Avrupa Bilim ve Teknoloji Dergisi
Sayı 18, S. 918-926, Mart-Nisan 2020

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No. 18, pp. 918-926, March-April 2020

Research Article

A Relative Assessment of the Life-Cycle Costs of Rigid and Flexible Pavement Coatings in Turkey

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(First received 22 January 2020 and in final form 31 March 2020)

(**DOI:** 10.31590/ejosat.678040)

ATIF/REFERENCE: Abut, Y. (2020). A Relative Assessment of the Life-Cycle Costs of Rigid and Flexible Pavement Coatings in Turkey. *European Journal of Science and Technology*, (18), 918-926.

Abstract

Choosing pavement type is a challenging and much-debated issue among public authorities. It includes engineering factors such as materials, labor, and long-term performance within the scope of the initial (construction) and life-cycle costs. In recent years, given the significant public expenditure on road construction and rehabilitation processes, the trends in vehicle ownership caused by an increasing need to travel, and the decrease in local resources, concerns have been raised about the efficiency of pavement coating types. To ensure that taxpayers understand the full value of road expenditure, it is important to identify a coating type selection process that seeks to include the most appropriate construction, maintenance, and repair strategies possible. In this study, an LCCA was performed for a 2.2 km–long Roller Compacted Concrete (RCC) test track constructed in Kocaeli city. If asphalt is chosen instead of RCC as the coating preference, the economic factors that may arise at a national scale (in this case, Turkey) are discussed. During the 20-year service period, maintenance, repair, and rehabilitation planning were carried out on the basis of a 30-year analysis period. In terms of initial construction costs, an RCC road is 39.4% more economical than an asphalt road and provides maintenance and repair economies of 62% during the service period. In terms of life-cycle costs, an RCC road is a 46% more economical paving alternative than an asphalt road. Although the first serious maintenance activity was carried out in the 10th and 20th years of the asphalt road, it was significant that it only took place during the 20th year for the RCC road, and the asphalt maintenance material was more expensive than that for the RCC road.

Keywords: Life cycle cost analyses; Concrete pavement; Asphalt pavement; Salvage value; Pavement type.

Türkiye'de Rijit ve Esnek Üstyapı Kaplamalarının Yaşam Döngüsü Maliyetlerinin Karşılaştırmalı Bir Değerlendirmesi

Öz

Kaplama tipinin seçimi kamu yetkilileri arasında zorlu ve tartışmalı bir konudur. Bu süreç, başlangıç (inşaat) ve yaşam döngüsü maliyetleri kapsamında malzeme, işçilik ve uzun vadeli performans gibi mühendislik faktörlerini içermektedir. Son yıllarda, yol yapımı ve rehabilitasyon süreçlerine harcanan önemli kamu giderleri, artan ulaşım talebinden kaynaklanan araç sahipliği eğilimleri ve yerel kaynaklardaki azalma göz önüne alındığında, kaplama tiplerinin etkinliği konusu tartışılmaya başlanmıştır. Vergi mükellefi olan halkın, yol harcamalarının tam değerini anlayabilmelerini sağlamak için, mümkün olan en uygun inşaat, bakım ve onarım stratejisini hedefleyen bir kaplama tipi seçim sürecinin belirlenmesi önemlidir. Bu çalışmada Kocaeli ilinde inşa edilen 2,2 km uzunluğundaki Silindirle Sıkıştırılmış Beton (SSB) test yolu için bir yaşam döngüsü maliyet analizi yapıldı. Kaplama tercihi olarak SSB yerine asfalt seçilirse, ulusal ölçekte (bu çalışmada Türkiye) ortaya çıkabilecek ekonomik faktörler tartışılmıştır. 20 yıllık hizmet süresi boyunca, bakım, onarım ve rehabilitasyon planlaması 30 yıllık analiz periyoduna göre gerçekleştirilmiştir. İlk inşaat maliyeti açısından SSB yolun, asfalt yoldan %39,4 daha ekonomik olduğu ve servis süresi boyunca da %62 oranında bakım ve onarım ekonomisi sağladığı tespit edilmiştir. Yaşam döngüsü maliyetleri açısından ise SSB yolun asfalt yoldan %46 daha ekonomik bir kaplama tercihi olabileceği belirlenmiştir.

