THE PRINCIPLES OF LIFE CYCLE COSTING OF THE ASSETS OF THE DEFENCE FORCES

Marek Mardo

ABSTRACT. Life cycle cost estimation enables decision-makers to have an overview of all costs related to a procured asset item during its service life and helps to make an optimal decision based on the total cost of a tender. Usually, armament or a weapon system is purchased with the lowest possible price. Ignorance in calculating the expenses that accompany the use of a purchased item will result in a situation where there are no budget resources left for maintenance. Without regular maintenance and updating, however, a purchased item will become unserviceable. This article[1] gives a short overview of the historic development of life cycle costing, describes the life cycle stages of an item, and introduces a method for analysing the costs related to owning an item.

Keywords: life cycle costing, life cycle cost estimation, cost breakdown structure (CBS), cost element, product tree, resources, cost of ownership (COO), total ownership cost (TOC), indirect cost, variable cost, direct cost, fixed cost, sunk cost

1. Introduction

Governmental defence acquisition programs are increasingly more focused on the total cost estimation of military equipment during its exploitation period instead of just relying on the lowest bid, and use this as a basis for making the final decision between tenders before signing a contract. Generally, from the acquirer's perspective, costs start with acquisition and end when the acquired asset is no longer in use. When done properly, costing is considered a powerful technique to measure the cost-effectiveness of a defence procurement[2]. The unbudgeted or un-estimated long-term cash flows related to life cycle costing (LCC) are causing a quick degradation in the required/achieved operational capabilities because there will not be enough (financial)

[1] This article was originally written in Estonian and first published in the Estonian Journal of Military Studies (Sõjateadlane), No. 18, pp. 105–129.

[2] **RTO-TR-SAS-069**, 2009. Code of Practice for Life Cycle Costing. NATO Research and Technology Organisation (RTO) Publication, September, p. 1. [**RTO-TR-SAS-069**, 2009]

resources allocated for sustainability; after a short period of exploitation, the acquired equipment becomes un-operational[3]. LCC is a process of evaluating all cost inputs related to the acquired asset over its planned operational usage that can be extended for up to 50 years. For example, the Boeing B-52 Stratofortress, a strategic bomber of the United States Air Force, made its first flight in 1952, and technical studies have determined that the service life of the bomber plane can be extended until the mid-2040s[4]. During its service so far, the B-52 bomber has been gradually modernised and its computer systems constantly updated. According to Tysseland, lacking knowledge on life cycle costing is one of the several problems that directly affect the assessment of the economic profitability of defence investments[5]. Why do we even need life cycle costing? As said in *Code of Practice for Life Cycle Costing*[6], a NATO publication, it is one of the best indicators to measure the value of money for assessing affordability, managing the budget, estimating future cash flows, evaluating different acquisition options and solutions in order to find the best alternatives, improving business processes, and analysing national defence programs. How much do different organisations actually consider life cycle costs? Since no research on the subject has been done in Estonia, we will have to look at the studies of our closest neighbours. According to a study of Lindholm and Suomala, the practice of life cycle costing is used to some extent in Finland but, in general, overall utilisation is rare[7]. It is believed that the relevance of life cycle costing will grow if each end user is willing to compile an inventory list for an asset to determine the lowest operational and maintenance costs during its entire exploitation period. Several life cycle costing models have been developed for users to assist in planning and performing long-term business activities (operations in the military) as a means

---

3 **Murumets, J**. 2014. Tankidest ja tabelitest. – Rahvusvaheline Kaitseuuringute Keskus. Blogi, julgeoleku planeerimine. https://icds.ee/et/tankidest-ja-tabelitest/ (14.12.2021).

4 In 1952–1962, a total of 744 planes have been constructed in eight modifications (from A to H). The plane has repeatedly been modified and its H-modification celebrated 50 years in service on 26 October 2012. See **Boeing** 2021. https://www.boeing.com/defense/b-52-bomber/ (20.08.2011).

5 **Tysseland, B. E**. 2008. Life cycle costs based procurement decisions: A case study of Norwegian Defence Procurement projects. – International Journal of Project Management, Vol. 26, Issue 4, p. 367. [**Tysseland** 2008]

6 **RTO-TR-SAS-069**, 2009.

7 **Lindholm, A.; Suomala, P**. 2005. Present and Future of Life Cycle Costing: Reflections from Finnish Companies. – Liiketaloudellinen aikakauskirja, Vol. 2, p. 288. [**Lindholm, Suomala** 2005]

of using their assets and predicting the necessary cash flow for sustainability. A report of the National Audit Office of Estonia specifically foregrounds the deficiencies in planning and organising defence procurements[8]. This gives ground to presume that neither the Republic of Estonia Centre for Defence Investment nor the Estonian Defence Forces have developed uniform standard procedures or a proper life cycle costing model for assets, involving their entire life cycle from concept development to disposal. The reform for organising procurements initiated by the Centre for Defence Investment will probably consider the recommendations listed in the 2020 report of the National Audit Office.

The objective of this article is to give an overview of the historic development of life cycle costing and introduce its fundamental principles and an initial cost allocation pursuant to a cost model—the cost breakdown structure (CBS) which could serve as the basis for future negotiations with capability planners, contracting authorities, and end users.

2. History of life cycle costing

This chapter will give a brief overview of the historic development of life cycle costing in major industrial countries and analyse several shortcomings in that field in Estonia. The earliest written references to life cycle management are probably found in 13th century England. The keeper of a king's ports and galleys was an official appointed by the King of England whose task was to build, man, supply, and maintain His Majesty warships[9].

Life cycle costing also raised some questions for the troops of the United States of America in World War II. The concept of life cycle costing gained more attention in the mid-sixties when the US Department of Defence (DoD) recognised the fallacy of justifying an acquisition based solely on the lowest price of tenders[10]. Even though a procurement document from that era,

---

[8] **Planning and cost-effectiveness of large-scale defence procurement (report summary)** 2020. Report of the National Audit Office to the Riigikogu, 11 November. Tallinn: National Audit Office of Estonia, p. 2. https://www.riigikontroll.ee/DesktopModules/DigiDetail/FileDownloader.aspx?FileId=14752&AuditId=2515 (20.11.2022). [**Planning and cost-effectiveness of large-scale defence procurement** 2020]

[9] **Rodger, N. A. M**. 1997. The Safeguard of the Sea: A Naval History of Britain. Vol 1: 660–1649. London: Penguin Books Ltd., p. 53.

[10] **Eisenberger, I.; Lorden, G**. 1977. Life-Cycle Costing: Practical Considerations. – The Deep Space Network Progress Report 42–40, p. 102. http://ipnpr.jpl.nasa.gov/progress_report2/42-40/40M.PDF (20.08.2021).

Armed Services Procurement Act of 947, included a suggestion to consider the price and other aspects before making a decision, the lowest price of a bid was still the deciding factor in all purchases[11]. According to Woodward, both the public and the private sector in the 1970s still made procurement decisions based on the best purchase price[12]. The Logistics Management Institute[13] was tasked with developing a method for and the fundamental principles of life cycle costing[14]. The term *life cycle costing* was first used in national defence documents published by the Logistics Management Institute. The term was described as the total cost of military equipment incurred by the Government, starting from the moment when the investigation of its generating idea elicits manpower usage within or without the Government until the moment when every piece of equipment is eliminated from the logistics system of the Defence Forces[15]. In the first half of the 1970s, the U.S. Department of Defence introduced guidelines for life cycle costing[16]. From this point on, the theory and practice of life cycle costing were transferred to other major industrial countries and used as a basis for establishing national rules and regulations in a particular field.

