

USING LIFE CYCLE COSTING FOR PRODUCT MANAGEMENT

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Case study
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Introducing a case study on product management, this paper applies the Life Cycle Cost (LCC) method to solve a particular problem of design selection in the area of mechanical engineering. It is clearly explained and illustrated that various cost types need to be taken into account, ranging over the whole life of the product from concept to end-of-life, and related to an appropriate unit of utility. In order to achieve maximum effect, such a comprehensive economic analysis should ideally be undertaken at a very early stage of the product's life cycle, such as its design or even conception. Advanced techniques, including sensitivity analyses and simulations, will typically be required to gain an adequate insight into various processes and uncertainties contained in any realistic life cycle model.

1. INTRODUCTION

As most users of durable goods ultimately find out, a product developed or purchased at the lowest initial cost need not necessarily be the one which also provides the same utility at the lowest overall cost. Taken in the broader context of economic decision-making, product ownership costs, over the whole product lifecycle, are often significant, sometimes exceeding their acquisition costs by a multiple. Researchers also argue that up to 70-90 % of these total life cycle costs become defined already in the design phase (Woodward, 1997; Lindholm and Suomala, 2004; Bescherer, 2005).

This is the essential reasoning, which has led to the development of the Life Cycle Costing (LCC) method, originally designed for procurement

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purposes in the U.S. Department of Defense and still used most commonly in the military sector. The construction industry has since become another major applicant of LCC, because buildings are typically used and operated over a long period of time. As a rule of thumb, after six to eight years the operational costs of a building are as high as the cost of its construction (Woodward, 1997; Staudt et al., 1999; Opuku, 2013).

A third major promoter of LCC is the public sector, whose heavy involvement in the area of life cycle cost calculations frequently combines with Life Cycle Assessment (LCA) studies, focusing primarily on sustainability and environmental issues. Initial investment costs are still most often used as the primary or sole criteria in purchase or acquisition decisions. In spite of the obvious long-term benefits of LCC, its adoption has been relatively slow in other industries. Applications and analytical approaches are also rather diverse (Woodward, 1997; Norris, 2001; Lindholm and Suomala, 2004; Dhillon, 2010).

To quote just a few examples, partially related to this paper's focus, Jun and Kim (2007) have showed the application of this technique in cost modeling of the brake module of a train vehicle. Several scenarios have been since with reduced or increased man hour requirements. Li et al. (2013) described a framework for the strategic planning of railway maintenance and renewal projects. Ficko et al. (2005) focused on the total costs of tool manufacture. Lamb (1996) attempted to connect business performance and competitiveness to maintenance in the context of paper and pulp industry. He discussed the concept of availability as a measure of business performance and made reliability and maintenance operations the key drivers for paper mill performance. Azzopardi et al. (2011) used LCC to compare the effects of technological advance in materials development.

This paper strives to summarize the specific features and benefits of life cycle cost analysis in the particular context of strategic product management. A case study illustrates the essential points.

2. LCC PRINCIPLES AND IMPLEMENTATION

The fundamental difference between the LCC and conventional management accounting systems is the tracking and accumulation of costs and revenues attributable to the product over its full life cycle, which may last for many years. The life cycle costs of products then comprise all costs attributable to a product from its conception and pre-production stage to those that customers incur throughout the life of the product, including the costs of

installation, operation, support, maintenance and disposal (Fabrycky and Blanchard, 1991; Arto, 1994). LCC also typically extends the scope of applicable costs, included in its analysis (Table 1).

Whereas conventional costing is essentially based on Cost Types I and II (direct and indirect), LCC usually adds Type III (contingencies), often Type IV (intangibles), and sometimes (primarily within the domain of public sector procurement) aspires to involve Type V (externalities) (Norris, 2001; Drury, 2007).

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 (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: External	Costs borne by other parties than those directly involved in the life cycle (e.g. society).

Source: Adapted from Norris (2001), Kong and Frangopol (2003).