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Bu durumun ortaya çıkmasında, ilk ciddi onarım faaliyetinin asfaltta 10. ve 20. yılda yapılmasına karşın, SSB kaplamada bu faaliyetin sadece 20. yılda gerçekleşmesi ve asfalt bakım malzemesinin SSB bakım malzemesinden daha pahalı olması etkili olmuştur.

Anahtar Kelimeler: Yaşam döngüsü maliyet analizleri; Beton kaplama; Asfalt kaplama; Kurtarma değeri; Kaplama tipi.

1. Introduction

The choice of coating type is a challenging and much-debated issue among public authorities. It includes engineering factors such as materials, labor, and long-term performance within the scope of the initial (construction) and life-cycle costs. In recent years, given the significant public expenditure on road construction and rehabilitation processes, the trends in vehicle ownership caused by an increasing need to travel, and the decrease in local resources, concerns have been raised about the efficiency of pavement coating types. To ensure that taxpayers understand the full value of road expenditure, it is important to identify a coating type selection process that seeks to include the most appropriate construction, maintenance, and repair strategies possible. This process is important for determining the equivalence of pavement design, life-cycle cost analysis (LCCA), transparency, and, most important of all, the benefits of healthy competition between pavement construction (concrete and asphalt road) authorities [1].

In 2011, the Transportation Research Board published its Pavement-Type Selection Guide under the National Cooperative Highway Research Program Project 10-75 [2]. This document provides a comprehensive set of procedures by means of which highway agencies are able to develop pavement-type selection policies and processes. According to the guide, the main objective of which is to provide the maximum benefit in the long run for both road users and taxpayers, economic indicators and engineering and environmental factors need to be addressed carefully and rationally. Through the LCCA, a period should be considered within a framework that leads to factors such as appropriate discount rates and management of user costs. The guide also states that an alternative screening matrix should be used to assess economic factors. If the analysis of these factors does not produce a clear choice, alternative proposals should be used for other projects with equivalent performance. If a significant period of time has occurred between the agreed pavement type and the bid price, the selected pavement type should be reviewed to ensure that the conditions and costs do not change significantly. In order to maximize economic value, other alternatives that encourage competition and include innovative approaches should be considered [3].

In other studies, Z. Guo et al. examined the suitability of flexible coatings for the design and construction of more economical and durable materials. They have determined the construction of the pavement by using the coating management system to assess the life-cycle costs of permanent and conventional semi-rigid coatings in China [4]. T. Ding et al. carried out a comprehensive and systematic survey of the most appropriate strategic decision about the road's Life Cycle Cost Analysis (LCCA). In the study, a certain section of Guangshao Freeway was taken as an example and data such as pavement performance, traffic and climate conditions, economic indicators were used [5]. In another study, J Santos et al. proposed a new LCCA system developed to help pavement designers choose the best pavement structure for the road or highway[6]. X. Zheng et al. carried out an exemplary study of thin hot mix asphalt concrete layer (THMACO), hot mix asphalt with hot mix additive Sasobit (HMAW) and recycled asphalt pavement and hot mix asphalt (HMAR) in Southeast China. The results showed that HMAR should be preferred for the best economic and social performance and HMAW for the best environmental performance [7].