In the first half of the 1970s, terotechnology was developed in Great Britain and it found immediate use. Terotechnology is a way of combining and utilising engineering-technological expertise and knowledge on management and finances to get an overview of the life cycle costs of devices, equipment, infrastructure, etc., for economic purposes[17]. Similarly to the USA, the

---

[11] **Life cycle costing in industry** 1967. Task 67–21. Washington, D.C.: Logistics Management Institute, p. 1. https://apps.dtic.mil/sti/pdfs/AD0660659.pdf (02.10.2021). [**Life cycle costing in industry** 1967]

[12] **Woodward, D. G**. 1997. Life cycle costing – Theory, information acquisition and application. – International Journal of Project Management, Vol. 15, Issue 6, p. 335. [**Woodward** 1997]

[13] An organisation established with an order by President John F. Kennedy on 3 October 1961 to advise national institutions (national defence, security, healthcare) independent of all political and commercial interests. See **LMI** 2021. LMI History. https://www.lmi.org/lmi-history (02.10.2021).

[14] **Life cycle costing industry** 1967, p. 1.

[15] **Okano, K**. 2001a. Life cycle costing – An approach to life cycle cost management: A consideration from historical development. – Asia Pacific Management Review, Vol. 6, Issue 3, p. 320. [**Okano** 2001a]

[16] *Life Cycle Costing Procurement Guide* (LCC-1), *Life Cycle Costing in Equipment Procurement-Casebook* (LCC-2), *Life Cycle Costing Guide for System Acquisition* (LCC-3). See **Okano** 2001a, pp. 320–321.

[17] **Okano** 2001a, p. 325.

Brits also added development, construction, employing, maintenance, and updating to life cycle costing, turning the focus more on the final user and a way for an asset owner to increase profitability and efficiency[18]. During the same period, two systems for managing life cycle costs were developed in Japan. In the second half of the 1960s Nippondenso CO. Ltd developed Total Productive Maintenance (TPM) with the goal of maximising equipment effectiveness with minimum life cycle costs through the stages of (1) initial investment and applied research, (2) use, including maintenance, (3) management (supplies and training), and (4) disposal[19]. The strategy was adopted by the company in 1971. Since Japan was one of the countries that lost in World War II, their ministry of defence and the defence industry engaged in close cooperation with the US Department of Defence and adopted the USA approach to life cycle costing in their field of defence[20]. Germany, as one of the great industrial countries of continental Europe, developed national standards, legislation, and procedures for life cycle costing (German *Lebenszykluskostenrechnung*), publishing these in 1980. The documentation was compiled based on the experiences of the USA, Great Britain, and Japan (see Annex, Figure 6). According to Sánches, the historic development of life cycle costing was greatly influenced by *Life-Cycle Costing Manual for the Federal Energy Management Program*, a standard for life cycle cost estimation published in the USA in 1987, and ISO/IEC 15288, specialised international standards published in 2002[21].

Although the need for calculating and modelling life cycle costs is constantly emphasised, such models are, according to Bengtsson and Kurdve, rarely used in industrial enterprises[22]. Lindholm and Suomala conclude in their study that Finnish industrial enterprises apply life cycle cost calculation

[18] **File, W. T**. 1993. Chapter 18: Terotechnology and Maintenance. – Koshal, D. (ed.). Manufacturing Engineer's Reference Book. Chapter 18.1. Butterworth-Heinemann, Elsevier Ltd.

[19] **Okano** 2001a, pp. 327–328.

[20] **Okano, K**. 2001b. Life Cycle Costing in Historical Perspective. – Matsuyama Daigaku Ronshu, Vol. 12, Issue 6, p. 69. https://core.ac.uk/download/pdf/230502989.pdf (20.08.2021).

[21] **Sánchez, P. J**. 2015. Life Cycle Cost Estimation Procedure for a Weapon System in Spain. – Journal of the Spanish Institute for Strategic Studies, No. 6, p. 5. https://revista.ieee.es/article/view/262/941 (20.07.2021). [**Sánchez** 2015]

[22] **Bengtsson, M.; Kurdve, M**. 2016. Machining Equipment Life Cycle Costing Model with Dynamic Maintenance Cost. 23rd CIRP (International Academy for Production Engineering) Conference on Life Cycle Engineering. – Procedia CIRP, Vol. 48, p. 102. [**Bengtsson, Kurdve** 2016].

and modelling only to a limited extent[23]. Both studies reveal that the academic models developed are too complex for practical use and there was no relevant and proper data available for end users to model estimations[24].

In 2020, the Estonian defence budget was approximately 636 million euros, a third of which was spent on procurements[25]. Since the actual need for financial resources exceeds the two percent of gross domestic product, it is important that each euro invested in national defence is spent as efficiently as possible and produces as much defence capability as possible[26].

In Estonia, the life cycle costing of assets and calculating future cash flows associated with maintenance have been problematic. The National Audit Office conducted an audit to assess the procedure and cost-efficiency of 17 defence procurements conducted in 2014–2019. The report revealed that life cycle cost was a selection criterion in several procurements, but in the auditing process they were not able to answer how exactly life cycle costs were determined and assessed in acquisitions. Most of the procurements indicated that the final decision was made based merely on the purchase price, and life cycle cost was not a determining factor in the decision-making process in any of the procurements analysed. On several occasions, clauses concerning life cycle costs were not included at all in procurement contracts[27].

In the same report, the National Audit Office indicates that procurement authorities had no organisation of work and implemented practices to establish procedures on how to conduct market surveys or prepare technical specifications and documents for procurement activities, including life cycle cost assessments. According to an audit report, the procurement authority must update and specify the rights, obligations, and areas of responsibility of participants, improve procedures for conducting market research, and complement technical documentations in relation to all stages of the procurement. The instructions of the National Audit Office specify that the entire life cycle cost (from the initial idea to the end of service life), including expenses for training, spare parts, and expendables of a purchased weapon system, must be determined during market research.

---

23 **Lindholm, Suomala** 2005, p. 288.

24 **Bengtsson, Kurdve** 2016, p. 102. See also **Lindholm, Suomala** 2005, p. 291.

25 **Planning and cost-effectiveness of large-scale defence procurement** 2020, p. 1.

26 **Riigi Kaitseinvesteeringute Keskuse eesmärgid 2019–2023**. Republic of Estonia Centre for Defence Investment. https://www.kaitseinvesteeringud.ee/organisatsioon/ (20.11.2022).

27 **Planning and cost-effectiveness of large-scale defence procurement** 2020, pp. 3–5.

The subject of life cycle costing has not been extensively analysed in Estonian scientific publications. In 2015–2020, only a handful of studies were conducted on the procurements and maintenance costs of the assets (weapon systems) of the Defence Forces. In 2018, a student of Tallinna Tehnikakõrgkool Mario Evestus defended his final thesis called *The life cycle cost model of the ground vehicles of the Defence Forces*[28]. The study focused on the fundamental principles of life cycle costing, determining the expenses for maintaining vehicles and developing a cost model example. In 2017, the Estonian Military Academy initiated a project for developing two experimental models in cooperation with researchers from the University of Tartu and representatives of the Navy. The first model was aimed at analysing and budgeting the exploitation costs of commissioned warships. The second model was a tool for assessing and estimating the future cash flows of planned asset acquisition programs to support the decision-making processes. Both models were delivered to the end user but their usage, as currently known, is negligible.

