



## CAPITAL BUDGET DECISION-MAKING IN LOGISTICS

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**ABSTRACT. Background:** Capital budgeting decisions in the logistics industry often combine three distinct characteristics. Firstly, they relate to capital assets – such as vehicles or equipment – being periodically replaced with different useful lives and efficiency features, and secondly, their performance is subject to particular operating and market risks. Lastly, externalities, such as regulatory interventions and technological evolution, also contribute to innovation – and thus also uncertainty – becoming a significant factor in logistics. Accordingly, this paper develops a valuation model which takes these characteristics into account and facilitates a robust decision-making process.

**Methods:** In order to properly capture the specifics of the problem, the proposed model is based on an application of the Life Cycle Cost budgeting method benchmarked to an appropriate functional unit, combined with the Monte Carlo simulation and sensitivity analyses of relevant risk factors.

**Results:** A realistic case study was developed, providing the necessary input parameters for the method's application. It was thus demonstrated that it provides useful and coherent resources for the decision-making process, including the tools needed to test various assumptions and determine project risks.

**Conclusions:** The presented model and its solution provide results which are superior compared to conventional capital budgeting methods in terms of properly capturing the essential value-determining factors for a common type of problem encountered in logistics. They are also adequately comprehensive to be applied by practitioners in a real-life managerial setting.

**Key words:** capital budgeting, life cycle costing, Monte Carlo simulation, logistics management.

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### INTRODUCTION

In production industries, fundamental capital budgeting projects typically feature nonrecurring and time-limited investments, allowing most decisions to be made based on conventional criteria, such as the Net Present Value (NPV) or the Internal Rate of Return (IRR). In contrast, logistics frequently uses servicing systems comprising various kinds of vehicles and equipment which periodically need to be replaced, maintained or renewed in order to achieve and sustain the required standard of service at an optimal cost [Christopher, 2011]. Particular decisions

are therefore seemingly marginal and relatively small in scale, but their systematic shortcomings are likely to result in a gradual deterioration of the system's efficiency, which would then be extremely difficult to rectify, with potentially critical consequences in regard to a firm's competitive position. A strategic approach therefore needs to be applied to these decisions, integrating a life cycle view with decisions made in uncertainty.

Numerous authors have addressed various aspects of broadly related problems. Current company practices and their impacts have recently been surveyed by Świerczek [2019], who looked at the role of demand planning,

and by González-Moralejo et al. [2015], who focused on the issue of logistics coordination through establishing outsourced relationships. The outsourcing decision process was described by Bajec and Jakomin [2010], while Lampe and Hofmann [2014] undertook a thorough econometric review of systematic risk determinants, leading to valuable conclusions on the appropriate costs of capital for logistics service providers. Zhang et al. [2017] explored the use of real options to determine optimal investment timing and capacity of logistics infrastructure.

This paper takes a more particular approach. It aims to resolve a characteristic problem encountered by decision-makers, which will be defined as a case study. A model will be developed allowing its general parametrization, thus serving as a procedural framework for solving a much more broadly defined class of problems. Finally, the model results will be tested in terms of their sensitivity towards selected parametric assumptions, which is, generally speaking, the main issue faced when using economic models, due to the error-in-variable factor [Chen et al., 2015].

## LITERATURE REVIEW AND THEORETICAL FOUNDATIONS

The model uses two fundamental techniques, and is novel primarily because of their specific combination and the functional nature of their feedback, while retaining good heuristic characteristics. One is the implementation of life cycle costing [Woodward, 1997], which mainly serves the objective of temporal and functional normalization, while the other is parametric statistical simulation [Mordechai, 2011], which allows the quantitative inclusion of risk factors. In this regard, there is some affinity to the approach taken by Vlachý [2017] when assessing the process of product and production innovation in a highly indeterminate industry development situation.