In this study, an LCCA was performed for a 2.2 km–long Roller Compacted Concrete (RCC) test track constructed in Kocaeli city. If asphalt is chosen instead of RCC as the coating preference, the economic factors that may arise at a national scale (in this case, Turkey) are discussed. Other comprehensive engineering data (material properties, mix and structural design, and road construction) have also been reported in other studies [8,9]. During the 20-year service period, maintenance, repair, and rehabilitation planning were carried out on the basis of a 30-year analysis period. The economic indicators are based on the expenditures made by the Kocaeli Metropolitan Municipality (KMM) for the construction and repair of the roads, which are developed according to a five-year strategic plan.

2. Material and Method

2.1. Analysis Period and Performance

Given the considerable economic constraints and increased infrastructure needs, road construction companies may not always have the opportunity to further their infrastructure investments. In the last 50 years, competition between road construction companies, as accepted and documented in the guidelines for the choice of pavement type, can make a significant contribution.

In order to examine the validity of competition in the pavement sector, taking into consideration the variations in highway agency offer costs with pavement type from 45 state databases (average five-year pavement cost), the combined use of asphalt and concrete pavement types showed better economic indicators than the use of asphalt pavement alone [1]. Regardless of the LCCA or the adoption of the latest pavement design tools, the analysis showed that in the states where both pavement types were constructed regularly, qualified staff and healthy industries developed, construction quality was improved, and lower cost alternatives were found. However, after developing life-cycle strategies for equivalence, the LCCA of each alternative should be determined and then compared. Here, it is important that realistic data for the pavement performance and analysis period be used, as well as annual real discount rates and real or relative price changes for inflation rates for different materials.

The term "analysis period" refers to the period during which costs are assessed. The LCCA period should be sufficient to reflect the long-term cost differences associated with design strategies and long enough to include at least one rehabilitation activity for each alternative [10]. Figure 1 shows the predicted analysis time for a pavement design.

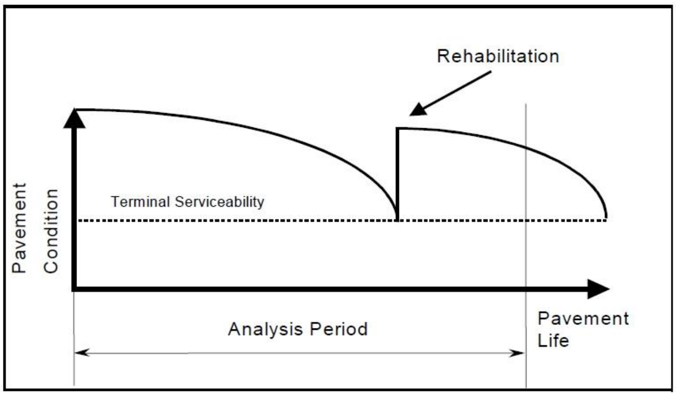

Figure 1. Analysis period for pavement design alternatives [6]

According to the LCCA document reported in [6], an analysis period of at least 35 years is recommended for all pavement projects, including the rehabilitation and reconstruction process. In some rehabilitation alternatives, shorter analysis periods may be appropriate, such as 10 years. It is possible to simplify activities provided that deviations from the recommended analysis period are minimal [6]. AASHTO [7] provides Recommendations for the selection of the analysis period by pavement type, shown in Table 1.

Table 1. Recommended analysis periods [11]

Highway Conditions	Analysis Period (Years)
High-volume urban roads	30-50
High-volume rural roads	20-50
Low-volume paved roads	15-25
Low-volume aggregate surface	10-20

Rehabilitation periods are quite vague and have a great impact on the outcome of an LCCA. Figure 2 shows the performance curves of two different rehabilitation alternatives. Alternative A refers to a long-term strategy implemented in a 15-year cycle, while Alternative B refers to minimal activities that are likely to occur in a five-year cycle [6]. As can be seen from Figure 2, performance levels vary for different rehabilitation strategies. This fluctuation in pavement performance may create differences in vehicle operating costs. Extensive research has been carried out on determining inputs into rehabilitation activities and determining the expected lifetimes of pavement [12,13]. The project period of reconditioning and rehabilitation are important factors in calculating user costs [14,15].