In conclusion, life cycle costing analysis helps to identify key cost drivers, provide better insight into the costs related to (armament) programs for planning and budgeting purposes, deliver an efficiency measurement tool for the procurement authority, and offer a comparison tool for the tender evaluation process in order to assist decision-making[29]. According to Tysseland, all procurement decisions made on behalf of the Norwegian Ministry of Defence since 2004 rely on thorough life cycle cost estimations, regardless of the fact that, sometimes, the initial investment in a weapon system may be significantly more expensive compared to competing offers[30].

3. Fundamentals of life cycle costing

The objective of the life cycle costing approach is to estimate the expenses that will accompany a purchased (weapon) system for its entire service life as precisely as possible without compromising the operational efficiency and performance of the manufacturer's design[31]. Another purpose of life cycle costing

[28] **Evestus, M**. 2018. Kaitseväe maismaasõidukite elutsükli kulumudel. Final thesis. Tallinn: Tallinna Tehnikakõrgkool.

[29] **RTO-TR-SAS-069**, 2009, p. 24.

[30] **Tysseland** 2008, p. 367.

[31] **Spickova, M.; Myskova, R**. 2015. Costs Efficiency Evaluation Using Life Cycle Costing as Strategic Method. – Procedia Economics and Finance, Vol. 34, p. 337.

is the management of production schedules to estimate possible cost impacts during the product development phase and support decision-making[32].

According to Langdon, life cycle costing is a tool for evaluating the total cost of an asset over its useful exploitation period, considering not only the initial cost but also successive utilisation costs in order to achieve better value for money from the acquisition[33]. By definition, life cycle costing (LCC) is a process of collecting and analysing data and applying quantitative tools and techniques for estimating the resources required for each life cycle stage of a system-of-interest[34]. Özkil points out that using life cycle costing serves two purposes. First, economic judgement: addressing the cost and benefit options to national coffers. Second, financial judgement: assessing affordability based on future cash flows and transfer of payments[35]. Life cycle cost estimation is not an exact science; while it does not give us the precise sum of expenses, it does, however, help to recognise major cost factors, provide the magnitude of costs, identify areas of possible technical and/or managerial improvements and financial savings, and compare different alternatives[36]. Available data, purpose of assessment, and time spent on analysis are the key factors of the life cycle cost estimation process.

The entire life cycle of an asset involves several stages that signify the major activities of the entire process. For the purpose of common understanding, the terms *phase*, *part*, *segment*, and *section* are used as synonyms for the term *stage* in specialised literature. At different times, costs have been allocated in different levels of detail. As explained by White and Ostwald, Woodward structured life cycle costing for the purpose of analysis and estimation into three sections: engineering and development costs, production and implementation costs, and operating costs (see Figure 2)[37]. Elmakis and

---

32 **ALP-10**, 2017. NATO Guidance on Integrated Logistics Support for Multinational Armament Programmes. NATO Standard. Edition, C, Version 1, October, p. 7. [**ALP-10**, 2017]

33 **Langdon, D**. 2007. Life cycle costing (LCC) as a contribution to sustainable construction: A common methodology. Final Report, May. Davis Langdon Management Consulting, p. 3.

34 **RTO-TR-SAS-069**, 2009, p. 1.

35 **Özkil, A**. 2003. The Use of Life Cycle Cost and Nature of Decisions. – Cost Structure and Life Cycle Cost (LCC) for Military Systems. RTO-MP-096, AC/323(SAS-036)TP/27. NATO Research and Technology Organisation Meeting Proceedings, June. Papers presented at the RTO Studies, Analysis and Simulation Panel (SAS) Symposium held in Paris, France, 24–25 October 2001. NATO Research and Technology Organisation, pp. 3-1, 3-2. [**Özkil** 2003]

36 **RTO-TR-SAS-069**, 2009, p. 2.

37 **White, G. E.; Ostwald, P. H**. 1976. Life Cycle Costing. – Management Accounting (US), January, pp. 39–42. Cited from **Woodward** 1997, p. 336. See **Woodward** 1997.

Lisnianski emphasise the importance of expenses arising from decommissioning a system and its disposal[38]. Decommissioned weapon systems usually entail significant costs; they must be safely stored and demilitarised and all hazardous substances (e.g., fuel, oils, asbestos) or parts that include such substances must be removed before demolition. In order to minimise or even get rid of disposal costs, owners are known to try and resell or donate equipment to third countries.

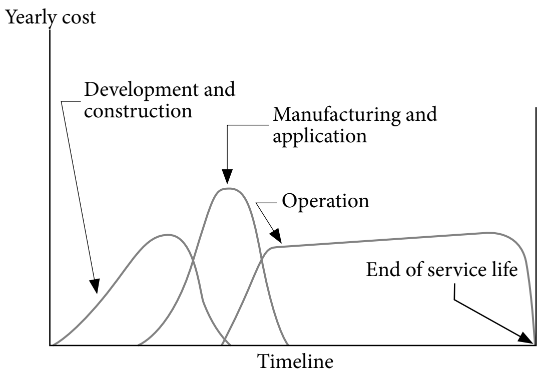

Figure 2. Stages of expense distribution[39]

Sherif and Kolarik as well as Asiedu and Gu have presented a more detailed overview of life cycle costing. According to them, life cycle costs can be divided into up to seven stages: research and development, product development, construction/acquisition, setup (set to work), exploitation (operating), maintenance and repair, and disposal[40]. In NATO, the life cycle stages of weapon systems are classified in accordance with standard ISO/IEC/IEEE 15288:2015 Systems and software engineering – System life cycle processes[41], dividing the life cycle of acquired assets into six distinct stages: concept development, research and development, production, exploitation, support and decommissioning.

---

[38] **Elmakis, D.; Lisnianski, A**. 2006. Life cost analysis: Actual problem in industrial management. – Journal of Business Economics and Management, Vol. 7, No. 1, p. 6.

[39] **Woodward** 1997, p. 336.

[40] **Sherif, Y. S.; Kolarik, W. J**. 1981. Life Cycle Costing: Concept and Practice. – Omega. The International Journal of Management Science, Vol. 9, Issue 3, p. 288; **Asiedu, Y.; Gu, P**. 1998. Product life cycle cost analysis: State of the art review. – International Journal of Production Research, Vol. 36, No. 4, p. 885.

[41] **Systems and software engineering – System life cycle processes** 2015. ISO/IEC/IEEE 15288:2015. Geneva, Switzerland: The International Organization for Standardization.

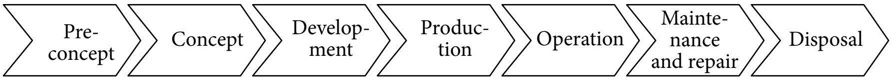

Figure 3. Stages of life cycle costing[42]

Each stage of the life cycle cost breakdown of equipment, a product or a weapon system has a certain role to play in estimating the total cost. The AAP-20[43] and Simões-Marques[44] have both emphasised the importance of the pre-concept phase which is the first stage in the life cycle process of the system of interest (SOI) and is a single point of entry (see Figure 3).

