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A Study on Life Cycle Cost on Railway Locomotive Systems

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ABSTRACT

Life cycle cost analysis is compulsively required for the system operation. System operation costs are consisted of acquisition, operation, maintenance and so on. In the beginning of the system planning, we need to take into account of various costs following the system operating. To implement LCC, we need to analyze system life cycle to identify all costs during system life. The costs can be divided into three parts. The first part is purchasing cost, the second for operating cost and the last for disposal cost. The second operating cost can be decomposed of operating cost included labor, energy consumption cost for system running, maintenance costs to keep systems healthy, delay cost caused from maintenance and hazard cost, and so on. In this paper, we carried out for railway locomotives which operate over more 30years and which cost about 10 million USD. We decompose the life cycle of the locomotives and break down the locomotives into subsystems to require maintenance or not, and subsystems to need energy or not. We showed how to decide optimal locomotives through cost identification and system breakdown.

1. Introduction

Customers have to consider the costs of procurement, energy consumption, maintenance and disposal when the customer buys a car or a boiler. Let's consider to buy a car. Then we consider whether we choose gasoline car or diesel car. The gasoline car is cheaper than the diesel, but the diesel efficiency is higher than the gasoline. The maintenance cost of the gasoline is less than the diesel. The customers have to take into account total cost through LCC. Similarly, railway systems which are consisted of largely various systems must be taken into account the LCC analysis for purchasing, operating and decommissioning. Railway locomotive life is considered more than 30 years. The locomotive management requires the LCC analysis to use economically. The need of LCC analysis is shown in Fig. 1 implicitly.

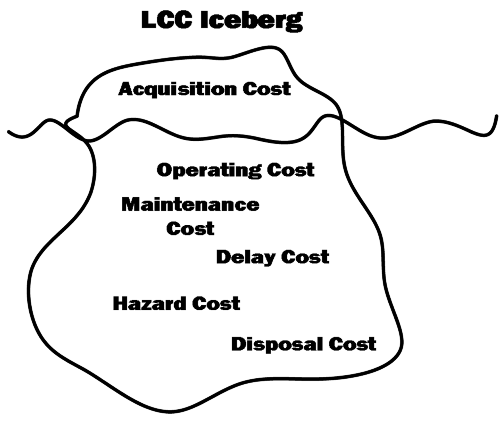

Fig. 1 Many costs are hided below water like an iceberg

The cost analysis is required for system life cycle to run systems optimally. The analysis calls for system inquiry in which a cost model introduces to show which costs are demanded for the life cycle and system breakdown takes place for which subsystems need maintenance, and so on

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2. Cost And System Analysis For Lcc

2.1. LCC general

The System LCC analysis is an analysis for all costs of systems use. The costs can be divided into three stages. The first stage is to analyze purchasing costs, the second for operating costs and the last stage for disposal cost. Automobiles doesn't need disposal cost, on the contrary, nuclear power plants require high cost for disposal. The operating costs include labor, energy consumption, hazard and costs of various types.

Breakdowns of systems show subsystem to require maintenance periodically or subsystems with maintenance-free. In case of automobiles, tires of the automobiles have to be replaced according as running distance, but car doesn't need maintenance without accident arises. In the beginning of life cycle cost analysis of a system, the system breakdown is essential into subsystems which allow of determining the related costs. We can estimate all costs of the dissembled subsystems for their life cycles.

The Fig. 2 shows effectually the relations of system breakdown, life cycle and its costs into which have a system decomposed.

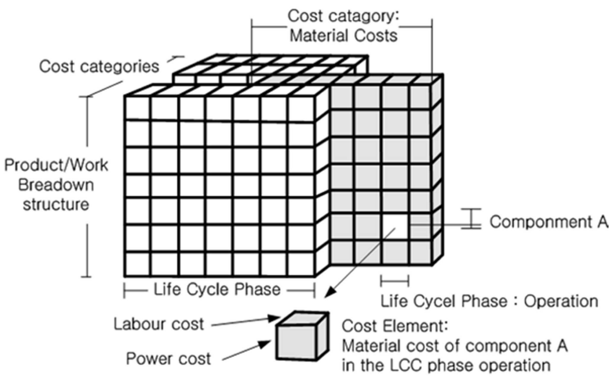

Fig. 2 LCC decomposition [2]

2.2. Railway system LCC

We need to take into account various factors. Ready-made articles simply consider the costs of procurement, maintenance, delay and insurance. But new systems such as high speed train systems or unmanned systems must contemplate whole system life cycle, which are concept, design and development, manufacturing, installation, and disposal. New railway systems follow infrastructures and fixed equipment, vehicles and tractive power consumption, and so on. The railway systems cannot easily estimate because of its very complex characteristics. It's better carrying out LCC analysis with specified systems. We introduce the LCC results by gathering the pieces of LCC activities.

