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IMPACT OF LIFE CYCLE COST ANALYSIS ON THE PONTOON BRIDGE CONCEPT SELECTION

Abstract. The article discusses main issues in relation to life cycle cost analysis (LCC) of armament systems. Examples of the application of LCC in civilian bridges are provided.

Furthermore, the structure of LCC for a pontoon bridge used in the Polish Armed Forces is analysed and a model for cost estimation with regard to LCC is presented. The LCC analysis was carried out for three concepts of a new pontoon bridge made of varying materials and the results of these analyses, as well as the probability of the application of LCC in the process of selecting the new design of the pontoon bridge for the Polish Army have been explored.

Keywords: pontoon bridge, life cycle costs, acquisition costs, operating costs.

1. LIFE CYCLE COST ANALYSIS IN MILITARY AND BRIDGE ENGINEERING

The beginnings of Life Cycle Cost (LCC) analysis date back to the late 1960s, when it was used mainly by the US armaments industry. Positive results of LCC application prompted the US Department of Defence in the years 1983/84 to publish the first guidebooks on the subject, among them [1] and [2]. New editions of these guidebooks are still often used by American businesses. The principles of LCC analysis have since then spread in most branches of industry and the theoretical and practical aspects of the analysis have been developed. At present the use of LCC analysis as a decision supporting tool in the assessment of alternative solutions is widespread.

General conditions for carrying out LCC analysis are detailed in a number of standard documents in force in the countries and armies of the world and in NATO. There are, however, slight differences in the approach demonstrated by the civilian and by military circles [3]. The knowledge of the life cycle of a system until the end of its service life enables effective managing thereof. The above is of more particular importance, when the life cycle applies to complex systems. Armament systems are undoubtedly such systems. In addition to being complex, they are expensive to purchase and they have a relatively long and costly operating life.

The new edition of STANAG 4728 [4] introduces the application by NATO of Allied Publications AAP-48 [5] and AAP-20 [6]. They adopt the classification set down in ISO/IEC 15288 [7] and accept the division of the whole product life cycle into six stages: concept, development, production, utilisation, support, retirement (Fig. 1) described in AAP 48. AAP-20 describes the processes that occur at the pre-concept stage of the process of acquiring military equipment. The complete list of documents recommended for use in LCC analysis is given in STANREC 4755 [8].

The Polish defence standard NO 06-A011:2013 [9] distinguishes the following stages of product life cycle:

1) product concept and definition;
2) product design and development;
3) product manufacture (production);

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4) product installation;

5) product usage;

6) product retirement.

The model life cycle of armaments system [10] adopted by the Ministry of National Defence includes 4 phases with stages. The nomenclature is different, but the scope of actions is the same as of stages in [5] and [9].

The greatest potential for controlling the life cycle costs of a new technical system is in the phase of its concept and of design and development. This phase may account for as much as 85% of the total cost of the object, which is difficult to reduce at subsequent stages of the life cycle [11]. The cost of purchasing (acquiring) a system may be determined with a relatively high accuracy, while the largest portion of cost appears at the stage of operating (possessing) the technical system.

In the course of estimating the life cycle cost of a new technical system the future costs associated with the stage of operation (use and maintenance) of a technical object are the most difficult to estimate, primarily due to the random nature of use (particularly in the case of combat systems and military bridges) and the randomness of the occurrence of damage.

Theoretical discourses regarding LCC conducted in Poland do not come up to the current needs [12], [13]. In particular there is a lack of foundations of practical calculation methodology related to the determination of the system life cycle cost structure, as well as methods and tools for estimating these costs. Knowledge of a system life cost structure and of the method of its calculation is important, especially at a time when selecting the system in the aspect of meeting operational requirements [13].

The balance of the cost of the various life phases of the object/system enables optimisation of the total cost, so that the acquisition cost has a positive and rational effect on future operating costs. Properly conducted analysis should include the costs of the various life stages (Fig. 1). The aim of the life cycle cost analysis is the selection of the concept of the product with optimised cost of acquisition and operation (Fig. 2), that is the total price of the product, and not just looking for savings in the purchase or design phase. Properly conducted life cycle cost analysis also helps the future user avoid unnecessary expenditures.

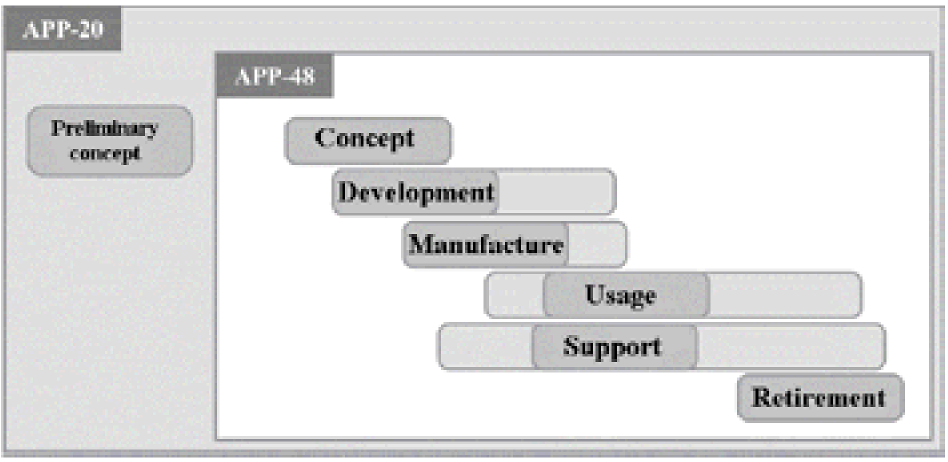

Fig. 1. Life stages of military equipment according to NATO concepts and relation between AAP-20 and APP-48 [5]

Acquisition cost means the cost associated with activities such as conducting market analysis, analysis of existing solutions, development of a concept, product design, model and prototype construction, pre-production batch, certification testing and purchase of the product. As shown in the graph (Fig. 2), minimising expenditures at the stage of product acquisition (extreme left part of curve A) causes an increase in operating cost (curve B). Operating cost plus acquisition cost of the product is the total cost (curve C). The minimum of the total cost curve determines the area of optimum product life cycle cost (hatched area). Navigating in this area allows for a relatively low cost of manufacture of the product and its use, due to the relatively high reliability and selection of the best solutions of the cost - effect type.