The pre-concept stage is devoted to collecting, assessing and defining shortfalls, enhancements and changes to the SOI capability requirements prior to proceeding to the concept and development stages. Processing these materials will reveal if technological readiness enables development of a proper device or a weapon system within an acceptable timescale and affordable cost. Initial risks will be determined and a plan for their management drawn concurrently[45]. The concept stage broadens the research, experiments and modelling done in the pre-concept phase and its objective is to determine system requirements, finalise the studies, and give a feasible design concept to a customer[46]. According to Özkil, it is unlikely at this stage that the costs would be identified in detail; rather, they tend to be broad and rough estimates of the general cost breakdown structure elements[47]. The development stage commences after the concept phase. Its objective is to fill the capability gap with a solution and complete the end user requirements for this particular solution[48]. Several studies have pointed out that 50–70%

---

[42] **RTO-TR-SAS-069**, 2009, p. 23; **AAP-48**, 2013. NATO System Life Cycle Stages and Processes. NATO Publication. Edition B, Version 1, March, p. 1–3; **Simões-Marques, M. J**. 2015. Modeling and Simulation in System Life Cycle. 6th International Conference on Applied Human Forces and Ergonomics (AHFE 2015) and the Affiliated Conferences. – Procedia Manufacturing, Vol. 3, p. 787. [**Simões-Marques** 2015]

[43] **AAP-20**, 2015. NATO Programme Management Framework (NATO Life Cycle Model). NATO Standard. Edition C, Version 1, October, p. 27. [**AAP-20**, 2015]

[44] **Simões-Marques** 2015, p. 787.

[45] **AAP-20**, 2015, p. 27.

[46] **Simões-Marques** 2015, p. 790.

[47] **Özkil** 2003, p. 3-2.

[48] **RTO-TR-SAS-069**, 2009, p. 23.

of all avoidable expenses are made in the research and development stage[49]. According to Sokri et al., this is a phase where the main decisions are made regarding the system[50]. When a SOI is available on market, the acquisition stage is completed by purchasing the main asset and sub-assets along with their delivery, setup and integration with other systems. Otherwise, the production stage would commence with manufacturing the main equipment (e.g., a warship) alongside related supporting and assisting systems. Obviously, weapon systems are not consumer goods and must be constructed in parallel with sub- and supporting systems. The production stage is usually considered to be part of the procurement phase. Before being given to the customer, a SOI will undergo a series of tests and trials. The exploitation, or utilisation, stage begins with commissioning a weapon system at operational theatres pursuant to its operational and cost-effectiveness[51]. The support stage is parallel with the utilisation phase; it offers maintenance, logistical and other support and operational sustainability services to the system until the end of its life cycle. In North America, the terms *operations and sustainment*, or *in-service stage* are used synonymously with utilisation. The service life of a device ends with retirement, followed by its demilitarisation and disposal. Retirement also means that the services for sustaining the capabilities of a device or a system are no longer necessary[52]. Disposal must be in concordance with valid international agreements and legal requirements.

4. Costs and cost elements

The previous chapter was devoted to the six structure elements of the life cycle of a system; in this chapter, we will have a closer look at the cost breakdown structure (CBS) of each element. Cost breakdown helps to identify, categorise, and combine all kinds of cost elements in the course of the service life of a device or weapon system.

[49] **Newnes, L. B.; Mileham, A. R.; Cheung, W. M.; Marsh, R.; Lanham, J. D.; Saravi, M. E.; Bradbery, R. W**. 2008. Predicting the whole-life cost of a product at the conceptual design stage. – Journal of Engineering Design, Vol. 19, No. 2, April, p. 100.

[50] **Sokri, A.; Ghergari, V.; Wang, L**. 2016. Development of Cost Breakdown Structure for Defence Acquisition Projects. Scientific Report, DRDC-RDDC-2016-R086, May. Defence, Research and Development Canada, p. 4. [**Sokri *et al***. 2016]

[51] **RTO-TR-SAS-069**, 2009, p. 33.

[52] **AAP-20**, 2015, p. 46.

Life cycle costing is a data driven process. The required methods and analyses are outlined by the amount, quality, and other elements of available data; life cycle costing is therefore not a precise science. It highlights the magnitude of costs, enables one to compare different alternatives, and identifies potential areas for saving resources and improving the overall organisation[53].

When commencing life cycle cost analyses, cost breakdown structure (CBS) is an essential first step followed by cost allocation estimation.

Cost breakdown helps to determine and line up all internal cost elements of the stages of the life cycle of a system that could be acquired[54]. The established cost breakdown structure must be:

- Flexible (simplistic) to make its setup, usage, amendment, adoptability or integration with other (similar) systems easy.
- Comparable with other breakdown structures.
- Comprehensive, involving relevant activities and cost items.
- Hierarchical, i.e., well-structured.
- With specific traits to support management.
- Unambiguous, i.e., having uniform terminology and definitions.[55]

According to Sokri et al., a cost element is created when a resource is used for an activity that applies to a particular element or product[56]. In order to determine all the expenses of an asset during its life cycle, one must create a list of activities (see Annex 2, Table 2) and sub-activities pursuant to the LCC stages (e.g., exploitation of system).

The next step is to connect the product tree with different activities. A product tree has three interrelated elements: the main system, the support elements, and specific means (Figure 4). For example, if the main system is a warship, its support elements are spares, special test and tool equipment, publications, training material, facilities, and so forth. Specific means combining the essential elements, including their own support elements that are

[53] **RTO-TR-SAS-069**, 2009, p. 11.

[54] **RTO-MP-096**, 2003. Cost Structure and Life Cycle Cost (LCC) for Military Systems. AC/323(SAS-036)TP/27. – NATO Research and Technology Organisation Meeting Proceedings 96, June, p. vii.

[55] **RTO-TR-SAS-069**, 2009, pp. 13–14; **Sokri *et al.*** 2016, pp. 7–8.

[56] **Sokri *et al.*** 2016, p. 8.

developed, manufactured and utilised for the acquisition program and not normally delivered to the end user (e.g., test and trials facilities).

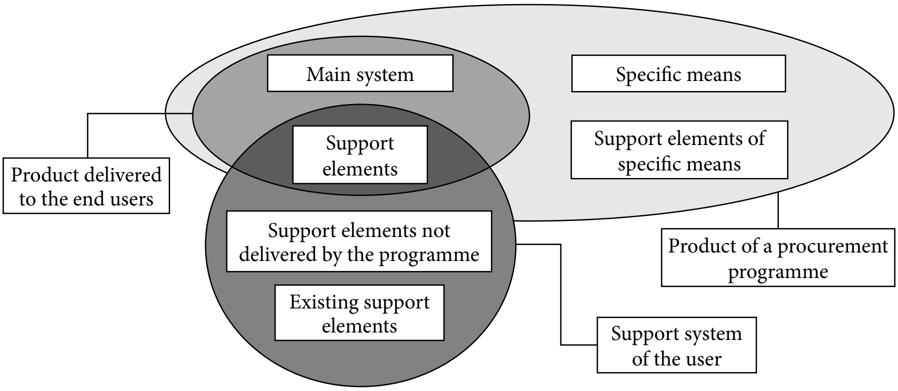

Figure 4. The product tree of a purchased device[57]

After an activity list and the product tree are created, all potential resources must be associated with it (see Annex, Table 3). It is important to understand that main system exploitation may require different resources compared to those of support systems, meaning that the allocation of resources must be thoroughly analysed prior to connecting the resources with the costs. The list of resources[58] includes:

- Personnel – for operating, maintenance, and support.
- Equipment – for maintenance, repair, and support.
- Consumables – for operating (e.g., fuel, oil, and lubricant) and training.
- Infrastructure – temporary or permanent (during the entire life cycle).
- Services – contractual partners.
- Information – copyright charges.