There are numerous distinct inputs to a typical LCC model, including, for instance in the case of engineering products: warranty coverage period, average material cost of a failure, cost of training, cost of installation, system's or item's listed price, cost of carrying spares in inventory, mean time between failures, mean time to repair, spares' requirements, cost of labor per corrective maintenance action, testing and integration costs, documentation and compliance costs, as well as time spent for travel (Boussabaine and Kirkham, 2004; Dhillon, 2010).

Clearly, the viability of any LCC analysis ultimately hinges on the availability of information spanning diverse locations and activities, frequently not held or collected by the particular decision-making entity. This necessitates an extensive, and sometimes creative, use of various cost-estimation models, often including advanced statistical tools. Generally, they may be systematized into three categories as shown in Table 2.

Table 2. Cost estimation model categories

Method	Description
Analogous	Compares costs according to similarities and differences with other projects.
Bottom-up	Collects all product cost values that are available, making it a highly data intensive method. Uses e.g. activity based costing.
Top-down (Parametric)	Derives cost estimating relationships and associated mathematical algorithms to reach cost estimates. Uses e.g. regression analysis, fuzzy logic, neural networks.

Source: Adapted from Asiedu and Gu (1998), Boussabaine and Kirkham (2004).

An LCC analysis would often be used when variant solutions of a particular problem exist, with regards to, for example, design or constructional alternatives, operational scenarios, logistics, distribution or recycling. In such cases, relative, rather than absolute, valuation would be required, resulting in somewhat reduced data requirements (Dhillon, 2010).

Whenever qualitative aspects influence the end-user's decision, it is convenient to benchmark LCC analysis against a functional unit, rather than a particular product or service. This allows a full life cycle comparison of fundamentally different solutions to the same utility need, which would be satisfied by a service or a product. Such a functional unit might relate to e.g. servicing capacity, degree of protection or system performance (Norris, 2001).

From the product's perspective, the life cycle is divided into several (usually 3 – 4) phases. The greatest overall effect will typically be achieved by LCC implementation in the earliest stages of the life cycle, i.e. design and development. Normally, time value is subsumed in the calculations through discounting all costs relative to the point of service initiation (Fabrycky and Blanchard, 1991; Bescherer, 2005; Kapp and Girmscheid, 2005).

3. CASE STUDY

3.1. Problem description

The producer is currently taking a strategic decision, selecting from two design proposals for a new gear unit to be used in public transport vehicles (buses). The designs vary in concept; one (A) being an automatic (self-changing) gearbox, the other one (M) mechanical (manual). The selection precedes a substantial investment into final product development, certification

and pre-production, necessary to construct and deliver trial units to the bus producer, who has an outstanding tender requirement for replacement vehicles submitted by the municipal transportation board. Of principal joint concern for all the parties are total life cycle costs, as these will ultimately be shared amongst them, albeit indirectly, through tender prices.

Based on thorough research, the gear unit producer has identified three relevant phases of the life cycle, distinguished by the particular entity retaining the product. These include the gear unit production (P), its installation into the bus (N), and its usage in municipal transport (U). Within the life cycle, each solution (design) features distinct properties, impacting total costs. From the sole perspective of its production costs, the automatic gear unit is more expensive, with direct and allocated overhead costs amounting to €4,800, while those of the mechanical unit total only €4,000. Its installation into the vehicle is also more costly, at €500, specifically requiring each bus to be initially fitted with electronic components worth €700; installation of the mechanical gear costs just €400. However, in the phase of use (service), the automatic gear brings certain benefits. In particular, it reduces average fuel consumption by 0.5 liters per 100 km. It is also expected to lessen the skills requirements for drivers, and thus staff costs, by €0.25 per hour.