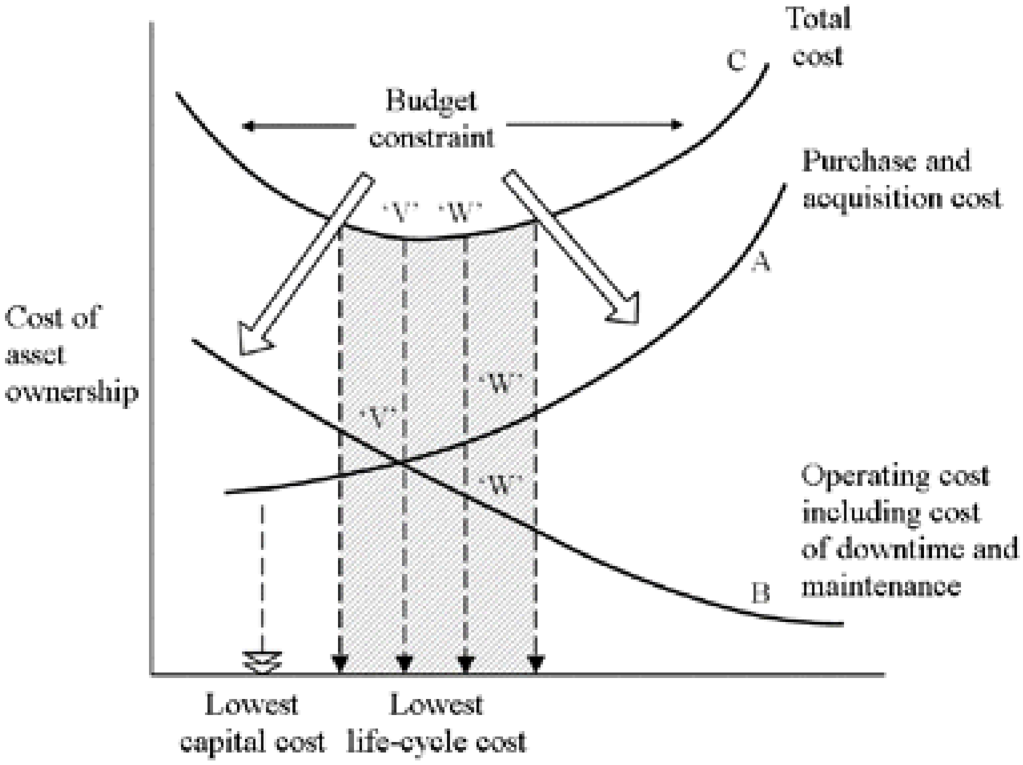

Fig. 2. Relationship between operating cost and acquisition cost illustrated with an example of a ferry [18]

There are no reports in Polish and foreign literature on the application of LCC analysis in the evaluation of military bridge concepts, including pontoon bridges. Military bridges differ significantly from the civilian bridges in use, design solutions and durability (civilian bridges are designed for a minimum of 100 years of use). Examples of LCC application in the Polish Army describe mainly the issues of modelling of the life cycle stages, as in the case of publications [12] and [13]. Only the work [11] deals with the estimation of the cost of combat vehicles on tracked platform.

As there are no examples of LCC analysis application to pontoon bridges, below are examples of its use in civilian bridge engineering and in shipbuilding for assessing ferries, because of the similarity of their function with that of the pontoon bridge.

An example of evaluating the options of modernising a steel truss bridge can be found in domestic literature [14]. Our study included a comparative analysis of the costs and environmental impacts during the life cycle of the bridge for three variants of modernisation of the bridge using a new bridge deck: of reinforced concrete, steel or aluminium. Economic and environmental assessment of modernisation options has enabled a holistic look at the nowadays common problem of deck replacement in this type of bridges. At the same time the results obtained clearly show that both the costs generated during the life cycle of the bridge, as well as the related environmental impact are lowest in the case of an aluminium deck.

The methodology of LCC analysis of bridges, adapted to evaluate the life cycle costs of new materials and/or design solutions, was developed by Ehlen and Marshall [15]. A special software, *BridgeLCC 2.0*, has also been developed to facilitate deterministic and probabilistic LCC analysis [16]. The methodology (and software) mentioned above has also been applied in this work to carry out comparative analysis of the bridge modernisation options.

In the case of construction of bridges, that is structures erected from scratch, with very little purchasing of ready-made components, a significant impact on the product life cycle cost is that of the materials technology selection. The paper [17] provides life cycle cost analysis of 5 bridges constructed with the use of 5 different materials including structural steel, stainless steel, composite, aluminium and reinforced concrete.

The analysis included cost and environmental impact and was based on:

- cost of materials used for bridge construction;
- applied construction technology, its cost, requirements they should fulfil and environmental hazards posed;
- method of transport and assembly of prefabricated bridge members and cost involved;
- frequency of inspections and operating requirements during life cycle;
- environmental impact of construction operations.

The conducted analysis identified and determined the life cycle cost of the presented concepts of bridges and the environmental impact (energy consumption, air and water pollution, etc.) of bridge structures made of different materials (Table 1, Fig. 3).