We confined our LCC activity to locomotives in this paper. In the case of the locomotives, we count only the costs for investment, revenue operation and decommissioning. Most of railway authorities have only interesting of locomotive purchasing which they want to choose proper locomotives for their operations. The life cycle cost of locomotives can be represented in Fig. 3 more detail. The investment costs for locomotives have to be considered engineering cost for new tools and equipment, training and spare parts. The other parts can be estimated on the basis of operation experiences.

3. Locomotive Cost Models

3.1. Locomotive system breakdown

Locomotive systems are very expensive materials and can be served for more than 30 years. The locomotives can be divided by propulsion systems into diesel, diesel electric and electric types. The general structure of locomotives represents in Fig. 4, the propulsion part can be changed to one diesel systems, diesel-electric system, or transformer-pantograph and traction motors.

Locomotive operation requires such as fuel or electric energies analysis, and maintenance periodically. So the subsystems of the locomotives can divide into operating cost required or not. The subsystems of locomotives can be classified into several categories which are wearable and non-wearable and which the subsystems require energies to operate and so on.

Table 1. Subsystem Characteristic Identification

subsystem name	Characteristics	maintenance	Energy (kw)	Failure rate (/hour)	economic life (years)
Car body	non wearable	painting	-	-	50
Electric Motors	wearable non wearable	insulation Bearing	1.5MW		30
Brake pad	wearable	replacement	10	10-9	1
Air filter	non wearable	replacement	-	-	1

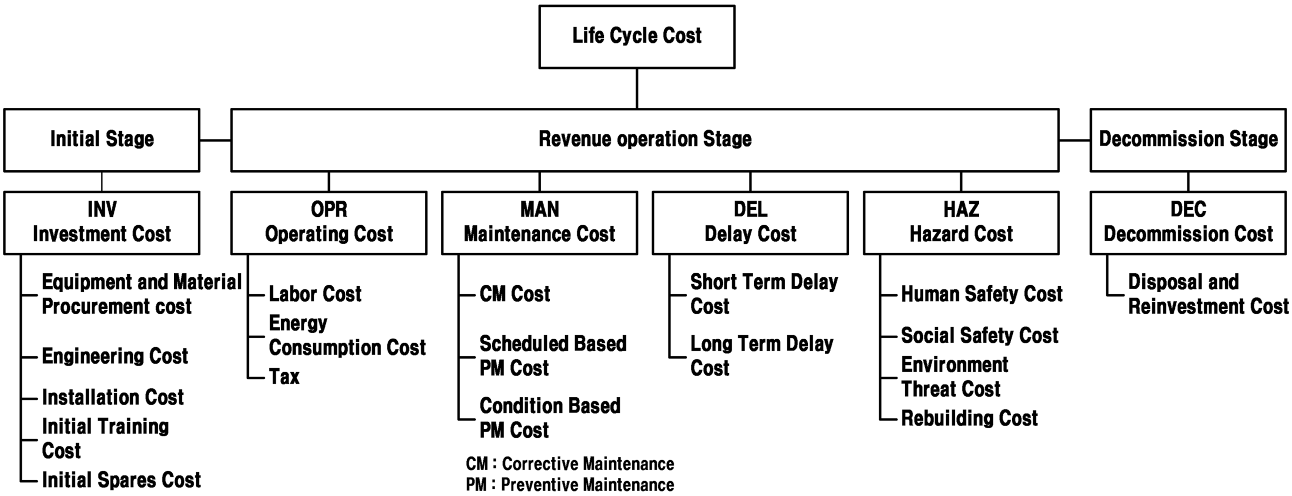

Fig. 3 Life Cycle Costs[1]