Applications of the life cycle costing (LCC) approach have been extremely diverse, and notably included the construction industry [Opuku, 2013] and the public sector [Dragos

and Neamtu, 2013]. In recent and more closely related applications, Fulton [2018] compared the total life costs of electric and hybrid drive vehicles, and El-Akruti et al. [2016] determined the optimal repair and replacement policies for an electric arc furnace used in the steel industry, while Favi et al. [2018] focused on design process implications in shipbuilding. Highlighting the need to take a strategic view on life cycle cost decisions, Bescherer [2005] noted that up to 70 to 90% of total life costs, depending on the industry, are already defined in the initial design phase.

There are some features of life cycle costing techniques which are particularly relevant in respect to solving the problem considered herein. Any LCC analysis is typically benchmarked against a functional unit rather than a product or service, which allows proper comparisons of different solutions to the same utility need; such a functional unit may then relate to, for example, servicing capacity, degree of protection or system performance over a uniform time horizon [Norris, 2001]. LCC analyses are also typical for decision-making when variant solutions to a particular problem exist, for example with regard to design or constructional alternatives, operational scenarios, logistics, distribution or recycling. Relative, rather than absolute valuation then needs to be applied, which results in somewhat reduced data requirements [Dhillon, 2010].

Finally, as noted by Norris [2001] and elaborated by Kong and Frangopol [2003] (see also Table 1), in contrast to conventional costing LCC frequently extends the scope of costs over and above the usual Type I and Type II (direct and indirect), to include Type III (contingent) and Type IV (intangible). Applicable financial formulas using continuous compounding and their derivations are described in detail by Los [2001].

As suggested by numerous studies, including Fuss and Vermeulen [2008], and Banker et al. [2014], the essential risk factor determining the economic viability of capital budgeting projects is the product demand, while market prices can reasonably be considered its proxy. The risk, in turn, can be integrated effectively in the assessment using

contingent claims analysis, as explained from a firm-valuation perspective by Vlachý [2009],

and more technically by Meier et al. [2001].

Table 1. Cost type breakdown

Cost type	Description
Type I (Direct)	Direct costs of capital investment, labor, raw material, waste disposal; may include both recurring and non-recurring costs.
Type II (Indirect)	Indirect costs not allocated to the product or process, i.e. overhead; may include both recurring and non-recurring costs.
Type III (Contingent)	Contingent costs such as fines and penalties, personal injury or property damage liabilities, production or service disruption, competition response, etc.
Type IV (Intangible)	Difficult to measure costs, including consumer acceptance, customer loyalty, worker morale, community relations, corporate image.
Type V (Externalities)	Costs borne by other parties than those directly involved in the life cycle, e.g. society.

Source: adapted from Norris [2001] and Kong, Frangopol [2003]

In principle, contingent claims problems can be solved using several methods, including generalized closed-form analytical solutions and decision trees [Broadie and Detemple, 2004], but they would be too complex to be practicable wherever substantial path dependencies are involved, as in the present case, as argued by Vlachý [2016]. We therefore apply a parametric statistical simulation (Monte Carlo) using Oracle Crystal Ball simulation software [Charnes, 2012] with 100,000 simulation cycles; the processing time for such simulation experiments does not exceed units of seconds with standard office hardware. Basic integration of the Monte Carlo simulation in management science problems is explained by Anderson et al. [2016]. Detailed characteristics of statistical distributions and their specific applications in parametric simulations are described by Mun [2006].

## CASE DEFINITION

A logistics delivery handling mechanism uses a critical component which may be designed and constructed using two alternative technologies, denoted A and B. These technologies differ in four life cycle phases: production of the component (P), its installation in the equipment (N), its operating use (U), and its disposal (D).

From the perspective of total production and installation costs, the more sophisticated technology A is more expensive, with direct and allocated overhead costs amounting to  ${}^A\text{CP} = \text{€ } 4,800$ , while those of component B are just  ${}^B\text{CP} = \text{€ } 4,000$ . Installation of A is also more costly, with  ${}^A\text{CN} = \text{€ } 500$  direct costs and a need to provide each newly fitted mechanism

with additional control components worth  ${}^A\text{FN} = \text{€ } 1,500$ , while the installation of B costs just  $\text{BCN} = \text{€ } 400$ .