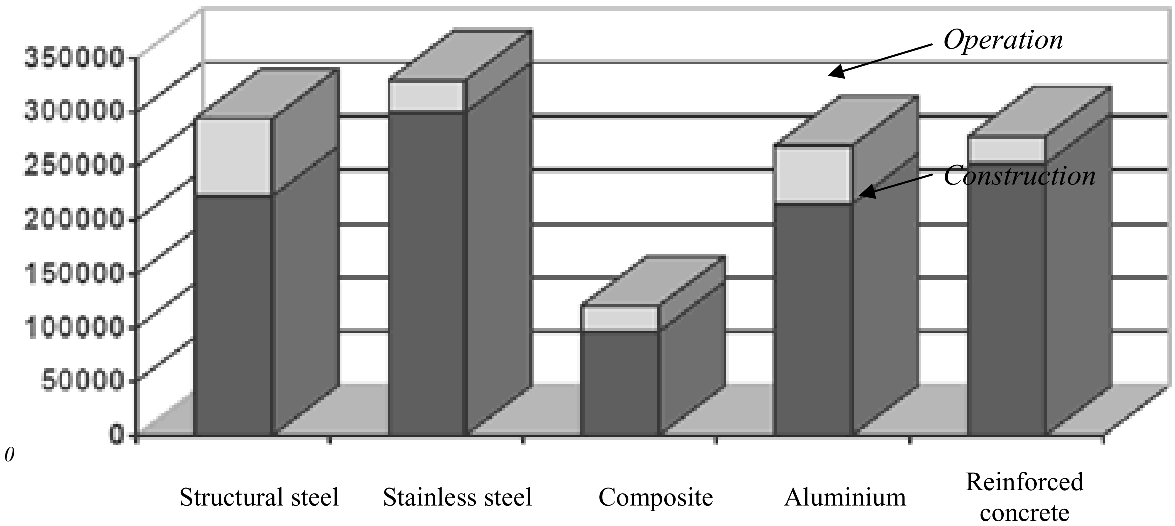

Fig. 3. Energy consumed during construction and operation of bridges made of different materials [17]

The following conclusions can be drawn from the conducted analysis:

- the lowest acquisition cost is that of a bridge of steel (structural steel) or concrete construction. The stainless steel bridge is the most costly at the construction stage;
- the lowest operating cost is that of a stainless steel bridge. The operating costs of a concrete bridge are also low. The most expensive in maintenance is a bridge made of structural steel provided with traditional paint coating;

– life cycle cost is the lowest in case of concrete, steel (structural steel), composite and aluminium bridges (in ascending order). The life cycle cost of a stainless steel structure is high;
– as indicated by analysis conducted using the "exergy" method, energy consumption is lowest in the case of a bridge made of composite materials;
– the composite bridge is a structure of the lowest environmental impact.

Table 1. Life cycle costs of bridges constructed of different materials [17]

Material	Criterion			
	Acquisition cost (€)	Operating cost (€)	Energy consumption; "exergy" method (MJ)	Pollutant volume (m^3)
Structural steel	Painted: 40,000 Aluminium coated: 50,000	Painted: 30,000 Aluminium coated: 6,000	294,000	Water: 697.4 Air: 7.09×10^6
Stainless steel	AISI 316L steel: 110,000 AISI 304L steel: 96,000	AISI 316L steel: 6,000 AISI 304L steel: higher, shorter life	329,600	n.a. (more than structural steel)
Composite	Pultrusion (FGRP): 70,000	Rough estimation: 17,000	120,000	Water: 85.8 Air: 7.09×10^6
Aluminium	AlMgSi1 acc. to DIN 1748: 77,000	Rough estimation: 19,000	268,700	Water: 565.3 Air: 31.10×10^6
Concrete	B53 concrete: 30,000	Rough estimation: 10,000	277,200	Water: 341.9 Air: 31.04×10^6

An example of the purposefulness of conducting life cycle cost analysis is the analysis of the selection of materials used in the manufacture of the hull of a ferry which, by its nature and function, is similar to military pontoon bridges. The choice between aluminium, steel or composite, when only the construction stage is taken into account, seems obvious in view of the low cost of fabricating a steel structure. The analysis provided in [18] shows that the cost of the construction stage constitutes a small portion of the total cost incurred during the product life cycle.

The material selected for the construction of the hull of a ferry will have an impact on the costs of the subsequent stages of the vessel's life: manufacture, usage, up to scrapping. Similar material options are taken into account when considering the structure of pontoons for a new bridge for the Polish Army [17]. In addition, more lightweight material will add to lower energy consumption by vessel propulsion. It has been proven that vessels with aluminium or composite hulls are least expensive, while the former are in addition characterised by the lowest fuel consumption [18].

The main feature that differentiates steel, aluminium and composite structures is their weight (Table 2) which has a significant impact on operating costs. As the weights of composite and aluminium hulls are similar, therefore the same type of drive was adopted for both versions. The same weight of paint coatings, of hull framework and deck, interior components and electrical systems has also been assumed for those versions. Savings on the weight of thermal insulation have also been taken into account in the case of the composite version.

Table 2. Weight of ferry components [18]

Vessel component	Version, component weight		
	steel (tonnes)	aluminium (tonnes)	composite (tonnes)
Hull	940	470	607
Superstructure	120	110	
Paint coatings	12	10	10
Hull and deck outfitting	250	230	230
Interior components	133	130	130
Thermal insulation	35	40	0
Fire installations			27
Machinery	485	380	380
Electrical systems	55	55	55
Total weight	2030	1425	1439

Because of the comparative nature of the conducted life cycle cost analysis, those costs that were identical for all three material versions were not taken into account. The costs incurred were split (depending on the stage of the life cycle at which they occurred) into: cost of concept stage, of production stage, of operation stage and cost of disposal of the vessel (Fig. 4). Detailed description of the components of the individual stages is given in [16].