According to Sokri et al., every cost element is related with a life cycle stage of the capital asset, the activity and/or sub-activity, resources, and the product[59].

[57] **RTO-TR-058**, 2003. Cost Structure and Life Cycle Costs for Military Systems. RTO Technical Report. NATO Research and Technology Organisation (RTO) Technical Report, September, p. 6-1. [**RTO-TR-058**, 2003]

[58] *Ibid.*, p. 7-1.

[59] **Sokri *et al.*** 2016, p. 8.

It is important to make a distinction between the procurement costs of an asset and future cash flows for its maintenance. The data regarding the expenditures already made must be collected and saved in a database in order to:

- Complement them for further analysis of the costs incurred.
- Determine all possible cost drivers.
- Analyse and compare cost estimations with actual expenses.
- Control the decisions of the management.[60]

The axis of an asset at a certain point of time *t* of its service life is displayed in Figure 5. During the timeline, an asset generally contains two types of costs: expenditures already incurred and future expenses. Expenditures are usually referred to as sunk costs. According to Mereste[61] and "Cost Structure and Life Cycle Costs for Military Systems"[62], sunk costs are monetary costs already made. These cannot be reclaimed, avoided, or decreased (e.g., property disbursements) and these will not affect the final decision. Mereste says that neither future decisions nor subsequent events can affect the payments already made, although decisions for the future are largely dependent on the sum and distribution of past expenses[63]. The approximate sum of future expenses (direct, indirect, fixed, and variable costs) can still be corrected[64].

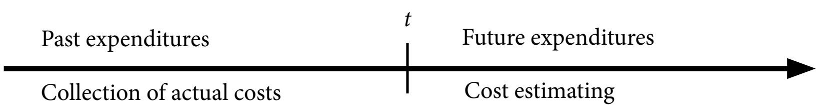

Figure 5. Timeline and factors[65]

Weapon systems are developed with a specific purpose. These are not consumer goods; generally, weapon systems are complex, include high-tech components, and require frequent modification or modernisation[66]. Considering all this,

[60] **Özkil** 2003, p. 3–6.

[61] **Mereste, U**. 2003. Majandusleksikon I–II. Tallinn: Eesti Entsüklopeediakirjastus, II, p. 144. [**Mereste** 2003]

[62] **RTO-TR-058**, 2003, G-3.

[63] **Mereste** 2003, p. 144.

[64] **RTO-TR-058**, 2003, p. 10-3.

[65] *Ibid.*

[66] **Sánchez** 2015, p. 2.

an estimation of the life cycle costs of a weapon system is a complicated and labour-intensive task. Since the in-service life of warships and military aircraft is usually between two and five decades, Newnes and Valerdi included the obsolescence of electronic components in the list of issues, making life cycle cost estimation even more complicated and obscure[67]. Life cycle cost estimation involves a number of risks and uncertainties. Kirkpatrick and von Deimling et al. also agree that the actual cost of the service life of a weapon system cannot be determined precisely. On the other hand, life cycle cost estimation plays a vital role in the procurement decision-making process and the prediction of all cost elements during an asset's expected lifespan is made pursuant to the prices, information and knowledge available at that particular moment in time[68]. Despite the fact that the US Department of Defence possesses a large amount of data that is focused on monitoring and reducing the total ownership costs (TOC) of assets, they are still struggling to estimate accurate operational and support costs that rely on the assessment and revision of incurred costs[69].

Life cycle costing became a subject of research in the second half of the 1960s, and a specialised English terminology has since been developed concurrently. In different publications, however, the terminology regarding life cycle costing is often misinterpreted and different terms are used as synonyms. Xu et al.[70] used *whole life cost* and *through life cost* in their article, while terms such as *cost of ownership* and *total ownership cost* can be found in

---

[67] **Newnes, L. B.; Valerdi, R**. 2012. Special issue on Through Life Cost estimating. – International Journal of Computer Integrated Manufacturing, Vol. 25, No. 4–5, p. 197.

[68] **Kirkpatrick, D. L. I**. 2000. Life cycle costs for decision support: A study of the various life cycle costs used at different levels of defence policy and management. – Defence and Peace Economics, Vol. 11, No. 2, p. 336; **Deimling, C. A. von; Essig, M.; Schaupp, M.; Amann, M.; Vafai, S**. 2016. Life-Cycle-Cost-Management as an Instrument for Strategic Public Procurement: State of the Art and Perspectives. Working Paper, p. 3. https://www.researchgate.net/publication/299393462_Life-Cycle-Cost-Management_as_an_Instrument_for_Strategic_Public_Procurement_State_of_the_Art_and_Perspectives (25.03.2021).

[69] **Ryan, E.; Jacques, D.; Colombi, J.; Schubert, C**. 2012. A Proposed Methodology to Characterize the Accuracy of Life Cycle Cost Estimates for DoD Programs. – Procedia Computer Science, Vol. 8. New Challenges in Systems Engineering and Architecting Conference on Systems Engineering Research (CSER), p. 363.

[70] **Xu, Y.; Elgh, F.; Erkoyuncu, J. A.; Bankole, O.; Goh, Y.; Cheung, W. M.; Baguley, P.; Wang, Q.; Arundachawat, P.; Shehab, E.; Newnes, L.; Roy, R**. 2012. Cost Engineering for Manufacturing: Current and Future Research. – International Journal of Computer Integrated Manufacturing, Vol. 25, Issue 4–5, p. 302.

different publications of the Alliance[71]. It is important to stress that these are not synonyms but components of life cycle costs and each has an individual definition and area of use[72].

Life cycle costs include all direct and indirect variable costs related to the purchasing, exploitation, support, and disposal of a weapon system. Mereste[73] defines direct costs as expenses made on the personnel that are directly involved with manufacturing a product, and the cost of materials. Direct costs are directly attributed to a cost object, whereas indirect costs cannot be associated with a specific cost object[74]. Indirect costs are notionally attributed to and distributed among several cost objects (e.g., system, platform)[75]. Keep in mind that all indirect costs related to activities or resources that are not affected by the introduction of the system are not part of life cycle costs[76]. Direct and indirect costs can also be divided into fixed and variable costs. According to Mereste, variable costs are expenses that can either increase or decrease in accordance with a rise or fall of production capacity[77]. Fixed costs are costs that are not directly dependent on a cost driver[78]. Fixed costs have to do with owning a device or a system (labour costs, interest rates) and do not depend on whether the volume of use increases or decreases[79]. Such fixed costs can be categorised as permanent ownership costs, whereas costs associated with constant management decisions (e.g., expenses on training and development) can be categorised as permanent arbitrary costs[80].

General expenses not affected by a weapon system under observation are commonly not considered to be part of life cycle costs. From an accounting viewpoint, general expenses are costs that cannot be directly related to the goods produced, purchased or sold by a company[81]. The result of life cycle cost

71 **RTO-TR-058**, 2003.

72 **Sokri *et al*.** 2016, p. 5; **ANEP-41**, 2006. Ship Costing. Allied Naval Engineering Publication. 4th ed. NATO International Staff Defence Investment (DI). NATO Standardization Agency, p. 2-1. [**ANEP-41**, 2006]

73 **Mereste** 2003, II, p. 57.