Nevertheless, in the operating phase, technology A brings considerable cost benefits. In particular, due to improved controls and automatization the component decreases power consumption by 1 MWh per 10,000 handled units and reduces personnel costs by € 1,200 per year.

Component B has an expected working life of  ${}^B\text{p} = 200,000$  handled units, and would thereafter be disposed of at a cost of  ${}^B\text{CD} = \text{€ } 500$ . Component A has the same  ${}^A\text{CD} = \text{€ } 500$  disposal cost, but it has a shorter serviceable life of  ${}^A\text{p} = 175,000$  handled units with a higher probability of premature breakdown than B, which is much more reliable. However, A can be refurbished by the producer, normally up to two times, at a cost of  ${}^A\text{RP} = \text{€ } 1,800$ . In order to avoid highly inefficient new component installations into handling mechanisms shortly before their retirement, old refurbished components will be used whenever a mechanism has less than 100,000 serviced units left until its scheduled retirement. An unscheduled service disruption is estimated to cost  ${}^A\text{DU} = \text{€ } 900$ , including opportunity costs.

On average, each handling mechanism (which is a universal platform carrying one of the components regardless of the technology used therein) operates 4,800 hours per year and, over that time, handles 160,000 delivery units. Its expected lifespan is 1 million handled units, which implies a replacement interval of cca 6.25 years.

The firm uses an continuously compounded annual discount rate of 8%.

## MODEL DESIGN

When using life cycle costing, it is vital to identify all relevant cost types and determine an appropriate functional unit against which total costs will be benchmarked. Clearly, it would not be adequate to simply compare the costs per device, because each alternative has a different structure and duration of its life cycle. Therefore, it is most practical to relate the functional unit to the number of processed units with a convenient benchmark value of 100,000 units, which thus becomes a measure of service time.

One measurement factor which then needs a recalibration is the discount rate. Given the stated 8 % annual rate and the expected average annual handling of 160,000 units, the discount rate per functional unit (i.e. 100,000 handled units) can be determined as  $d = 8\% \times 100,000 / 160,000 = 5\%$ . Note that such a simple linear interpolation is facilitated by the use of continuous compounding.

The life cycle and functional unit costs for technology B, which are stipulated solely by Type I and II costs, are simple to estimate. Its complete life cycle is forecast to last 200,000 handled units, and includes the initial € 4,000 cost of production and € 400 component installation cost, and the terminal € 500 disposal cost. Accordingly, the discounted life cycle cost for component B can be calculated as the net present value of all relevant costs according to Equation (1), with  $t$  representing multiples of functional units.

$$NPV = \sum_t C_t e^{-td} \quad (1)$$

Substituting for the actual costs in time results in  ${}^B NPV = 4,400 + 500 e^{-2 \times 5\%} = € 4,852$ , which relates to the component's total life of 200,000 serviced units. The functional unit cost will then be determined using Equation (2), which is an analogy of the well-known equivalent annual annuity formula, where  $T$  represents the total life cycle duration in functional unit multiples.

$$C = \frac{NPV}{(1 - e^{-Td})} \quad (2)$$

Accordingly, we substitute  ${}^B C = 4,852 / (1 - e^{-2 \times 5\%}) = € 2,550$ . Note that periodic costs of operation (such as energy, maintenance and operator staff) need not be dealt with at this point in time, because only the differential vis-à-vis technology A is relevant for decision-making. There is also an exact fit of five component lives in the planned life of the complete handling mechanism, which allows perfect replacement scheduling.

While Type I and II costs are assessed deterministically, i.e. using their best point estimate, a different approach needs to be taken with Type III costs, constituting statistically random processes. Namely, there is a reliability factor involved, which requires the creation of a statistical model for variant A.

This will be rendered by an exponential distribution with its parameter  $\lambda = 250,000$  units, representing the mean life expectation of the component. Each 1,000,000 unit-long life cycle of the mechanism fitted with this component will vary because of the different lives (and thus replacement and refit timings) of each component.