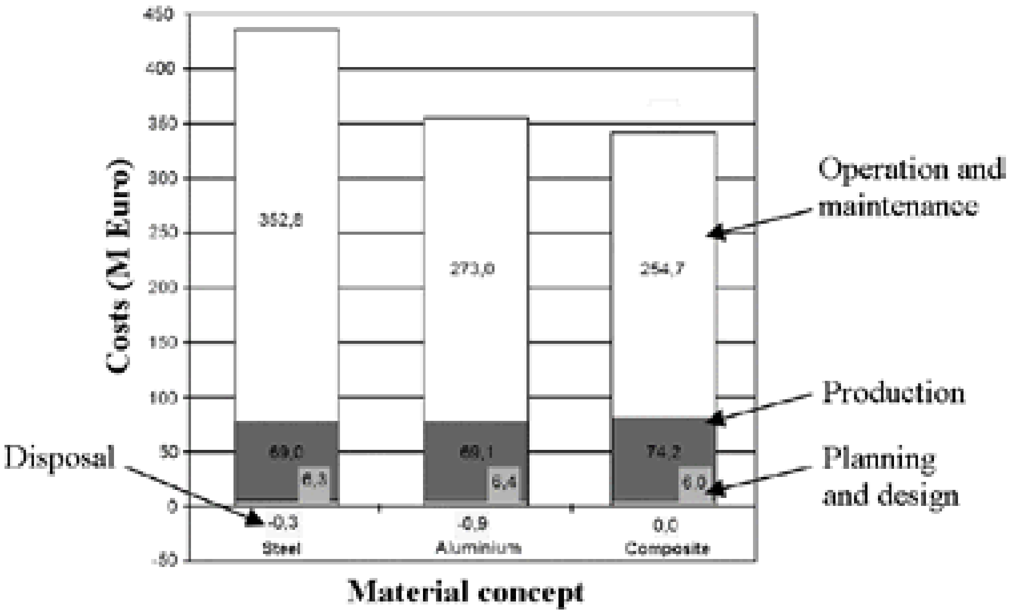

Fig 4. Life cycle costs of a ferry constructed of different materials [18]

2. ASSUMPTIONS ADOPTED IN THE LCC ANALYSIS OF THE PONTOON BRIDGE

A pontoon bridge is a complex system in the structural and logistics aspect, where the need to use vehicles is combined with pontoons as the structure of the bridge or of a ferry and a means of propulsion on water. Of fundamental importance for developing a concept of estimating the life cycle cost of a bridge is the comprehension and identification of the life cycle of the bridge and of actions taken in the subsequent phases of the life cycle. For the purpose of proper analysis of the life cycle cost of a pontoon bridge, the same assumptions were made regarding the operating parameters of the product, such as: length of the analysed bridge segment, operating time during a year, distances covered by transport means of the pontoon fleet, etc.

a) b) c)

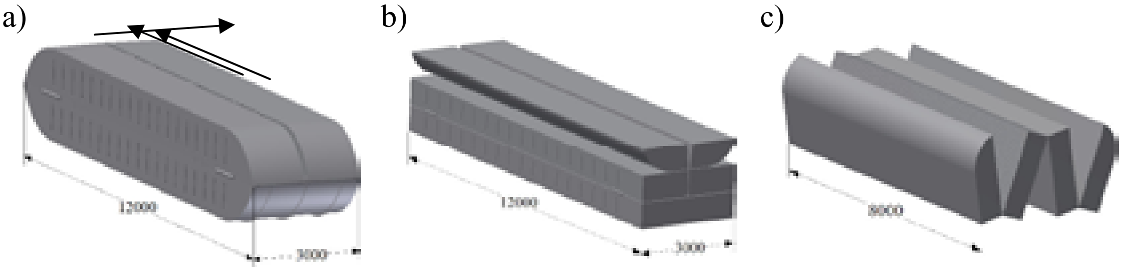

Fig. 5. Analysed concepts of pontoon blocks in transport arrangement with indicated vehicle movement direction [17]:
a) concept I; b) concept II; c) concept III

Three concepts of pontoon structure (steel, aluminium and composite) (Fig. 5, Table 3) were subjected to analysis. The concepts were developed in the course of conceptual work carried out as part of a project: "Lightweight, resistant to degradative environmental action, hybrid aluminium/composite pontoon for constructing floating bridges of MLC 70/110 class" [19]. These concepts were developed with account taken of the requirements set for a modern pontoon bridge for the Polish Armed Forces [20]. For the sake of unambiguity, comparison was made under the assumption of identical operating conditions of a section of the bridge with a length of 100 m.

Table 3. Parameters of the analysed concepts of pontoon blocks and of pontoon bridge segments created with the blocks

Parameters	Concepts		
	I	II	III
Width of pontoon block (transport) (m)	3.0	3.0	3.0
Length of pontoon block (transport) (m)	12.0	12.0	8.0
Height of pontoon block (transport) (m)	2.2	2.2	2.4
Estimated weight of pontoon block (t)	11.5	12.0	9.5
Width of bridge segment (on water) (m)	12.0	9.0	9.6
Length of bridge segment (on water) (m)	6.0	12.0	8.0
Height of bridge segment (on water) (m)	1.1	0.73	0.75
Displacement of 1 running metre of bridge segment	12.1	5.84	6.45

2.1. Pontoon block design objectives

The pontoon blocks under analysis differ between one another in, among others: overall dimensions, method of transporting, launching, manoeuvring on water and retrieving from water obstacles. Some of these tasks may be completed for every concept with the use of identical means, e.g. transporting the pontoon blocks on trailers. However, pontoon blocks can be transported on the frame of a 4-axle vehicle only in the case of concept III, where dimensions are smaller. Concept I is the only one, due to the height of pontoons, where blocks can be self-propelled and be combined on water to form a "ribbon", maintain the bridge along the centre line and propel ferries. With other concepts it is necessary to use boats (concept III) or integrated outboard engines (concept II). These and other objectives that have an impact on acquisition costs of complete pontoon fleets are listed in Table 4.