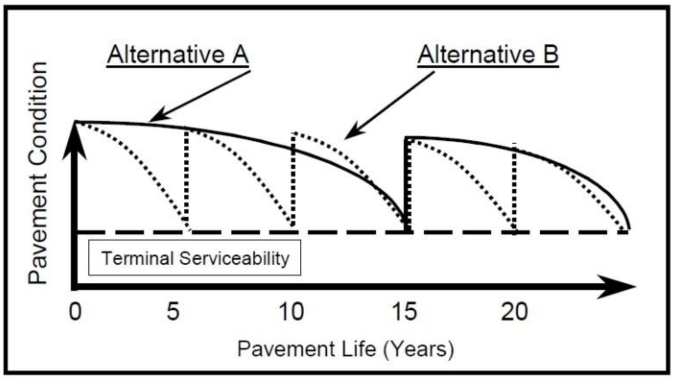

Figure 2. Performance curve versus rehabilitation strategy [6]

At the end of the analysis period, the residual and salvage values of the factors, along with their effective life, should be calculated [16]. If there are differences in the remaining pavement life at the end of this period, these differences should be taken into consideration in the back-calculation analysis. For example, if the remaining life of Alternative A is 10 years and the life of Alternative B is 5 years, failure to consider the salvage value in the LCCA may result in the unfair elimination of Alternative B. According to [6], the final rehabilitation costs can be obtained by multiplying by the percentage of design life remaining at the end of the analysis period. Figure 3 shows the different rehabilitation costs over a long-term overlay and the salvage value remaining at the end of the analysis period.

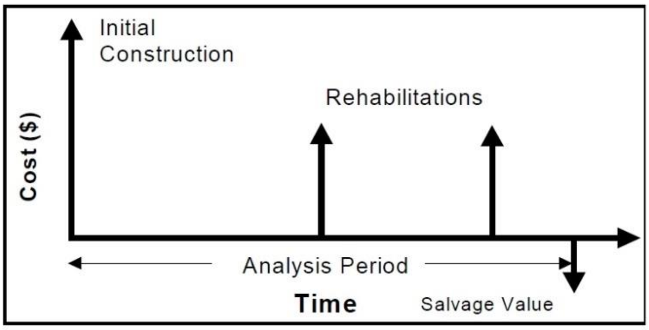

Figure 3. Typical expenditure stream diagram for a pavement design alternative [6]

Such diagrams help visualize initial construction, rehabilitation activities, and, in some cases, salvage value schedules. Typically, costs are shown upward and useful costs, such as salvage value, are shown downward. Discount rate is an important factor in life-cycle cost and can have significant effects on results. When analyzing long-term public investments, discount is an important factor in comparing costs that arise at different times [12]. Since time has a measurable tangible value, the future monetary value is less than the current monetary value. Therefore, the costs and benefits dealt with at different times and points should be transformed into a common point.

2.2. A Comparative LCCA Assessment

Although concrete roads have not been sufficiently adopted by the Turkish General Directorate of Highways (KGM), they are still being constructed by some municipalities and are increasingly common. Consequently, real costs have been obtained for pavement types and the competition between two industries has resulted in outcomes that are more efficient.

Turkish Cement Manufacturers' Association (TCMA), reported that in terms of initial construction costs, the RCC road network, which is the responsibility of local municipalities, costs about the same as concrete paving-blocks (4.14 $\$/m^2$); it is also 38% more economical than asphalt road and 44% more expensive than an aggregate-surface course [17]. In this analysis, for comparison of the cost of coating, the most important material item is the type of binder, since aggregate is common in both mixture contents [13]. Bitumen, obtained by refining raw oil, reflects the fluctuating financial conditions over long periods of time, increasing the volatility in asphalt prices. Because the asphalt industry dominates the road construction sector, meaning that there is a lack of competition at the desired level between these two industries in Turkey, economic indicators, such as the long-term characteristics of construction and rehabilitation activities, are not adequately discussed.