74 **Mereste** 2003, I, p. 348.

75 **ALP-10**, 2017, A-2.

76 **ANEP-41**, 2006, p. 4-3

77 **Mereste** 2003, I, p. 632.

78 **Mereste** 2003, II, p. 147.

79 **RTO-TR-058**, 2003, G-2.

80 **Mereste** 2003, II, p. 147.

81 *Ibid.*, p. 592.

estimation is a minimum component of the total cost, used to compare different options. Life cycle costing is normally used as a minimum to compare options between alternatives and is frequently used for economic analysis[82]. Total ownership cost (TOC) includes expenses that arise from owning a weapon system. In addition to life cycle costing, these also include indirect, direct, and linked costs[83]. Total Cost of Ownership and Cost of ownership (COO) are synonyms[84] and they are part of budgeting and financial analyses. Whole life cost (WLC) includes all expenses that a company has to make when owning a certain weapon system. Compared to cost of ownership, this also includes non-linked costs.

Table 1. Associations between costs and variations of life cycle costing85

Type of cost	PLCC	TLCC	TOC	WLC
Direct-fixed-linked costs	×	×	×	×
Direct-variable-linked costs	×	×	×	×
Indirect-fixed-linked costs			×	×
Indirect-variable-linked costs		×	×	×
Non-linked costs				×

Life cycle costs, total ownership cost, and whole life cost are actually components of the cost breakdown structure of a weapon system. Even more precisely, life cycle costs can be divided into different components hierarchically: sail-away costs, (program) procurement costs, program life cycle costs (PLCC), and total life cycle costs (TLCC)[86]. For example, the sail-away cost of a warship includes the cost of the hull, power and navigation equipment, electronics, shipyard program management elements, testing and validation of ship systems, changes in construction projects, warranties, taxes, etc. After adding procurement costs and the remaining linked-direct components of the exploitation, support and disposal phases, it will result in establishing the minimum level of LCC, the Program Life Cycle Cost (PLCC, see Table 1).

82 **RTO-TR-058**, 2003, p. 11-2.

83 **Sokri *et al.*** 2016, p. 6.

84 **RTO-TR-058**, 2003, p. 1-1.

85 **ANEP-41**, 2006, p. 4-2, adjusted by the author. See also **Sokri *et al.*** 2016, p. 6.

86 **ANEP-41**, 2006, p. 2-1.

When supplementing PLCC with the linked indirect variable costs of manpower, we will achieve the next level of LCC, e.g. the TLCC[87].

Costs can be categorised in a number of ways to facilitate analysis, for example, according to:

- Time (month, year, stage of life cycle).
- Type of costs (direct, indirect or fixed costs).
- Products (system, subsystem).
- Activities or processes (management, maintenance, repair).
- Resources (labour, equipment).
- Organizational hierarchy (units, services).[88]

There are two types of constraints that have an effect on the life cycle costing process: external and internal. These can vary in different organisations and NATO Member States. External factors include, for example, timely constraints of decision-makers (e.g., the government), the number of organisations involved in an acquisition program, or the availability of resources (labour, time) to support life cycle costing. The maturity level of capability requirements, resources spent on analyses, and the availability of collected data and information are usually internal hindering factors[89]. A database with updated and sufficient information is the key factor in estimating life cycle costs. The US Department of Defence began collecting and storing cost data in 1942 when they started acquiring assets in large quantities, focusing primarily on the manufacturers of aircrafts and missiles in the 1940s and 1950s[90]. According to Robinson, the data collection of that time was not consistent, nor did it always comply with existing standards. Because of that, successive data processing was extremely complicated, but databases were constantly complemented and collection processes refined, leading to the creation of

---

87 **ANEP-41**, 2006, p. 4-5.

88 **RTO-TR-SAS-069**, 2009, p. 14; **Sokri *et al.*** 2016, pp. 7–8.

89 **RTO-TR-SAS-069**, 2009, p. 1.

90 **Robinson, D. M**. 2003. Innovations and Improvements in Cost Information Management. – Cost Structure and Life Cycle Cost (LCC) for Military Systems. RTO-MP-096, AC/323(SAS-036)TP/27. NATO Research and Technology Organisation Meeting Proceedings 96, June. Papers presented at the RTO Studies, Analysis and Simulation Panel (SAS) Symposium held in Paris, France, 24–25 October 2001. NATO Research and Technology Organisation, p. 7–1. [**Robinson** 2003]

Contractor Cost Data Report[91] in 1970, a standardised and unified database for defence expenses. This data report has become a pillar for the analytics of the US Department of Defence in estimating life cycle costs.

The estimation of life cycle costs cannot only consider the financial aspects but must also account for national defence needs (capability requirements), the specificities and pace of military operations, and environmental and social factors. Technological progress and the application of new technologies are becoming increasingly important, making the estimation of life cycle costs all the more complicated. Some research conducted in the field of unmanned systems have shown a rise in the costs of repair and maintenance work. Some of the mentioned aspects were not covered in this paper at all.

5. Conclusion

The purpose of this article was to give an overview of the fundamental principles and aspects of life cycle costing. It is important to be aware of the historical background and theoretical development of this area to appreciate the benefits that an organisation may gain from life cycle costing.

The topic of the life cycle costing of defence equipment became more relevant in the USA in the 1960s when procurement decisions were primarily made pursuant to the optimal price of an offer. As a result, the lacking resources for maintaining existing equipment had to be covered by resources meant for purchasing new equipment elements. Life cycle costing as a discipline was initiated by the administration of President John F. Kennedy and the knowledge and expertise of USA researchers was quickly utilised by other larger industrial countries. Even though life cycle costs can be approached from an interdisciplinary viewpoint, it lies in the area of expertise of accounting. In Estonian scientific publications, the subject of life cycle costing has garnered little interest, which gives grounds for more intense research in the field of national defence.

Weapon systems are usually not consumer goods. They are technically very complicated and include high technology electronic parts that require them to be frequently modified and modernised. This, in turn, suggests that life cycle cost estimation is a complicated and vague activity that needs extensive analyses. The purpose of life cycle costing is to determine the cost elements of a purchased weapon system during its entire service life and

91 *Ibid.*, p. 7-1.

assess approximate exploitation expenses. Total costs must be calculated at each stage of a life cycle, from concept to disposal. When analysing total life cycle costs, one must first establish a cost breakout structure for the internal cost elements of all life cycle stages, then determine the costs and make an estimation. A cost breakout structure must be simple, comprehensive, well-structured, comparable to other similar structures, and terminologically unequivocal.

The result of life cycle cost modelling and analysis gives us a chance to compare systems with similar performance, save budget resources, and determine the fields where technological or management innovations can be applied. Life cycle costing gives a wider perspective to assessing the balance between expenses and benefits in national economy and finances, and helps to analyse future cash flows and the need for their national redistribution.

In light of the issues discussed in the National Audit Office's 2020 report summary on internal security and national defence, *Planning and cost-effectiveness of large-scale defence procurement*, the tasks and areas of responsibility of procurements held in the administrative area of the Ministry of Defence still require further analysis. A universal model must be developed to cover life cycle costing in the army, the navy, and the air forces, plus all costs accompanying purchased weapon systems during their service life. The approximate results of cash flow necessities determined with life cycle cost analysis enable decision-makers to make the optimal choice for the Defence Forces from all potential offers.

