an appropriate cost estimation method (see LCC types 2.2 to 2.4 in Table 1)

Cost estimation methods / **Framework conditions of cost estimation**	First-order exponential smoothing (Günther and Tempelmeier, 2009, pp. 152–158)	Second-order exponential smoothing (Günther and Tempelmeier, 2009, pp. 152–158)	Average method (Eberlein, 2010)	Regression (Rencher, 2012)	Box-Jenkins-Method (Maiti *et al.*, 2016)	Cash-Flow-Method (Dhillon, 2010)	Monte Carlo Simulation (Fleischer *et al.*, 2007)	Optimized set reduction (Wieczorek, 2001)	COCOMO (Constructive Cost Model) (Hummel, 2011)	Process-cost accounting (Hunkeler and Rebitzer, 2005)
Annual cost calculation (Dervisopoulos *et al.*, 2006)	Y	Y	Y	Y	Y	Y	N	N	Y	Y
Freely selectable period under review (Dervisopoulos *et al.*, 2006)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Consideration of random fluctuations (Fleischer *et al.*, 2007, p. 449)	N	Y	N	(Y)	Y	N	Y	N	N	N
Comparability of calculations (Geissdörfer *et al.*, 2012, p. 255)	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Low-effort cost estimation (Fleischer *et al.*, 2007, p. 449)	Y	Y	Y	Y	N	N	N	N	N	(Y)
Availability of historical data to model future costs, including any trend-affected row (Günther and Tempelmeier, 2009, pp. 152ff)	N	Y	N	(Y)	Y	N	N	N	N	Y
Possibility of implementing input sizes that are independent of output sizes (Rencher, 2012, pp. 94-110)	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
Standardised calculation (Geissdörfer *et al.*, 2012, pp. 255–257)	Y	Y	Y	Y	N	Y	Y	Y	N	Y

Y = fulfilled / (Y) = conditionally fulfilled / N = not fulfilled

Findings

Altogether, 34 LCC types grouped into four phases were identified (see Table 4).

Table 4: Identified LCC types for intralogistics systems

LCC phase	LCC types	
0. Concept and design phase	0.1 Project management, planning	0.3 Administrative costs
	0.2 General procurement costs	0.4 Monetary effects
1. Procurement and implementation phase	1.1 Acquisition price	1.5 Quality control, inspection
	1.2 Installation costs	1.6 Personnel training
	1.3 Network infrastructure costs	1.7 Administrative costs
	1.4 Extension costs	1.8 Monetary effects
2. Operation phase	2.1 Maintenance and inspection	2.10 Cleaning, waste disposal
	2.2 Repairs	2.11 Support services
	2.3 Unscheduled repairs	2.12 Insurance
	2.4 Spare parts costs / storage	2.13 Occupancy costs
	2.5 Material costs	2.14 Software costs
	2.6 Energy costs	2.15 Warranty and liability
	2.7 Personnel costs	2.16 Administrative costs
	2.8 Tooling costs	2.17 Monetary effects
	2.9 Set-up costs	
3. Disposal and decommissioning	3.1 Disposal	3.4 Administrative costs
	3.2 Decommissioning	3.5 Monetary effects
	3.3 Renovation	

In analysing the calculated LCC with the help of the project cost calculations, an LCC type is defined as being significant if its share of the total LCC is more than 1 percent. With the help of the project cost calculations, it was found that the significant LCC types of intralogistics systems are (see Table 5):

- Acquisition price
- Maintenance and inspection
- Repairs
- Unscheduled repairs
- Spare part costs
- Energy costs
- Personnel costs
- Monetary effects (inflation, taxes, etc.)

Table 5: Distribution of LCC types on the total LCC (project-specific)

	Project	A	B	C*	Average
1. Procurement and implementation phase	Acquisition price	7.66%	28.34%	15.15%	17.05%
2. Operation phase	Maintenance, inspection	1.91%	2.95%	1.55%	2.14%
	Repairs	31.01%	9.82%	1.10%	13.98%
	Unscheduled repairs	2.99%	8.80%	2.03%	4.61%
	Spare parts costs / storage	0.58%	2.74%	0.22%	1.18%
	Energy costs	8.31%	12.82%	20.59%	13.91%
	Personnel costs	43.36%	27.41%	54.00%	41.59%
	Monetary effects	2.65%	1.93%	2.42%	2.33%

* The maintenance and repair costs are very low in comparison with the two other projects. It is probable that only a small proportion of the maintenance and repair works executed were performed and accounted for by the operator or provider.

The significant LCC types can add up to more than 95 percent of the total LCC within the projects analysed. In particular, the personnel and maintenance costs primarily influence the operational costs (about 60 percent). The energy costs show a lower share than expected (only about 15 percent). With regard to the managerial problem described at the start of this study, the investment expenditure amounts to a maximum of 20 percent of the total LCC.

This result is not a static result, but gives an insight into the structure of the LCC of intralogistics systems. Moreover, the results underline the significance of operational costs compared to the investment. Planners and operators of intralogistics systems need to consider planning aspects that influence the significant LCC types listed, rather than making procurement decisions based solely on the investment. (Cerri and Terzi, 2015; Doha *et al.*, 2013)

The results obtained can help make the structure of intralogistics systems LCCs more transparent. The results of the project calculations support the expectation that the majority of intralogistics systems LCCs can be attributed to the significant types mentioned above. Thus, these findings give some indication of economic risks concerning the operation strategy or constructive aspects of such a system, which can therefore be minimised as early as during the planning phase (Boussabaine and Kirkham, 2004). Potential for cost optimisation can be detected, e.g. if accessibility to the conveyor technology is improved, the time required for maintenance and inspection, and thus the maintenance and repair costs, can be reduced. Furthermore, the results provide a basis for generating an LCC model.

With the help of LCCs, planners and operators of intralogistics systems are able to compare system design alternatives economically in the planning phase. Furthermore, the significant cost factors can be taken into account as adjusting criteria for operation, cost-effectiveness, construction and technique in practice and research.

Acknowledgements

The authors are grateful for the support of the Dr. Friedrich Jungheinrich Foundation.

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