The life cycle can be simulated using a stochastic dynamic process, illustrated by Figure 1, with its control parameters listed in Table 2.

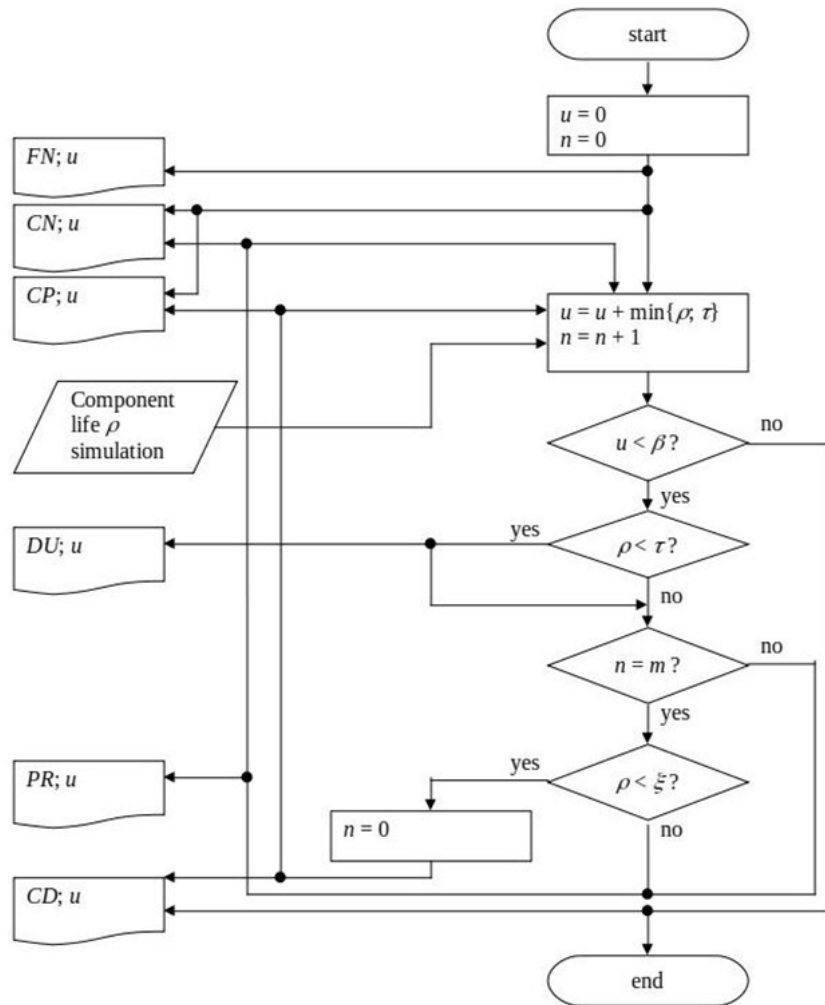
The simulation results in a discounted life cycle cost  ${}^A NPV$  determined according to Equation (1) over a period of 1 million serviced units. This allows the calculation of a functional unit cost according to Equation (2) as  ${}^A C = {}^A NPV / (1 - e^{-10 \times 5\%})$ . For example, a randomly generated  ${}^A NPV = € 1,500$  results in  ${}^A C = 1,500 / (1 - e^{-10 \times 5\%}) = € 3,812$ .

The decision-making criterion in terms of preference for technology A or technology B is their functional unit cost differential  $\Delta$  determined by Equation (3).

$$\Delta = {}^A C - {}^B C + {}^{Op} \Delta \quad (3)$$

Note that all its terms represent costs and  ${}^{Op} \Delta$  is the operating cost differential per

functional unit. A positive value of  $\Delta$  therefore implies an advantage of A over B, and vice versa.