Bibliography

AAP-20, 2015. NATO Programme Management Framework (NATO Life Cycle Model). NATO Standard. Edition C, Version 1, October

AAP-48, 2013. NATO System Life Cycle Stages and Processes. NATO Publication. Edition B, Version 1, March.

ALP-10, 2017. NATO Guidance on Integrated Logistics Support for Multinational Armament Programmes. NATO Standard. Edition C, Version 1, October.

ANEP-41, 2006. Ship Costing. Allied Naval Engineering Publication. 4^{th} ed. NATO International Staff Defence Investment (DI). NATO Standardization Agency.

Asiedu, Y.; Gu, P. 1998. Product life cycle cost analysis: State of the art review. – International Journal of Production Research, Vol. 36, No. 4, pp. 883–908.

Bengtsson, M.; Kurdve, M. 2016. Machining Equipment Life Cycle Costing Model with Dynamic Maintenance Cost. 23^{rd} CIRP (International Academy for Production Engineering) Conference on Life Cycle Engineering. – Procedia CIRP, Vol. 48, pp. 102–107.

Boeing 2021.
https://www.boeing.com/defense/b-52-bomber/ (20.08.2011).

Deimling, C. A. von; Essig, M.; Schaupp, M.; Amann, M.; Vafai, S. 2016. Life-Cycle-Cost-Management as an Instrument for Strategic Public Procurement: State of the Art and Perspectives. Working Paper.
https://www.researchgate.net/publication/299393462_Life-Cycle-Cost-Management_as_an_Instrument_for_Strategic_Public_Procurement_State_of_the_Art_and_Perspectives (25.03.2021).

Eisenberger, I.; Lorden, G. 1977. Life-Cycle Costing: Practical Considerations. – The Deep Space Network Progress Report 42–40.
http://ipnpr.jpl.nasa.gov/progress_report2/42-40/40M.PDF (20.08.2021).

Elmakis, D.; Lisnianski, A. 2006. Life cost analysis: Actual problem in industrial management. – Journal of Business Economics and Management, Vol. 7, No. 1, pp. 5–8.

Evestus, M. 2018. Kaitseväe maismaasõidukite elutsükli kulumudel. Final thesis. Tallinn: Tallinna Tehnikakõrgkool.

File, W. T. 1993. Chapter 18: Terotechnology and Maintenance. – Koshal, D. (ed.). Manufacturing Engineer's Reference Book. Chapter 18.1. Butterworth-Heinemann, Elsevier Ltd.

Kirkpatrick, D. L. I. 2000. Life cycle costs for decision support: A study of the various life cycle costs used at different levels of defence policy and management. – Defence and Peace Economics, Vol. 11, No. 2, pp. 333–368.

Langdon, D. 2007. Life cycle costing (LCC) as a contribution to sustainable construction: A common methodology. Final Report, May. Davis Langdon Management Consulting.

Life cycle costing in industry 1967. Task 67–21. Washington, D.C.: Logistics Management Institute.
https://apps.dtic.mil/sti/pdfs/AD0660659.pdf (02.10.2021).

Lindholm, A.; Suomala, P. 2005. Present and Future of Life Cycle Costing: Reflections from Finnish Companies. – Liiketaloudellinen aikakauskirja, Vol. 2, pp. 282–292.

LMI 2021. LMI History.
https://www.lmi.org/lmi-history (02.10.2021).

Mereste, U. 2003. Majandusleksikon I–II. Tallinn: Eesti Entsüklopeediakirjastus.

Murumets, J. 2014. Tankidest ja tabelitest. – Rahvusvaheline Kaitseuuringute Keskus. Blogi, julgeoleku planeerimine.
https://icds.ee/et/tankidest-ja-tabelitest/ (14.12.2021).

Newnes, L. B.; Mileham, A. R.; Cheung, W. M.; Marsh, R.; Lanham, J. D.; Saravi, M. E.; Bradbery, R. W. 2008. Predicting the whole-life cost of a product at the conceptual design stage. – Journal of Engineering Design, Vol. 19, No. 2, April, pp. 99–112.

Newnes, L. B.; Valerdi, R. 2012. Special issue on Through Life Cost estimating. – International Journal of Computer Integrated Manufacturing, Vol. 25, No. 4–5, pp. 297–299.

Okano, K. 2001a. Life cycle costing – An approach to life cycle cost management: A consideration from historical development. – Asia Pacific Management Review, Vol. 6, Issue 3, pp. 317–341.

Okano, K. 2001b. Life Cycle Costing in Historical Perspective. – Matsuyama Daigaku Ronshu, Vol. 12, Issue 6, pp. 55–81. https://core.ac.uk/download/pdf/230502989.pdf (20.08.2021).

Özkil, A. 2003. The Use of Life Cycle Cost and Nature of Decisions. – Cost Structure and Life Cycle Cost (LCC) for Military Systems. RTO-MP-096, AC/323(SAS-036) TP/27. NATO Research and Technology Organisation Meeting Proceedings, June. Papers presented at the RTO Studies, Analysis and Simulation Panel (SAS) Symposium held in Paris, France, 24–25 October 2001. NATO Research and Technology Organisation.

Planning and cost-effectiveness of large-scale defence procurement (report summary) 2020. Report of the National Audit Office to the Riigikogu, 11 November. Tallinn: National Audit Office of Estonia. https://www.riigikontroll.ee/DesktopModules/DigiDetail/FileDownloader.aspx?FileId=14752&AuditId=2515 (20.11.2022).

Riigi Kaitseinvesteeringute Keskuse eesmärgid 2019–2023. Republic of Estonia Centre for Defence Investment. https://www.kaitseinvesteeringud.ee/organisatsioon/ (20.11.2022).

Robinson, D. M. 2003. Innovations and Improvements in Cost Information Management. – Cost Structure and Life Cycle Cost (LCC) for Military Systems. RTO-MP-096, AC/323(SAS-036)TP/27. NATO Research and Technology Organisation Meeting Proceedings 96, June. Papers presented at the RTO Studies, Analysis and Simulation Panel (SAS) Symposium held in Paris, France, 24–25 October 2001. NATO Research and Technology Organisation, p. 7-1.

Rodger, N. A. M. 1997. The Safeguard of the Sea: A Naval History of Britain. Vol 1: 660–1649. London: Penguin Books Ltd.

RTO-MP-096, 2003. Cost Structure and Life Cycle Cost (LCC) for Military Systems. AC/323(SAS-036)TP/27. – NATO Research and Technology Organisation Meeting Proceedings 96, June.

RTO-TR-058, 2003. Cost Structure and Life Cycle Costs for Military Systems. RTO Technical Report. NATO Research and Technology Organisation (RTO), September.

RTO-TR-SAS-069, 2009. Code of Practice for Life Cycle Costing. NATO Research and Technology Organisation (RTO) Publication, September.

Ryan, E.; Jacques, D.; Colombi, J.; Schubert, C. 2012. A Proposed Methodology to Characterize the Accuracy of Life Cycle Cost Estimates for DoD Programs. – Procedia Computer Science, Vol. 8. New Challenges in Systems Engineering and Architecting Conference on Systems Engineering Research (CSER), pp. 361–369.

Sánchez, P. J. 2015. Life Cycle Cost Estimation Procedure for a Weapon System in Spain. – Journal of the Spanish Institute for Strategic Studies, No. 6. https://revista.ieee.es/article/view/262/941 (20.07.2021).