The mechanical unit has a projected working life of 200,000 km, and will thereafter be disposed of at a cost of €500. The automatic unit, whose disposal cost is also €500, has a shorter serviceable life of 175,000 km, with a higher probability of its pre-mature break-down than that of the mechanical gear, which is much more reliable. However, the automatic gear can be refurbished by the producer, normally up to two times each, at a cost of €1,600. An unscheduled service disruption is estimated to cost €650 (including opportunity costs). On average, each vehicle (bus) operates 4,800 hours / year and, over that time, covers a distance of 180,000 km. The economic life of a bus is 1 million kilometers (this implies a replacement interval of cca. 5.5 years). The time factor of production and installation is included in their respective costs, an annual discount rate of 9% (using continuous compounding) will be used for the life-cycle stage of product use. Annual deliveries are expected to reach approximately 50 units.

3.2. Problem solution

While using the LCC method, it is essential to identify all relevant cost types, and, wherever comparison is undertaken, also to determine an appropriate

functional unit, against which total costs will be benchmarked. Several cost types are involved in this particular case:

- Type I (direct) costs, numerous;
- Type II (indirect) costs are relevant primarily in the production stage, but many would be essentially equal for both alternatives and therefore need not be accounted for because the projects are mutually exclusive;
- Type III (contingent) costs relate to the reliability of product A;
- Type IV (intangible) costs may relate e.g. to the acceptance of the product by the users (i.e. drivers).

Under certain circumstances, Type V costs might also be considered, e.g. relating to the environmental perspective. In the present case, both variants are, for the most part, comparable from that point of view. Some differences may ensue from combustion efficiency (A consuming less fuel) and recycling (A allowing refurbishment). These are, however, already taken into account within the frame of other cost types. It is generally assumed that all regulatory requirements are met and will continue to be so in the foreseeable future.

The life cycle and functional unit costs for product M, all of whose costs are given as Type I, are quite straightforward to estimate. Its life cycle is projected to last 200,000 km and includes the costs of production of the gear-box (€4,000) and its installation costs (€400) at the beginning of the period, and disposal costs (€500) at the end of the period, as shown by Figure 1.

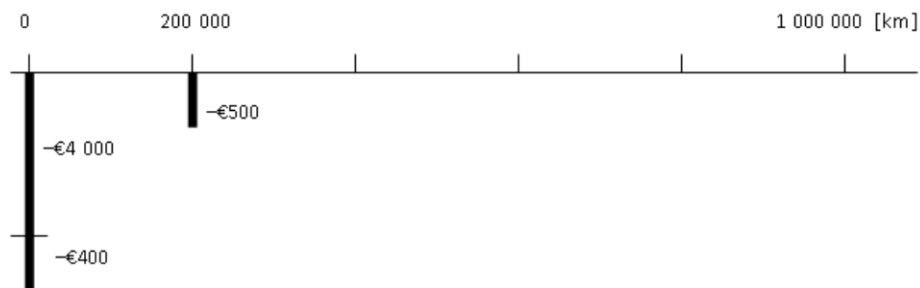


Figure 1. Life cycle time line (unit M)

Source: Author.

There are also costs of operation to consider (staff and fuel), but as these are only compared on an incremental basis with product A, they will be dealt with later. Five mechanical gear-box life cycles also exactly fit into the full life cycle of a bus, which thus becomes irrelevant (if that were not the case, one

might have to consider either a premature life cycle termination or extension of the final gear-box installed in a vehicle before its retirement, as will be shown later with variant A).

As the two alternatives are not equal in terms of utility per product, having a different duration and structure of their life cycles, we have to benchmark total costs against a common functional unit. In the present case, it is most practical to relate the functional unit to the number of kilometers of service, and we shall thus select 100,000 kilometers (the actual number being arbitrary).