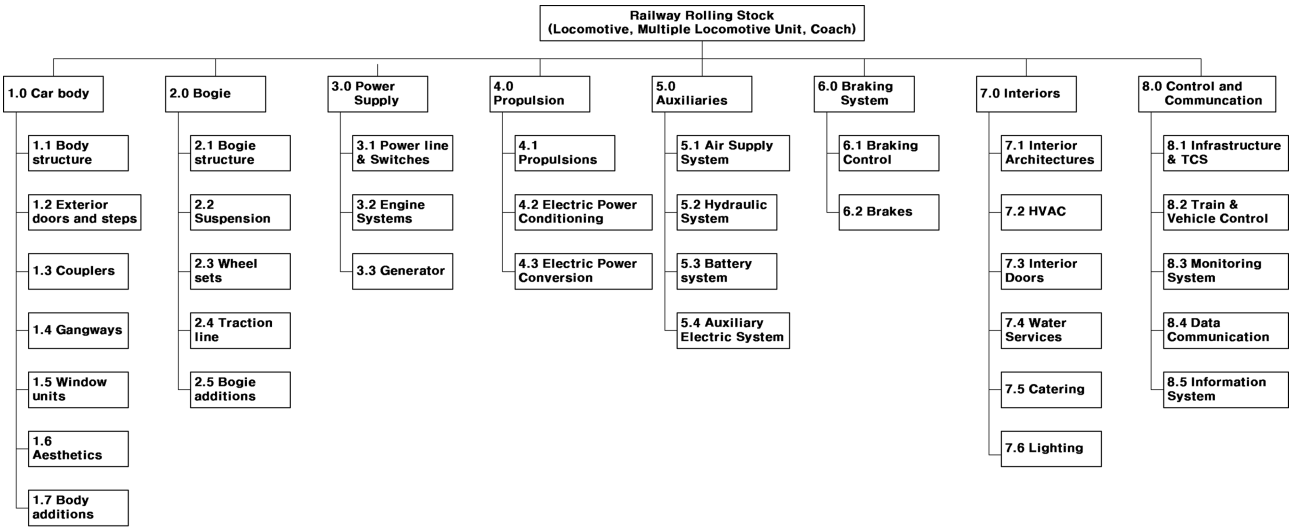

Fig. 4 Locomotives Breakdown into Subsystems[14]

3.2. Locomotive costs

The essential costs during the locomotive life cycle can be estimated on the basis of the subsystem analysis. To maintain an operable state of the locomotives constantly, we have to determine the maintenance levels such as light or heavy maintenances, and then, we can fix the maintenance shop size and equipment, and the maintenance staff skill level according the maintenance levels. Additionally, it has to include the shop operation, training and so on. The life cycle costs for the locomotives is simply represented in Table 2.

As mentioned above, locomotive operations require a lot of jobs which follow incidental expenses. We need to assess more exact expenses for the operations. We identify the expenses items for the subsystems in their life cycles and calculate in point of view in total amount.

3.3. Locomotive LCC models

Locomotive LCC is consisted of four part costs which are investment cost C_{inv}, maintenance cost C_{man}, and operating cost C_{ope}, delay cost C_{del}, and hazard C_{haz}. The investment costs of the locomotives are composed of equipment and material procurement, engineering cost for maintenance shop etc. The second term is on the maintenance and operation costs which contain maintenance expenses, operating expenses included labor works and energy consumption. The delay costs

Table 2. Subsystem life cycle cost analysis

Classification		Subsystem name			
		Car body	Traction Motors	Brake pad	Air filter
INV	Procurement cost	○	○	○	○
	Engineering cost		○		
	Installation cost		○		
	Initial spare cost			○	
	Initial training cost		○		
OPR	Operating Cost		○	○	○
	Energy consumption cost		○		
MAN	CM Cost	○	○		
	Scheduled Based PM cost		○	○	○
	Condition Based Cost				
DEL	Short term delay cost			○	○
	Long term delay cost	○	○		
HAZ	Human safety cost			○	
	Social safety cost			○	
	Environment threat cost				○
	Rebuilding cost				
DEC	Disposal Cost			○	○

embrace loss during maintenance and repairing caused from such as accidents. The last term is hazard costs which would provoke expenses coming after unwanted events during operation, such as contaminations, injuries and so on.

$$C_{LCC} = C_{inv} + C_{man} + C_{ope} + C_{del} + C_{haz} \quad (1)$$

The maintenance and operating, delay, and hazard costs consists of two parts : the one part forecasts the costs and the another cannot forecast because of their randomness. The maintenance activities are divided into preventive and corrective maintenances. The corrective maintenance and the delay caused from the maintenance and accidents take place randomly, on the contrary, the preventive maintenances and the delay are scheduled jobs which can be determined. The hazard cost is similar to the two costs. The operating cost can exactly be predicted and fixed by the train operation.