In this part of the study, after the initial construction cost analysis for the RCC test track, a comparison with the asphalt paved road was made. In the LCCA, where the discount rate was taken as 4%, in accordance with [6], for both pavement-types the analysis period was accepted as 30 years, and the service life was 20 years, in accordance with AASHTO [7]. For the two pavement types, three different categories of repair were planned within the analysis period: routine repair, periodic repair, and rehabilitation. The construction and repair costs were based on the Turkish General Directorate of Highways (KGM) unit prices. *Equation (1)* was used to convert future repair costs to current values, and *Equation (2)* was used to calculate the salvage value.

$$PW = F\left(1/(1+i)^n\right)n \tag{1}$$

$$SV = C \times (RL/DL) \tag{2}$$

Where,

PW *: Present worth, ($)* is the net discounted monetary present value of future cash flows i.e. costs (e.g. maintenance or preservation costs) minus future benefits (e.g. residual value).

F *: Future construction cost, ($)* is associated with the construction and operation of a building over a period of time.

i : *Discount rate, (%4)* is the interest rate that balances the money value of time for the investor.

n : *Number of years from year zero, (year*) is the period during which LCCA activities are evaluated.

SV *: Salvage value, ($)* is the term "remaining service life" (RSL) or it can also be taken as the percentage of initial pavement construction cost.

C *: Last cycle construction cost, ($)* is a sum of costs of operation and facility over a time of last maintenance or rehabilitation activity.

RL *: Remaining service life, (year)* is a residual life when the analysis period expires.

DL *: Last cycle design life, (year)* is remaining life after the last maintenance or rehabilitation activity.

3. Results and Discussion

3.1. Initial Construction Cost

The RCC test road project, which was realized with the budget of KMM, was completed at a cost of 7.51 $\$/m^2$. The impact of construction materials on total costs is given in Figure 4 as a percentage. It can be seen from this graph that concrete paving at 32% and Plant-Mix Base (PMB) laying at 24% constitute the two highest expenses of the total cost. The lack of reinforcement and molds in the RCC process are the most important factors in the economic efficiency of paving. It should also be noted that economic benefits, such as opening the road to traffic earlier and faster construction per unit time, are not included in Figure 4 in the comparison with traditional concrete pavements. The initial construction cost analysis of the RCC and asphalt pavements by KMM in the last two years is given in Figure 5. According to these analyses, the initial construction cost of the RCC test road, constructed for the first time in Kocaeli, is 39.4% more economical than that of the asphalt road.