Table 4. Parameters of the analysed concepts for a bridge segment 100 m long

Parameters	Concepts		
	I	II	III
No. of blocks required for a 100m long bridge	16	8	12
Personnel	42	34	46
Drive type on water (no.)	self-propelled, 16	self-propelled, 16	boat, 8
Means for transporting pontoon blocks + approach ramp (no.)	16 ... 4	8 ... 4	12 ... 4
Means for transporting boats (no.)	–	–	8
Means for transporting equipment (no.)	6	6	10

2.2. Operating assumptions

Determination of the operating costs of a pontoon bridge assembly requires making assumptions regarding fuel prices, the amount of man-hours allocated to maintenance, number of repairs or, for example, fuel consumption by transport means. An exact cost analysis allows to determine the acquisition and operating costs ratio in relation to the three concepts of the pontoon fleet. It is helpful in determining whether a greater financial contribution at model, prototype or production stages will result in future savings. In order to determine the annual cost of using pontoon fleets, assumptions must be made regarding the frequency of using pontoon bridge assemblies and distances to be covered by transport means (Table 5). The calculated annual cost of maintaining the pontoon fleet may differ from the actual expenditure incurred in this respect, as it depends on many variables, such as method of use or market prices. This has no effect on the final result because the essence of this type of analyses is to compare the total cost of the presented concepts under the same assumptions. The adopted intensity of bridge usage was 8 hours per day, 50 days per year, during an operating life of 30 years.

Table 5. Operating assumptions adopted in annual cost analysis

Parameters	Concepts		
	I	II	III
Annual operating time (hours)	400	400	400
Distance covered by vehicles (km/yr.)	1000	1000	1000
Cost of fuel oil (PLN/ltr)	5.1	5.1	5.1
Fuel consumption in vehicles/tractors (ltr/100km)	–/50	–/50	40/–
Fuel consumption in boat/installed drive (ltr/h)	–/20	–/2×15	20/–
Man-hours repairs (man-hrs.)	860	860	860
Man-hours construction and maintenance of bridge or ferry crossing (man-hrs.)	84672	68544	92736
Cost of 1 man-hour (PLN/h)	50	50	50

3. COST OF PONTOON BRIDGE LIFE CYCLE

At the stage of drawing up design objectives for the product in accordance with the rules applied by the Ministry of National Defence [10], there are yet no final accurate data on the cost of future design solutions. However, even a simplified life cycle cost estimation may be used as a criterion for assessing pontoon bridge concepts. The obtained results of the analysis of product acquisition cost also enable further studies, for instance of the purposefulness of manufacturing new equipment as opposed to modernisation of existing equipment or purchase of equipment on the market.

3.1. Acquisition cost

Acquisition cost comprises cost of research and development, cost of manufacture and cost of purchase. The cost of research and development depends on the number of man-hours and cost of materials used to construct a model and prototype according to the concepts. As the cost of the individual stages is high, pontoon blocks, equipment and transport means used at the model stage may also be used at the prototype stage with account taken of the observations made during model testing.

The cost of a pontoon bridge manufactured in series production depends on the cost of fabricating pontoon blocks, drives of pontoon blocks, bridge equipment and mainly on acquisition cost of transport means. Estimated acquisition cost of pontoon blocks is presented in Table 6, whereas the total acquisition cost of a 100 m long segment of a pontoon bridge assembly is presented in Table 7.

Table 6. Estimated cost of pontoon blocks

Parameters	Concepts		
	I	II	III
Weight of pontoon block, t	11.5	12.0	9.5
Acquisition cost of pontoon block made of:			
– steel (PLN) (50,000 PLN/t)	575,000	600,000	475,000
– aluminium (PLN) (65,000 PLN/t)	747,500	780,000	617,500
– composite (PLN) (80,000 PLN/t)	920,000	960,000	760,000
Number of pontoon blocks	16	8	12
Acquisition cost of complete set of pontoons made of:			
– steel (PLN)	9,200,000	4,800,000	5,700,000
– aluminium (PLN)	11,960,000	6,240,000	7,410,000
– composite (PLN)	14,720,000	7,680,000	9,120,000

Table 7. Estimated acquisition cost of 100 m long segment of a pontoon bridge

Parameters	Concepts		
	I	II	III
Acquisition cost of complete set of pontoons made of:			
– steel (PLN)	9,200,000	4,800,000	5,700,000
– aluminium (PLN)	11,960,000	6,240,000	7,410,000
– composite (PLN)	14,720,000	7,680,000	9,120,000
Acquisition cost of approach ramps (PLN)	1,500,000	2,000,000	1,500,000
Acquisition cost of pontoon drives (PLN)	3,000,000	1,000,000	5,600,000
Acquisition cost of means for transporting:			
– pontoon blocks (PLN)	36,800,000	18,400,000	21,600,000

Parameters	Concepts		
	I	II	III
– boats [PLN]	0	0	14,400,000
– approach ramps (PLN)	3,700,000	3,700,000	5,600,000
– equipment. (PLN)	13,800,000	13,800,000	18,000,000
Acquisition cost of equipment (PLN)	3,000,000	3,000,000	3,000,000
Total acquisition cost:			
– steel (PLN)	**71,000,000**	**46,700,000**	**75,400,000**
– aluminium (PLN)	**73,760,000**	**48,140,000**	**77,110,000**
– composite (PLN)	**76,520,000**	**49,580,000**	**78,820,000**

3.2. Operating cost

The total operating cost of a pontoon fleet depends on the prices of fuel, cost of materials, man-hours needed to make overhauls, number of staff needed to maintain the pontoon bridge throughout its life cycle. For the adopted assumptions (Table 5), the estimated annual operating costs are presented in Table 8.