Source: own work

Fig. 1. Total cost simulation process for component A

Table 2. Control parameters of the cost simulation for component A

Parameter	Description [unit]	Quantity
CP	Cost of component production [€]	4,800
RP	Cost of component refurbishment [€]	1,800
CN	Cost of component installation [€]	500
FN	Cost of controls installation [€]	1,500
DU	Cost of service disruption [€]	900
CD	Cost of component disposal [€]	500
$\tau$	Scheduled life of component [units]	175,000
$\beta$	Scheduled life of handling mechanism [units]	1,000,000
$\xi$	Maximum age of handling mechanism to install new component [units]	900,000
$m$	Maximum number of new component refurbishments	2
$d$	Discount rate (per functional unit)	5 %
$\lambda$	Mean life expectation of component [units] - stochastic distribution parameter	250,000
$\rho$	Actual life of component [units]	stochastic
$k$	Units currently serviced	var.
$n$	Current number of refits	var.

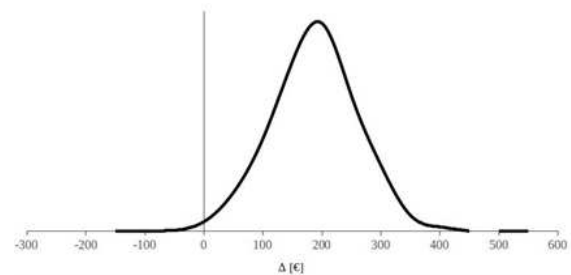
Source: own work

## PROBLEM SOLUTION AND DISCUSSION

Decision-making should be based on the result of Equation (3). This requires three inputs, the functional unit cost for technology B, which has already been established as  ${}^B C = € 2,550$ , the functional unit cost for technology A, determined by statistical simulation using the process in Figure 1, the parameters in Table 2 and the operating cost differential per functional unit  ${}^{Op} \Delta$ .

The last value requires assessment of relevant factor costs and their proper functional unit (i.e. 100,000 handled units) allocation. Forecasting a wholesale price of energy  ${}^E P = 60 € \text{ MWh}^{-1}$  (sensitivity towards this factor will be discussed later) and an energy saving of 1 MWh / 10,000 units, there would be an energy cost differential of  ${}^E \Delta = 60 \times 1 \times 10 = € 600$  per functional unit. Besides this, there will be a saving in personnel costs amounting to € 1,200 per year, which equates to  ${}^P \Delta = 1,200 \times 100,000 \div 160,000 = € 750$  per functional unit. The total is  ${}^{Op} \Delta = {}^E \Delta + {}^P \Delta = € 1,350$  per functional unit.

These are the final inputs needed for the simulation, which generates a probability distribution of functional unit cost differential results shown in Figure 2.



Source: own work

Fig. 2. Functional unit cost differential distribution

Essential results of the simulation include its mean  $\mu(\Delta) = € 153$  and its fifth percentile  ${}^{5\%} q(\Delta) = € 9$ , which serves as a convenient measure of risk (in other words, the advantage of A over B is expected to be € 153, and likely to exceed € 9 with a 95 % degree of confidence).

As with any model used for decision-making, it is now necessary to test the results for their robustness in respect to parametric assumptions. Two parameters seem particularly critical, because of their potential volatility or insufficient information; the energy price forecast  ${}^E P$  on the one hand, and the mean component life expectation  $\lambda$  for A on the other hand.

The test uses sensitivity analyses as follows: a) the estimates for both parameters were reduced by 10 % and 20 %, and b) their break-even points (B-E) were determined by iteration in respect to  $\mu(\Delta) = 0$ . The results are summarized in Table 3.