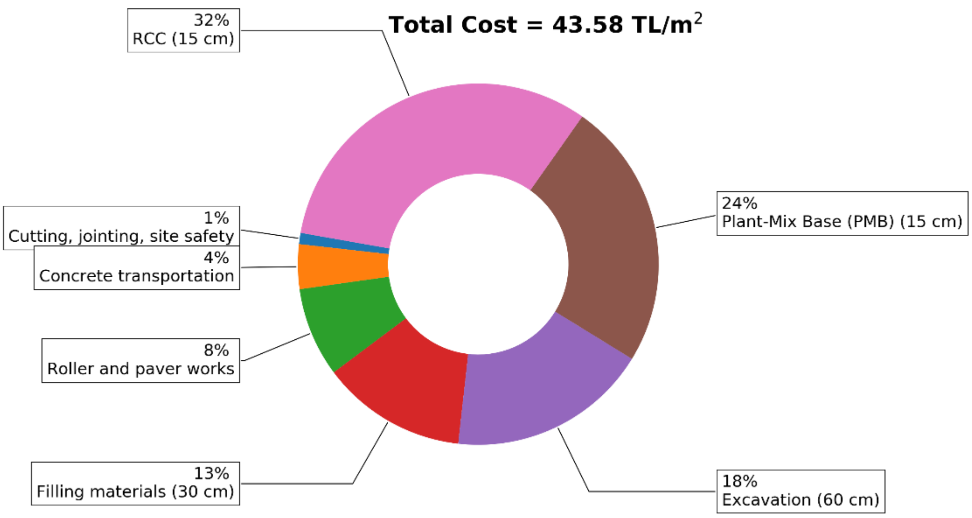

Figure 4. Percentages of costs by activity of RCC construction

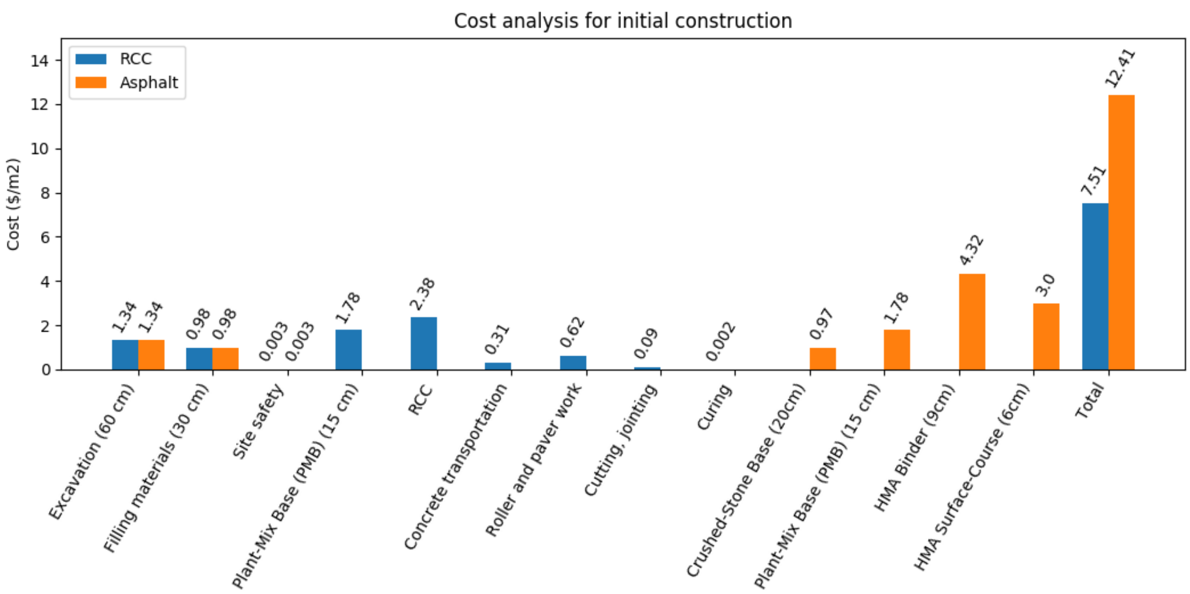

Figure 5. Cost analysis for initial construction

3.2. LCCA

In order to produce equivalent prices, budgets to be allocated for future maintenance and repairs in the LCCA need to be determined for current conditions. In addition to the initial construction cost, maintenance and repair planning was carried out for the asphalt and concrete pavements, and possible costs per activity occurring during the analysis period were expressed as a percentage in Table 2. In order to estimate the LCCA of different pavement types and make comparative cost estimates, it is necessary to determine the time of repair activities, but also to know their types, quantities and their service life. The activity period and quantity of repair activities for pavement types can be estimated according to some probability data or past experiences [18,19]. In this study, each activity period and quantity given in Table 2 were determined based on past maintenance or repair experiences in metropolitan projects in Turkey.