Table 8. Estimated annual operating cost of a pontoon bridge

Parameters	Concepts		
	I	II	III
Cost of repairs (PLN)	43,000	43,000	43,000
Cost of staff during operations (PLN)	4,233,600	3,427,200	4,636,800
Cost of fuel for pontoon blocks (PLN)	652,800	489,600	612,000
Cost of fuel for transport means (PLN)	66,300	45,900	69,360
Annual operating cost (PLN)	**4,995,700**	**4,005,700**	**5,361,160**

An important item in the life cycle of a pontoon fleet, due to unfavourable operating conditions and the need to maintain the level of availability of the bridge at 90%, is the cost of overhauls. Properly conducted repairs should restore the bridge to a condition close to the initial state, taking into account the need to renew the paint coatings and repair damage occurring during use. It was assumed that the cost of these tasks will be at the level of 15% of the cost of mass production of the pontoon bridge assembly, and these tasks will be carried out within 10 years from the start of bridge usage in the case of steel blocks, and 15 years in the case of aluminium or composite blocks. Estimated overhaul costs are shown in Table 9.

Table 9. Estimated repair costs of pontoon blocks

Parameters	Concepts		
	I	II	III
Cost of conducting an overhaul of pontoon blocks made of:			
– steel, every 10 years (PLN)	10,650,000	7,005,000	11,310,000
– aluminium, every 15 years (PLN)	11,064,000	7,221,000	11,566,500
– composite, every 15 years (PLN)	11,478,000	7,437,000	11,823,000

3.3. Cost of decommissioning

The last item in life cycle cost analysis is the estimation of the cost of decommissioning of the worn out equipment (Table 10). The simplest way to assess the cost of decommissioning is to take into account the recycling possibilities of non-ferrous metals used in the manufacture of the pontoon fleets. Due to this fact, the cost of disposal will be the income determined from the weight of the metals contained in the pontoon blocks and vehicles and the scrap buying price. For the sake of the analysis the assumed steel scrap buying price was 0.75 PLN/kg and that of aluminium scrap 5 PLN/kg. The effect of the lack of composite scrap recyclers is that composite pontoon blocks cannot be disposed with any recovery of expenses.

Table 10. Estimated disposal cost of pontoon bridge assemblies

Parameters	Concepts		
	I	II	III
Weight of disposed pontoons (kg)	184,000	96,000	114,000
Weight of disposed vehicles (kg)	572,000	396,000	748,000
Income from decommissioning of pontoon fleets made of:			
– steel (PLN) (0.75 PLN/kg)	567,000	369,000	646,500
– aluminium (PLN) (5 PLN/kg)	1,349,000	777,000	1,131,000
– composite (PLN) (0 PLN/kg)	429,000	297,000	561,000

3.4. Life cycle cost of a 100 m segment of pontoon bridge

The conducted analyses allow for an assessment of the costs of the life stages of the pontoon bridge assembly and for determination of the total life cost for each concept. The results of analysis are presented in the form of graphs (Fig. 6 – various concepts, steel; Fig. 8 – concept II, various materials) and tables. The results obtained allow for varied presentation thereof with respect to the types of concepts and materials. Here the presentation is limited to the most important results and to comparisons. The life cycle of pontoon bridges begins with the stage of research and development spread over 5 years, followed by stage of manufacture which also lasts 5 years, during which the funds are utilised according to the schedule of tasks. The flat section of the graph after the manufacturing stage corresponds to the stage of use (Fig. 6) during which staff and maintenance costs appear. Temporary rises in costs in subsequent years of operation of the pontoon fleet are due to the need to carry out overhauls and to renovate paint coatings. A detailed breakdown of the acquisition and operating costs of the individual components of the pontoon bridge is represented by a graph in Fig. 7.

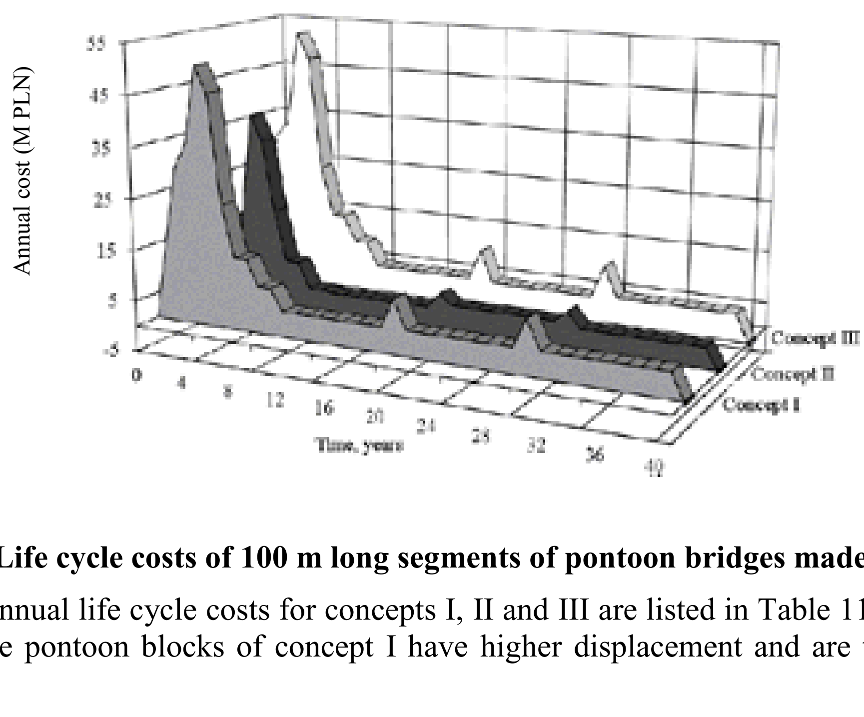

Fig. 6. Life cycle costs of 100 m long segments of pontoon bridges made of steel

The annual life cycle costs for concepts I, II and III are listed in Table 11. It should be noted that the pontoon blocks of concept I have higher displacement and are the only ones that allow two-way traffic of MLC 40 vehicles [18]. Ferries made of such pontoon blocks are, due to higher displacement, shorter, but have larger draught.