Using this particular functional unit, it will be effective to relate the discount rate to the period of 100,000 km, which essentially serves as a measure of service time. Knowing the annual mileage of a bus (180,000 km), we shall thus henceforth be using the discount rate of $9\% \times 100\,000 / 180\,000 = 5\%$ (per 100 000 km, i.e. 0.56 years). The discounted life cycle cost for the mechanical gear (excluding costs of operations) can then be calculated as $LC_M = 4\,400 + 500 e^{-2 \times 5\%} = \text{€}4,852$ (financial formulas using continuous compounding and their derivations are described in detail by e.g. Los, 2001).

To convert the life cycle cost, which relates to 200,000 kilometers of service, to the functional unit cost (per 100,000 km of service), we use the equivalent annual annuity method, deriving the cost per functional unit $C_M = 4\,852 \times 5\% / (1 - e^{-2 \times 5\%}) = \text{€}2\,550$.

While the Type I and II costs are being assessed deterministically (i.e. using their best estimate), a fundamentally different approach has to be used with Type III costs, which constitute statistically random processes. This makes the cost of the automatic gear unit much more complicated and requires the creation of a statistical model.

The reliability-based process of unit break-down (for A) will be described using the simple exponential distribution (Mun, 2006, p. 119) with a mean $\mu = 300,000$ km. Each life cycle of a gear unit is thus going to differ (not only because of its absolute length, but also the frequency of refits, as well as their planned or unplanned nature) and there is also due to be a different fit within the life cycle of the bus. We must now therefore consider the complete life cycle of the bus, i.e. 1,000,000 km. The unit's lifecycle will then be determined by a dynamic process, illustrated by Figure 2, with its control parameters summarized by Table 3.