Table 3. Sensitivity analysis results

Parameter	Base scenario	${}^E P(-10\%)$	${}^E P(-20\%)$	$\lambda(-10\%)$	$\lambda(-20\%)$	B-E( ${}^E P$ )	B-E( $\lambda$ )
${}^E P$ [€/MWh]	60	54	48	60	60	42	60
$\lambda$ [units]	250,000	250,000	250,000	225,000	200,000	250,000	218,000
$\mu(\Delta)$ [€]	153	105	55	68	-102	0	0
${}^{5\%} q(\Delta)$ [€]	9	-32	-59	-52	-221	-128	-124

Source: own work

The sensitivity analysis clearly shows that the operational risk due to a potentially shorter mean life of the component compared to the expected one is much more significant than the price risk of energy. Whereas even a 20% decline in the price of energy would still

clearly merit replacement of component B by A and this conclusion would hold unless the price were to fall under 42 €  $\text{MWh}^{-1}$  (i.e. by 30%), a relatively moderate increase in the component break down rate - given the

uncertainty in its estimation - would suffice to reconsider such a decision.

However, further simulation also suggests an operational measure, which would mitigate this risk and thus again increase the cost advantage of A over B. Provided the firm increases the scheduled life (i.e. replacement time) of component A to  $\tau = 200,000$ , even an actual value of  $\lambda = 218,000$  units then results in  $\mu(\Delta) = \text{€ } 194$ . Of course, such an adjustment of operational procedure would be viable only if not constrained by regulatory or other overriding factors.

## CONCLUSIONS

This paper developed a model combining Life Cycle Cost budgeting with parametric statistical simulation to solve a problem in the logistics servicing industry related to using different technologies. This allowed the involvement of conventional cost assumptions, as well as operationally dependent contingent costs with disparate replacement timings, providing for a complete assessment of the decision value drivers. It is easy to see how this technique can be adjusted to solve a broad range of similarly defined problems.

In contrast to conventional capital budgeting methods, the model is capable of capturing quality- and customer satisfaction-related factors (i.e. Type III and possibly Type IV costs), which tend to be of particular significance in service industries. As a matter of fact, the model combines several essential components of financial and operational analysis in a single integrated framework.

It has also been shown that developing such a model is perfectly viable for industry practitioners and - when combined with proper sensitivity analyses - simulation-based models can therefore provide meaningful and easily understandable groundwork for practical decision-making.

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## PODEJMOWANIE DECYZJI BUDŻETOWYCH W LOGISTYCE

**STRESZCZENIE. Wstęp:** Decyzje kapitałowe budżetowe w logistyce często wyróżniają się trzema charakterystycznymi cechami. Są one powiązane z aktywami kapitałowymi, takimi jak pojazdy lub sprzęt, które są okresowo zastępowane, z różnymi okresami życia oraz z faktem, że ich działanie podlega operacyjnemu i rynkowemu ryzyku. Warunki zewnętrzne, takie jak uwarunkowania prawne, rozwój technologii, innowacyjność (wszystko wpływające na niepewność działania) są również istotnym czynnikiem wpływającym na postępowanie w obrębie logistyki. W pracy jest zaprezentowany opracowany model ewaluacji, biorący pod uwagę powyżej wymienione charakterystyki oraz ułatwiający rozbudowany proces podejmowania decyzji.

**Metody:** W celu prawidłowego ujęcia specyfikacji problemu, proponowany model jest oparty na aplikacji metody budżetowania Life Cycle Cost w odniesieniu do odpowiedniej jednostki funkcjonalnej, w połączeniu z symulacją Monte Carlo and analizą wrażliwości istotnych czynników ryzyka.

**Wyniki:** Zostało opracowane realistyczne studium przypadku, dostarczające niezbędnych danych wejściowych dla proponowanej metody analizy. Dostarczyło to przydatne spójne dane wejściowe dla procesu podejmowania decyzji, włączając w to narzędzia potrzebne do testowania różnych założeń oraz oceny podejmowanego ryzyka.

**Wnioski:** Prezentowany model i jego rozwiązania dostarcza wyników porównywanych z konwencjonalnymi metodami budżetowania kapitałowego pod względem prawidłowego ujmowania czynników wartościowych dla powszechnie występujących problemów w logistyce. Można go stosować w szeroko pojętej praktyce zarządzania.

**Słowa kluczowe:** budżetowanie kapitałowe, kosztorys cyklu życia, symulacja Monte Carlo, zarządzanie logistyczne

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