The random factors can be determined by failure rate $\lambda_{fail}/year$ and accident rate $\lambda_{acc}/year$ and average costs caused from the failures and the accidents, which can be fixed on the basis of past year data.

4. Simulation

The application of the life cycle coasting is to select the cost effective equipment from competing manufactures or alternative systems. The cost effectiveness is closely correlated with system's reliabilities. The higher the reliability is, the higher the cost is. We have to find an optimum point between cost and reliability which systems require. There is always a cost associated with changing a design, due to change of vendors, use of higher-quality materials, retooling cost, administrative fees, or other factors. We cannot take into all factors in this paper. We choose one examples such as Table 3 to find a better solution. This example can be extended to real cases by adding more detail factors.

Table 3. Arbitrary allocated traction motor costs

Classification			Traction Motors I	Traction Motors II
1	Procurement cost	C_{inv}	$ 30,000	$28,000
2	Expected useful life in years	n_{year}	30	30
3	Annual failure rate	n_{frate}	0.07	0.08
4	Cost of a failure	C_{fail}	$2,500	$3,000
5	Annual accident rate	n_{acrate}	0.00009	0.0001
6	Cost of an accident	C_{haz}	$30,000	$28,000
7	Annual interest rate	n_{inra}	0.05	0.05
8	Annual operating cost	C_{opr}	$5,000	$5,100

The four costs are introduced in this example. We can consider maintenance and delay costs are included in the failure and hazard costs. The costs from failure, accident and operation have to be considered uniform periodic payments. The payments is concerned with determining the present value or worth at the end of n interest years of equal payments made at the end of each interest year. The presents value is represented in the equation (2). The procurement takes place only one time at the beginning.

$$PV_{type} = C_{type}\left(\frac{1-(1+n_{inra})^{-n}}{n_{inra}}\right) \quad (2)$$

The life cycle cost of the locomotive is represented in the equation (3).

$$LCC_i = PV_{inv} + PV_{fail} + PV_{haz} + PV_{opr} \quad (3)$$

Where

PV_{inv} is traction motor life cycle procurement cost.

Table 4. LCC calculation

		5	10	15	20	25	30
PV_{fail}	Type I	909	1621	2179	2617	2959	3228
	Type II	1039	1853	2491	2990	3382	3689
PV_{haz}	Type I	116	208	280	336	380	415
	Type II	121	216	290	348	394	430
PV_{opr}	Type I	2164	3860	5189	6231	7046	7686
	Type II	2208	3938	5293	6355	7187	7839
sum	Type I	33190	35690	37649	39184	40387	41329
	Type II	31368	34007	36075	37695	38965	39959

PV_{fail} is present value of traction motor life cycle failure cost.

PV_{haz} is present value of traction motor life cycle accident cost.

PV_{opr} is present value of traction motor life cycle operating cost.

We assume that the economy life of the traction motors is 30 years. The procurement cost PV_{inv} is \$30,000. The sum is calculated by using Equation (3). We calculate the LCC, we can get the results as Table 4.

5. Conclusion

The life cycle costing processes are to need detailed skill to make system breakdown into subsystems. It is important that the subsystems can be classified into non-wearable subsystems and wearable systems, and all costs are identified during life cycles. The cost analysis can be carried out by operators or manufacturers. The life cycle cost for operation is dependent on maintenance level which the operators want to do it. The more high level maintenance wants, the more maintenance facilities are requires.

All methods required for life cycle cost analysis would be developed. We need to find balance points for system operation during the life cycle. The life cycle cost analysis aims at optimizing the costs, so the costs become to vary to the planning of system purchasing and operation. The result of the life cycle cost analysis strongly depends on system operation approach for each subsystem.

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