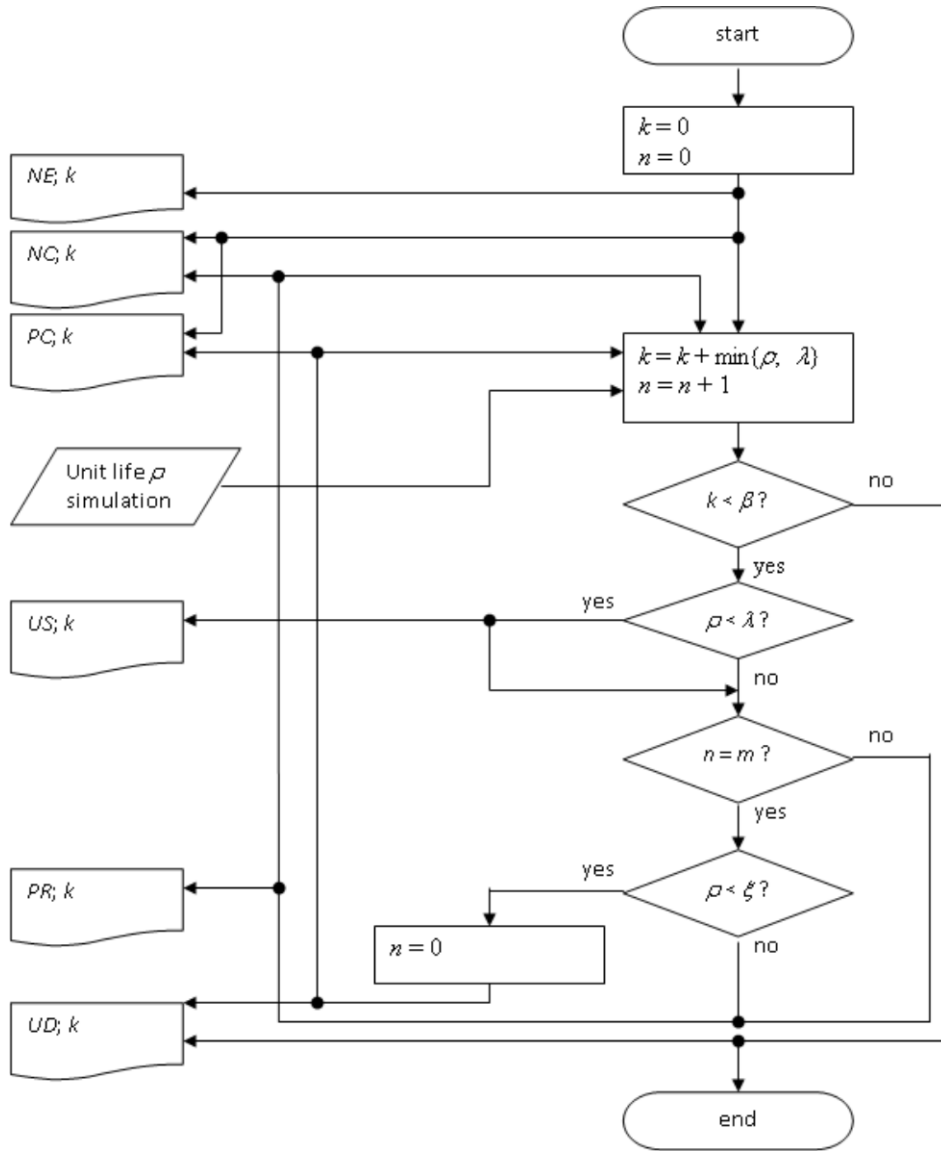


Figure 2. Life cycle algorithm (unit A)

Source: Author's algorithm.

Note that a special rule had to be established, in line with operating manuals and applicable regulations, to mitigate the occurrence of brand new gear-box installations into vehicles just before their retirement, which would

clearly be highly inefficient. This goal has been achieved by stipulating that refitted gears from retired buses would be used whenever a bus had less than 100,000 km to retirement. The cost differential for fuel Δ_F depends on its price p (per liter) and the consumption differential Δ_C described by $\Delta_F = \Delta_C \times p \times 100\,000 / 100$; the cost differential for staff Δ_S depends on the wage differential Δ_W as in $\Delta_S = \Delta_W \times 4\,800 \times 100,000 / 180,000$ (each per the functional unit of 100,000 km).

Table 3. Control parameters of the life cycle algorithm (unit A)

Par.	Description	Spec.
PC	Cost of production (€)	4,800
PR	Cost of refurbishment (€)	1,600
NC	Cost of installation (€)	500
NE	Cost of electronics (€)	700
US	Cost of service disruption (€)	650
UD	Cost of disposal (€)	500
λ	Construction life of gear unit (km)	175,000
ρ	Actual life of gear unit (km)	stoch.
β	Construction life of bus (km)	1,000,000
ξ	Maximum life of bus to qualify for new gear-box (km)	900,000
k	Kilometers of service	var.
m	Maximum number of refits	2
n	Number of refits	var.

Source: Author.

The life cycle cost for the automatic gear will be determined using parametric (Monte Carlo) simulation (Mun, 2006). As we are only concerned about the differential costs per functional unit, the costs of the mechanical gear, as well as differential operational costs, will be directly subtracted using a criteria measure denoted as *NAA* (Net Advantage of the Automatic gear per functional unit) and calculated according to:

$$NAA = C_M - LC_A \times 5\% / (1 - e^{-10 \times 5\%}) + \Delta_F + \Delta_S \quad (1),$$

where LC_A represents the simulated discounted life cycle cost of the automatic gear (per its 1 million km life cycle), the term $C_A = LC_A \times 5\% / (1 - e^{-10 \times 5\%})$ stipulating its cost per functional unit (100 000 km), presuming a life cycle spanning 10 functional units and a discount rate of 5%.

Postulating the parameters $p = 1.40 \text{ €/l}$, $\Delta_c = 0.50 \text{ l / 100 km}$, and $\Delta_w = 0.25 \text{ €/h}$ and assuming batches of 50 units, the simulation output (using 10,000 simulation runs), in line with the annual demand projection, generates an *NAA* probability distribution, illustrated by Figure 3. According to its shape and position, there is a clear advantage to using the automatic gear (with a mean *NAA* of €580 per 100,000 km of use and a negligible probability of attaining a negative value).