Table 2. Planned maintenance and repair strategy within the analysis period

Activity	Activity Period	Quantity (%)	Damage Type And Repair Method	Unit Price ($/m^2)
RCC				
Routine Maintenance	Once a year	50	*Crack Filling (Bitumen or Epoxy Resinous)* Non-structural low and medium cracks Partial damages in joints	0.28
Periodic Maintenance	Once in 10 years	15	*Local Repair with Fresh Concrete* Blowups in joints Pumping effect in joints Pothole Polished aggregate Popouts Scaling Spalling Longitudinal and transverse cracks greater than 10 mm Corner cracks	8.58
Rehabilitation	Once in 20 years	10	*Full-depth New Surface Coating* Sitting or separating blocks Durability (D) cracks Crocodile cracks Horizontal or vertical erosion	8.58
ASPHALT				
Routine Maintenance	Once in 2 years	5	*Crack Filling (Bitumen)* Transverse crack Longitudinal crack Block crack Reflective crack	0.28
Periodic Maintenance	Once in 3 years	5	*Patching with Asphalt* Crocodile cracks Bleeding or rutting Pothole Shoving *Thin Surface Coating* Polished aggregate Ravelling	12.97
Rehabilitation	Once in 10 years	15	*Full-depth New Surface Coating* Significant structural damages	12.97

After determining the maintenance and repair strategy for both pavement types in the 30-year analysis period, the LCCA of the expenditures that are likely to be realized by year is given in Table 3. The graphs showing the change in expenditures for the activities over the years and the first construction, maintenance, repair, and life-cycle cost comparison between the two pavements are given in Figure 6, in which the gray columns show the benefit costs (1 dollar = 5.80 Turkish Liras).

Table 3. LCCA

Year	Activity	Unit Price ($/m²)	Quantity (%)	Future Construction Cost (F) ($/m²)	Present Worth (Pw) ($/m²)
			RCC		
0	Initial Construction Cost			7.51	7.51
3	Routine Maintenance	0.28	50	0.14	0.12
6	Routine Maintenance	0.28	50	0.14	0.11
9	Routine Maintenance	0.28	50	0.14	0.10
10	Periodic Maintenance	8.58	15	1.29	0.87
12	Routine Maintenance	0.28	50	0.14	0.09
15	Routine Maintenance	0.28	50	0.14	0.08
18	Routine Maintenance	0.28	50	0.14	0.07
20	Rehabilitation	8.58	10	0.86	0.39
21	Routine Maintenance	0.28	50	0.14	0.06
24	Routine Maintenance	0.28	50	0.14	0.05
27	Routine Maintenance	0.28	50	0.14	0.05
30	Periodic Maintenance	8.58	15	1.29	0.40
Salvage Value (SV)				-0.43	-0.13
LIFE CYCLE COST ($/m²)					**9.76**
			ASPHALT		
0	Initial Construction Cost			12.41	12.41
2	Routine Maintenance	0.28	5	0.01	0.01
3	Periodic Maintenance	12.97	5	0.65	0.58
4	Routine Maintenance	0.28	5	0.01	0.01
6	Periodic Maintenance	12.97	5	0.65	0.51
8	Routine Maintenance	0.28	5	0.01	0.01
9	Periodic Maintenance	12.97	5	0.65	0.46
10	Rehabilitation	12.97	15	1.94	1.31
12	Periodic Maintenance	12.97	5	0.65	0.40
14	Routine Maintenance	0.28	5	0.01	0.01
15	Periodic Maintenance	12.97	5	0.65	0.36
16	Routine Maintenance	0.28	5	0.01	0.01
18	Periodic Maintenance	12.97	5	0.65	0.32
20	Rehabilitation	12.97	15	1.94	0.89
21	Periodic Maintenance	12.97	5	0.65	0.28
22	Routine Maintenance	0.28	5	0.01	0.01
24	Periodic Maintenance	12.97	5	0.65	0.25
26	Routine Maintenance	0.28	5	0.01	0.00
27	Periodic Maintenance	12.97	5	0.65	0.22
28	Routine Maintenance	0.28	5	0.01	0.00
30	Rehabilitation	12.97	15	1.94	0.60
Salvage Value (SV)				-1.94	-0.60
LIFE CYCLE COST ($/m²)					**18.06**