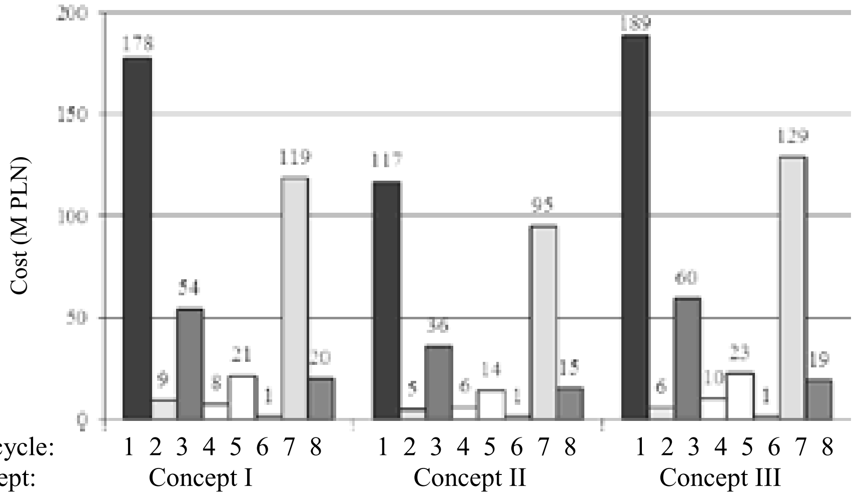

Fig. 7. Cost breakdown for pontoon fleets made of steel
1 – research and development stage; 2 – pontoon manufacture; 3 – vehicle manufacture;
4 – acquisition cost of ramps, drives and equipment; 5 – overhauls;
6 – repairs, 7 – staff; 8 – fuel for transport means and pontoons.

Table 11 shows that concept II has the lowest life cycle cost of a pontoon bridge. The costs of each year of the life-cycle of concept II in various material versions is shown in Fig. 8. Fig. 9 lists acquisition and operating costs of pontoon fleets, various concepts in different material versions, for the purpose of comparing costs at the various stages of the life cycle of a pontoon bridge.

Table 11. Life cycle costs of the various steel pontoon bridge concepts

Concept:	Stages / Years / Cost (M PLN)																																									
	Research and development					Manufacture					Operation									OH*	Operation									OH*	Operation										Disposal	
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	**TOTAL**
I	15.5000	30.5000	35.5000	50.5000	45.5000	24.2000	14.2000	14.2000	9.2000	9.2000	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	10.6500	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	10.6500	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	-0.5670	**409,1126**
II	3.3500	18.3500	23.3500	38.3500	33.3500	0019.34	9.3400	9.3400	4.3400	4.3400	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	7.0050	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	7.0050	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	4.0057	-0.3690	**289,2506**
III	22.7000	31.2000	34.2000	52.7000	47.7000	25.0800	15.0800	15.0800	10.0800	10.0800	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	11.3100	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	4.9957	11.3100	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	5.3612	-0.6465	**432,6976**

*OH – overhaul

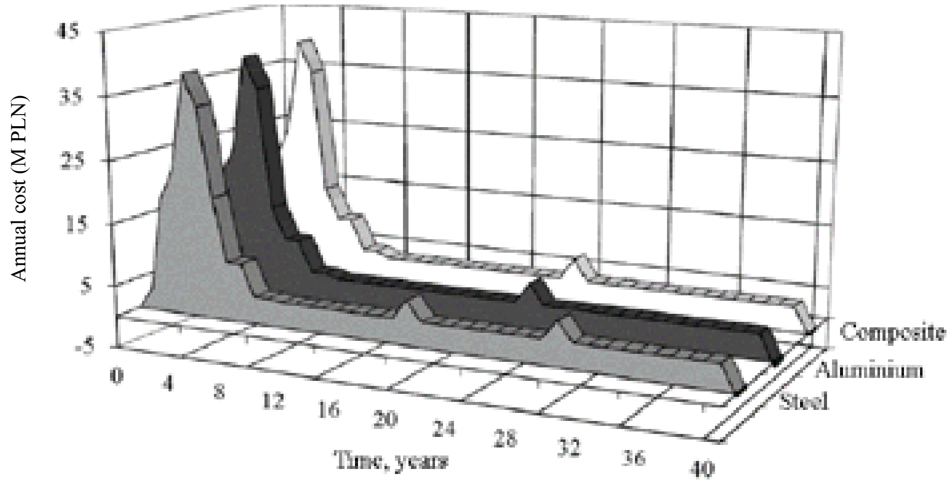

Fig. 8. Life cycle costs of 100 m segments of pontoon bridges according to concept II constructed of different materials

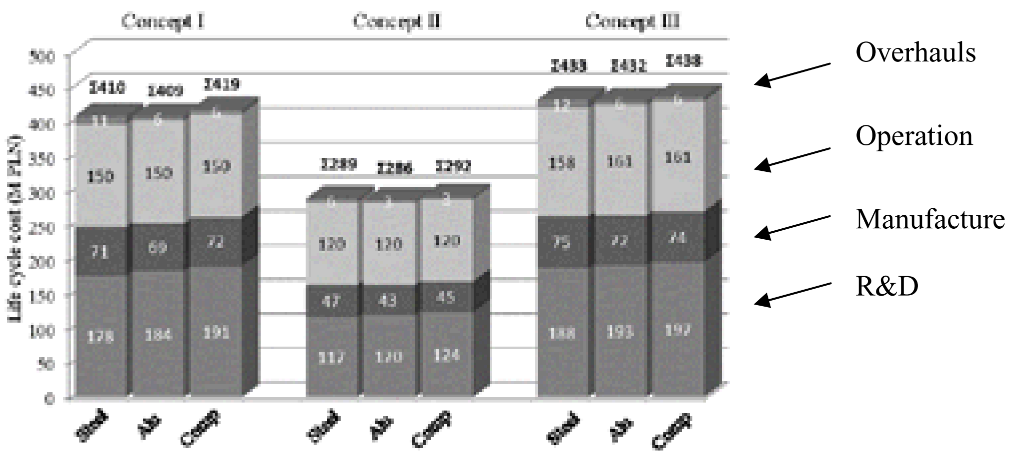

Fig. 9. Life cycle costs of the various bridge concepts (millions PLN)