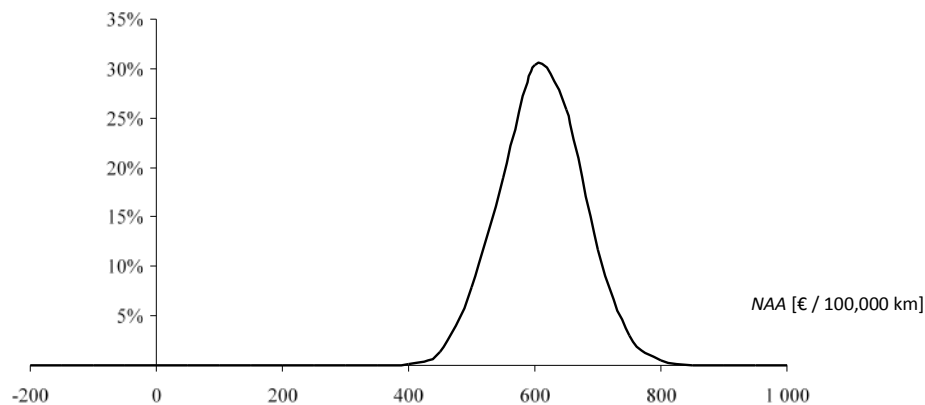


Figure 3. Net Advantage to using Automatic gear unit (base assumptions)

Source: Author's calculation.

3.3. Sensitivity analysis

Based on the previous result only, it might seem that the automatic gear should be the obviously preferred choice. There are, however, a number of underlying assumptions, whose uncertainty has to be properly dealt with. This process is always an essential component of LCC and uses various kinds of sensitivity analyses and scenario-based simulations. Accordingly, we shall now present a rudimentary example of such an approach.

In the present case, crucial uncertainties may be presumed to relate mainly to the operating cost differential estimates. On the one hand, there is the market price of fuel factor, which is difficult to predict and volatile over time. Its rising price increases the *NAA*, with a positive sensitivity $\Delta NAA / \Delta p = 500$ (i.e. an increase in the oil price by €1 increases *NAA* by €500 per 100,000 km); even more telling is its break-even point, amounting to just €0.20 per liter (both of

these values can either be inferred analytically, through derivation of (1), or numerically, using the simulation model). On a stand-alone basis, price risk would thus be essentially irrelevant, as far as the product selection is concerned.

On the other hand, however, there is a risk that the projected wage differential would not be sustainable (for example due to trade union pressure, or the operational necessity to maintain uniform qualification standards for all drivers). This is essentially a Type IV cost, not to be underrated (more so that it comes under the auspices of the municipality, not the producer). Based on a repeated simulation instating $\Delta_w = 0$, we find that the resulting *NAA* distribution now has a mean of €0 (standard deviation €160, assuming the 50 unit batches), all of a sudden making the fuel price (and possibly other assumptions) an essential value driver with a dominant influence on the ultimate decision.

Taking such a scenario into account, we would now be inclined to prefer the automatic gear unit solution only provided fuel prices were projected to rise, rather than fall in the medium term. This point of view is further facilitated by the fact that, due to its lower reliability, the automatic gear unit may incur additional operating risks. For example, an increase in the projected cost of service disruption (there may be various reasons for such a development, including regulatory or market-driven) to €850 (retaining $\Delta_w = 0$) results in a negative mean *NAA* of – €70, which would only be mitigated (from the point of view of the ultimate selection of variant A) by a projected fuel price growth exceeding €0.15 per liter.

4. CONCLUSION

In this paper, we have described and shown how the life cycle cost approach may be of vital assistance for strategic decision-making, such as the selection of the appropriate product solution. A very high degree of understanding is obtained, relating to all value-relevant factors and processes spanning the whole life cycle, and also their particular risks and mutual relationships. Besides managerial decisions of the individual parties, such as the designers, producers or users of a product, an LCC analysis may thus also facilitate their commercial communication or negotiations.