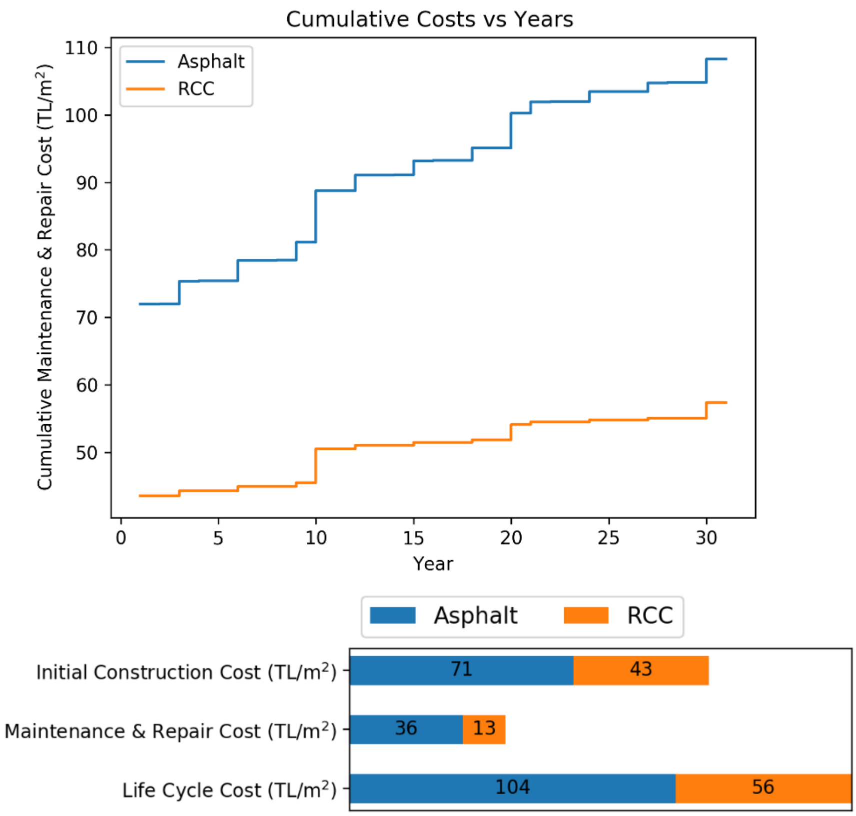

Figure 6. Comparison of life-cycle cost by pavement type

4. Conclusions and Recommendations

Since the salvage value for pavements is defined as a benefit cost, it is assigned a negative value in the LCCA and is calculated using Equation (2) as follows:

$SV_{RCC} = 0.87 \times (10/20) = 0.43\ \$/m^2$

$SV_{ASPHALT} = 1.94 \times (10/10) = 1.94\ \$/m^2$

In terms of initial construction costs, an RCC road is 39.4% more economical than an asphalt road and provides maintenance and repair economies of 62% during the service period. In terms of life-cycle costs, an RCC road is a 46% more economical paving alternative than an asphalt road (Figure 6). There are increasing cost differences over time because maintenance and repair activities on asphalt roads are more frequent. In addition, although the first serious maintenance activity was carried out in the 10th and 20th years of the asphalt road, it was significant that it only took place during the 20th year for the RCC road, and the asphalt maintenance material was more expensive than that for the RCC road.

It may be possible for the public authorities in Turkey to take these maintenance and repair activities into consideration and to transfer these significant maintenance budgets to other sources with the RCC coating preferences, especially in rural areas where infrastructure has been completed. The RCC test track with the KMM budget has shown that these maintenance budgets can be used more effectively thanks to well-designed rehabilitation strategies.

Acknowledgement

I would like to thank Kocaeli Metropolitan Municipality for their valuable contribution to this study.

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