Sherif, Y. S.; Kolarik, W. J. 1981. Life Cycle Costing: Concept and Practice. – Omega. The International Journal of Management Science, Vol. 9, Issue 3, pp. 287–296.

Simões-Marques, M. J. 2015. Modeling and Simulation in System Life Cycle. 6th International Conference on Applied Human Forces and Ergonomics (AHFE 2015) and the Affiliated Conferences. – Procedia Manufacturing, Vol. 3, pp. 785–792.

Sokri, A.; Ghergari, V.; Wang, L. 2016. Development of Cost Breakdown Structure for Defence Acquisition Projects. Scientific Report, DRDC-RDDC-2016-R086, May. Defence, Research and Development Canada.

Spickova, M.; Myskova, R. 2015. Costs Efficiency Evaluation Using Life Cycle Costing as Strategic Method. – Procedia Economics and Finance, Vol. 34, pp. 337–343.

Systems and software engineering – System life cycle processes 2015. ISO/IEC/IEEE 15288:2015. Geneva, Switzerland: The International Organization for Standardization.

Tysseland, B. E. 2008. Life cycle costs based procurement decisions: A case study of Norwegian Defence Procurement projects. – International Journal of Project Management, Vol. 26, Issue 4, pp. 366–375.

Woodward, D. G. 1997. Life cycle costing – Theory, information acquisition and application. – International Journal of Project Management, Vol. 15, Issue 6, pp. 335–344. Original of footnote No. 36: **White, G. E.; Ostwald, P. H**. 1976. Life Cycle Costing. – Management Accounting (US), January, pp. 39–42.

Xu, Y.; Elgh, F.; Erkoyuncu, J. A.; Bankole, O.; Goh, Y.; Cheung, W. M.; Baguley, P.; Wang, Q.; Arundachawat, P.; Shehab, E.; Newnes, L.; Roy, R. 2012. Cost Engineering for Manufacturing: Current and Future Research. – International Journal of Computer Integrated Manufacturing, Vol. 25, Issue 4–5, pp. 300–314.

Lieutenant Commander **MAREK MARDO**, MSc
Junior research fellow of the Research Management Group of the Department of Applied Research of the Estonian Military Academy

Annex

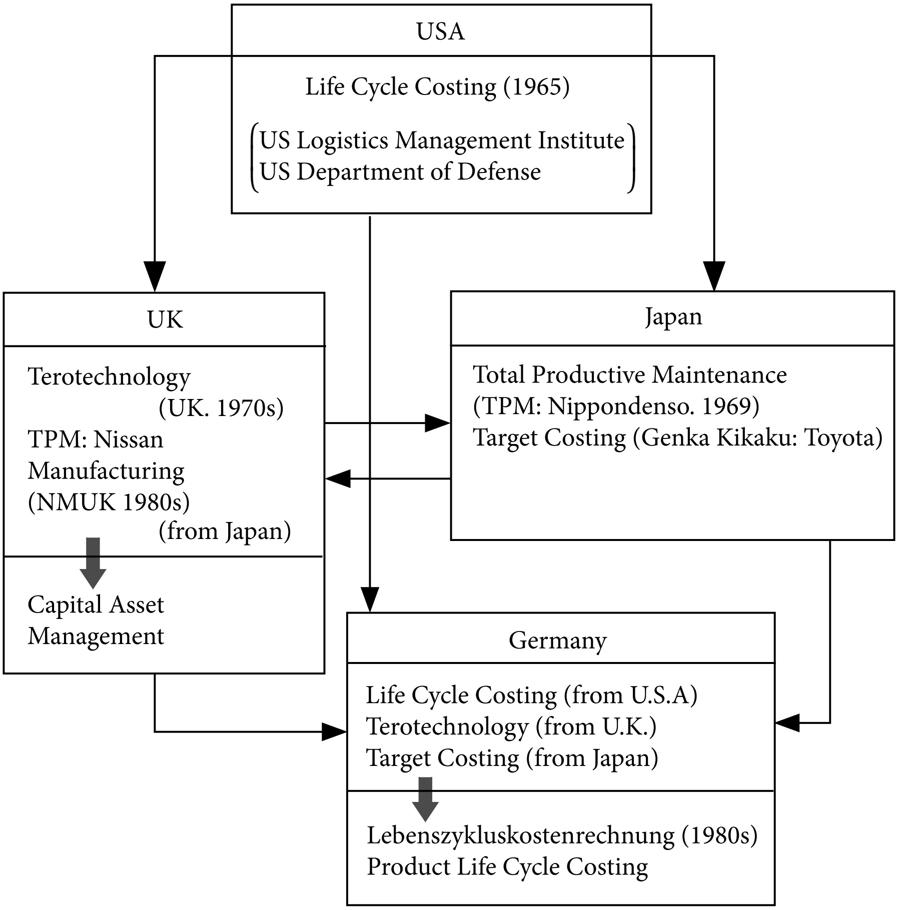

Figure 1. Transition of the knowledge and expertise of life cycle costing[92]

[92] **Okano** 2001a, p. 336.

Table 2. Distribution of life cycle costs, stages and activities of the service life of a device[93]

Level 1: Stages	Level 2: Activities
Pre-concept (concept development) costs	- Program management, project management - Research, initial testing, analysis, simulation
Concept costs	- Project management - Research, initial testing, analysis, simulation - Other
Product development costs	- Project management - Research, studies analysis, simulation - Engineering - Solicitation and contract management - Development (research and design) - Procurement (purchasing) - Other
Investment and procurement costs	- Project management - Research, studies analysis, simulation - Engineering and manufacturing - Procurement (purchasing) - System integration (sub-activities, e.g., integrating existing weapon systems with the purchased system) - Testing, trials, demonstration, and evaluation of equipment or a system - Deployment - Infrastructure investments - Other
Operation (exploitation) costs	- Personnel costs (direct personnel) - Fuel, oil, lubricants; training materials, victuals, etc. - Services and support directly related with exploitation
Maintenance and support costs	- Maintenance of equipment (weapon system) (levels 1–4) - Replenishing spare parts, expendables, etc. - Training - Sustainment - Packing, handling, storing, and transport (PHST) - Indirect support activities
Modernisation (upgrading) costs	- Equipment or system updates and upgrades
Decommissioning and disposal costs	- Planning and initiating disposal - Treatment of hazardous substances and waste - Dismantling, disposal, and storing of systems - Transport costs - Reselling equipment or systems

93 **Sokri *et al.*** 2016, pp. 13–17; **Simões-Marques** 2015, p. 787; **RTO-TR-SAS-069**, 2009.

Table 3. Costs of using a system[94]

Stage	Activity	Product tree			Resource	Cost (referencing cost account: Level 4)
		Final user of the main system	Support services	Special systems		
Operating 1	Weapon system personnel	Ship staff	Weaponsystem technican of a Naval Base Support Unit	–	Personnel	Wages (5003), bonus payments (5003)
	Direct costs of operating the system	Platform			Expendables	Fuel (5513) Water (5511) Victuals (5521) Ammunition (5531)
Operating 2	Direct costs of operating the system	Self-propelled artillery	Transport and support services	Central polygon	Weapon system personnel Polygon personnel Expendables (fuel, ammunition, etc.) Services	Wages and bonuses (5003) Fuel (5513), ammunition (5531), transport services from contractual partners (5540)

94 **Sokri *et al***. 2016, p. 19; **RTO-TR-058**, 2003.