Obviously, as compared to conventional budgeting, the LCC method tends to involve much more sophisticated tools and procedures, and requires substantial skills and resources in order to obtain the necessary data. Outstanding business experience and judgmental skills are also crucial for achieving a well-substantiated and practicable interpretation of the results of the

analysis. Generally, its application may be beneficial wherever significant investments are being considered, incurring costs, direct or indirect, over relatively long periods of products' use. Application of the LCC method, as a case study for project management, is discussed by the teaching notes, illustrated by Table 4.

Table 4. Teaching Notes – Instructions on LCC-based project assessment

Instructional direction	Student understanding	Discussion or simulation
<ul style="list-style-type: none"> Introduce the product life cycle concept using several practical examples. 	<ul style="list-style-type: none"> Students focus on the distinction between different life cycle stages and their respective contribution to the total ownership cost. 	<ul style="list-style-type: none"> Identify particular decision-making areas where the life cycle approach makes a difference compared to the conventional budgeting methods.
<ul style="list-style-type: none"> Introduce and explain the nature of different types of costs and applicable valuation methods. Highlight the essence and importance of using estimates and statistical methods in cost estimation. 	<ul style="list-style-type: none"> Students should clearly distinguish between the cost types and understand the basic valuation methods. 	<ul style="list-style-type: none"> Simulate and discuss the cost of particular items.
<ul style="list-style-type: none"> Explain the obstacles and fall-backs when obtaining data and assumptions for the LCC models. Relate this issue to major challenges when interpreting results. 	<ul style="list-style-type: none"> Students should become comfortable with collecting and processing various types of relevant data and test hypotheses using tools like sensitivity and scenario analysis. 	<ul style="list-style-type: none"> Simulate particular models with a focus on various sensitivities and interpretations of results. Discuss real-life implications.
<ul style="list-style-type: none"> Introduce the concept of functional unit and functional unit costing. 	<ul style="list-style-type: none"> Students should be able to design suitable functional units and understand their essential role in comparative costing. 	<ul style="list-style-type: none"> Using simple cases, propose appropriate functional units. How does the functional unit impact total life cycle cost results under different end-users' preferences?
<ul style="list-style-type: none"> Explain how various objectives may be addressed by different types of decision-maker. 	<ul style="list-style-type: none"> Students should be able to identify and clearly distinguish between various utility functions. 	<ul style="list-style-type: none"> Compare a project's total life cycle cost from a commercial and a public entity's perspective. Discuss potential conflicts and their resolution.

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KORIŠTENJE MODELA IZRAČUNA TROŠKA TIJEKOM ŽIVOTNOG CIKLUSA U UPRAVLJANJU PROIZVODOM (STUDIJA SLUČAJA)

Sažetak

Koristeći studiju slučaja u upravljanju proizvodom, u ovom se radu primjenjuje metoda izračuna troškova tijekom cjelokupnog životnog ciklusa proizvoda, kako bi se riješio specifičan problem izbora dizajna proizvoda u području strojarstva. Pritom se objašnjava i predočava da u obzir treba uzeti različite vrste troškova, koji se pojavljuju tijekom cijelog života proizvoda (tj. od njegove konceptualizacije, pa do kraja životnog ciklusa), a treba ih usporediti s odgovarajućom razinom korisnosti. Da bi se postigao najveći učinak, ovako bi složenu ekonomsku analizu trebalo obaviti u vrlo ranoj fazi životnog ciklusa, kao što je faza dizajna ili, čak, inicijalnog osmišljavanja proizvoda. Pritom će biti potrebno koristiti napredne tehnike, kao što se analiza osjetljivosti i simulacija, s ciljem odgovarajućeg razumijevanja procesa i neizvjesnosti, koji se pojavljuju u svim realističnim modelima životnog ciklusa proizvoda.

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