The presented bar chart shows that the presented concepts are characterised by the following percentages of the costs of individual stages in relation to the total life cycle cost:

Steel:
- Concept I: R&D 43.3%, Manufacture 17.3%, Operation 36.6%, OH 2.8%;
- Concept II: R&D 40.4%, Manufacture 16.1%, Operation 41.5%, OH 2.0%;
- Concept III: R&D 43.5%, Manufacture 17.4%, Operation 36.4%, OH 2.7%.

Aluminium:
- Concept I: R&D 45.1%, Manufacture 16.8%, Operation 36.7%, OH 1.4%;
- Concept II: R&D 42.0%, Manufacture 15.0%, Operation 41.9%, OH 1.1%;
- Concept III: R&D 44.6%, Manufacture 16.7%, Operation 37.3%, OH 1.4%.

Composite:
- Concept I: R&D 45.6%, Manufacture 17.1%, Operation 35.8%, OH 1.5%;
- Concept II: R&D 42.4%, Manufacture 15.3%, Operation 41.1%, OH 1.2%;
- Concept III: R&D 45.0%, Manufacture 16.8%, Operation 36.7%, OH 1.5%.

The statement above shows that concepts I and III are characterised by a higher percentage share of costs at the R&D and manufacture stages in relation to total cost than concept II. Concept II, on the other hand, has higher cost shares during the operation period in relation to concepts I and III. The cost shares of overhauls related to the total cost is comparable for all three concepts.

The adopted assumptions on the annual usage intensity of the bridge (Table 5) had an effect on the minimisation of differences in operating costs of the individual concepts. The expected usage intensity of a bridge has a significant effect on its operating cost. In the case of increasing the intensity of the pontoon bridge usage for training or supporting the population in crisis situations, these differences grow in favour of the concepts that require lower staffing and less transport means per bridge assembly. In such case concept II achieves a significant advantage.

4. CONCLUSIONS

Selection of solutions of a new pontoon bridge is in every army a major issue in cost and risk management. Taking a decision on the manufacture or purchase of a new floating bridge has many operational and economic aspects that affect combat abilities of the army and operating costs for the next several tens of years. Future and total costs of a product are affected already at the stage of concept development – the sooner the life cycle cost is assessed, the better.

The LCC analysis of a pontoon bridge at the stage of determining design objectives requires making a number of assumptions instead of taking real data on bridge acquisition and operation. As a result the estimation made depends on the quality of assumptions made. It may be used to determine the hierarchy of importance of the individual concepts of technical solutions. It is much more useful for comparing existing solutions available on the market and for economic justification of the selection made.

The selection of a pontoon bridge concept is very complex because of the complexity and diversity of possible technical solutions of the armaments system, part of which is a pontoon bridge. Analyses performed [19], [21] indicate that there are a few decision points which, in addition to LCC analyses, should be taken into account before detailed structural analyses are conducted. The most important include:

- selection of transport means – standard or non-standard (vehicle or trailer);
- selection of drive for use on water (boats, outboard engines, integrated drive);
- selection of the manner of attaching to the bank (ramps, shore sections);
- selection of construction material for the main components of the bridge.

Apart from the costs, important, and perhaps most important, are the tactical and technical aspects, expressed in the ability to meet tactical and technical objectives (TTO) [20]. It may, of course, be adopted that every concept has to completely meet the requirements of TTO. However, the TTO stage [10] also serves to make the requirements more realistic in relation to research and industrial capabilities. The economic analysis must also clearly take into account operational needs so that economics do not limit the fundamental objective function of military equipment. The possibility of multifunctional use of pontoon supporting vehicles affects the unambiguity of the assessment of the individual concepts.

The final selection of a pontoon bridge concept and material version is affected by many usage factors that were not considered in this LCC analysis, for instance:

– displacement parameters – concept I is the only one that offers two-way traffic of MLC 30 vehicles carrying 1 set of a bridge;
– initial and operational draught of the bridge – concept I has the largest initial and operational draught;
– attained pulling power – concept II, due to the use of outboard engines, has the lowest pulling power; its operation, however, is the most economical and least time-consuming;
– ability to make repairs under field conditions – only the steel version allows for making emergency repairs.

The results of the LCC analysis of 100 m long segments of pontoon bridges, according to the various concepts and of various construction materials, lead to the following conclusions:

1) concept II has the lowest life cycle cost, particularly the aluminium version;
2) the lowest share of R&D cost in the total life cycle cost is in concept II, although the span of these costs is relatively narrow (40.4% ... 45.6%);
3) the lowest share of operating cost in the total life cycle cost is in concepts I and III (36.4% ... 37.3%);

LCC analysis facilitates the preliminary selection of the concept, in this case the transport means. The decision, however, must be taken together with the end user with regard to priorities in meeting operational, technical and tactical requirements. In Poland there are currently no tools available in the form of computer software [16] with appropriate databases that enable conducting life cycle analyses at a much higher level of reliability of the result obtained for pontoon bridges. In addition they should comply with the procedures used by the Ministry of National Defence and NATO. Analyses based on proprietary procedures and estimates calculated using Excel spreadsheet are sufficient for preliminary assessment, but they may not be used to compare results obtained by various design offices.

The Ministry of National Defence should introduce uniform computer software for analysing life cycle and environmental, economic and social factors related to product life cycle (materials, processes). This process will ensure reliable cost optimisation at the early stages of military equipment acquisition.

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