



## Research article

## Evaluating the cost of collection, processing, and application of face masks in hot-mix asphalt (HMA) pavements

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## ABSTRACT

Human activities significantly contribute to the yearly generated plastic wastes. Moreover, the enormous increase in face masks and face shields caused by the emergence of the COVID-19 pandemic has doubled the generated plastic wastes. Although there is an added benefit of using plastic waste in construction, the cost associated with their application, specifically the face mask, has not been addressed. This paper presents a simplified and rapid estimation of the cost associated with the collection, processing, and application of face masks in hot-mix asphalt (HMA) pavements. Two scenarios, mask modified asphalt pavement and conventional asphalt pavement, are considered. The total cost is based on market price and prices from waste management facilities and plastic processing companies. Life Cycle Cost Analysis (LCCA) is used to evaluate the long-term costs of mask modified asphalt pavement and conventional asphalt pavement. Results show that no significant difference in initial total cost between the two scenarios for pavement sections with lengths less than 500m and the number of lanes less than 6. The difference in total cost begins with lengths greater than 500 m for 5 and 6 Lanes. Despite the higher initial costs for the mask modified asphalt pavement, the LCCA shows that there is a 29% maintenance cost reduction over the 40 years life cycle of the asphalt pavement. The use of LCCA shows the benefit of the selection of the most cost-effective strategy and how the use of mask modified asphalt pavement over the conventional asphalt pavement can save money over the life cycle of the asphalt and improve rutting and stiffens.

## 1. Introduction

Human activities have made a significant contribution to the yearly generated and discarded plastic wastes. However, the high expenses of landfilling, and land-space consumption are significant barriers to the waste management. One of the numerous solid wastes threatening the sustainability of our world is plastic waste (Jambeck et al., 2018) and about 300 million metric tons of plastic waste are produced annually (Singh and Sharma, 2017). Additionally, approximately 500 billion plastic bags are used worldwide each year, and based on current statistics, plastic waste disposed of on land and in water is expected to increase to 1.3 billion tons by 2040 (Vuleta, 2022). Besides, plastic pollution affects the natural environment and harms plants, animals, or humans. According to Bai and Sutanto (2002), recycling is the most widely accepted method of plastic waste management and a vital part of sustainable waste management. Despite the recycling of

plastics is considered complex, mechanical, chemical, or thermal recycling of plastic waste is possible (Hahladakis and Iacovidou, 2019; Rahat et al., 2022). Moreover, recycling of plastic waste is a multifaceted process that involves collection, processing, storage, transport, treatment, and application. Waste collection, and transportation operations account for about 70% of total process costs (Greco et al., 2015; Tavares et al., 2009). A proper cost estimation method is essential to calculate the total cost of the process accurately (Huang et al., 2011; Jacobsen et al., 2013).

On the other hand, with the increase of urbanization and population growth, the demand for different infrastructures will increase proportionally (Awoyera et al., 2016). Hence, the use of recycled plastic waste in a variety of construction applications seems to be an efficient approach to address this sustainability problem while also meeting future infrastructure demand. In addition to its effectiveness as a construction material, plastic waste should be affordable and sustainable.

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Additionally, the enormous increase in face masks and face shields caused by the emergence of the coronavirus “COVID-19” pandemic has doubled the generated plastic wastes all around the world (Skrzyniarz et al., 2022). The whole world is facing the problem of COVID-19 pandemic and millions of people died by getting unconscious of using Personal Protection Equipment (PPE) (e.g., Face masks, face shields, hand gloves) (Adyel, 2020; Abedin et al., 2022; Shi et al., 2021; Rowan et al., 2021; Garel and Petit-Romec, 2021). Since the emergence and appearance of COVID-19, labeled a public health emergency of worldwide concern by world health organization (WHO), many nations have taken different precautions and preventions (Al-Jabir et al., 2020; He et al., 2021; Sohrabi et al., 2020). The use of face masks as part of the health campaign against the coronavirus has been so successful that it has become a necessity for global public health initiatives to prevent the spread of the virus (Maderuelo-Sanz et al., 2021; Royo-Bordonada et al., 2020). Though the use of face masks is incredibly needed, disposing them is threatening the environment (Rahman et al., 2022; Boroujeni et al., 2021). Daily, a large amount of waste is generated from the disposal of millions of masks (Benson et al., 2021; Ilyas et al., 2020), and a sharp 20% growth is expected in between 2020 to 2025 (Cai et al., 2022; Morone et al., 2022; Prata et al., 2020).

Littering face masks in parking lots, neighborhood streets, sidewalks, and parks and donning discarded masks may lead to social, environmental, and animal issues (Prata et al., 2020; Saberian et al., 2021). There appears to be a problem of waste in households and medical facilities due to the accumulation of protective clothing and equipment (i.e., gloves, gowns, masks) (Chowdhury et al., 2022; Sarkodie and Owusu, 2020; Ma et al., 2020). Secondary transmission of COVID-19 might be increased if medical and household wastes are not handled properly. Toxic exposure from dumping, open burning, and incineration may have a negative impact on air quality and health (WHO, 2020). Moreover, most face masks are made of polypropylene, which is non-biodegradable materials and will not break down in the environment for several hundred years (Kwak and An, 2021; Dhawan et al., 2019; Henneberry, 2020) causing a solid waste problem in addition to microplastic contamination in marine and freshwater environments (Kilmartin-Lynch et al., 2021; Torres and De-la-Torreb, 2021; Aragaw, 2020).

Since COVID-19 face mask is made of polypropylene, which is plastic and easy to recycle, it can be a good construction substitute material (Saberian et al., 2021; Kilmartin-Lynch et al., 2021; Rahat et al., 2022; Tejaswini et al., 2022). Few studies have conducted on the use of disposable face masks for construction applications and found improvement in the mechanical characteristics of the structures (i.e., base/subbase of pavement, concrete and HMA pavements) (Batayneh et al., 2007; Kilmartin-Lynch et al., 2021; Saberian et al., 2021; Wang et al., 2022). Saberian et al. (2021) found that using 1–2% shredded face masks (SFM) and 99%–98% recycled concrete aggregate (RCA) in pavement base and subbase increase in strength and stiffness of the blends of SFM/RCA; Kilmartin-Lynch et al. (2021) found the improvement of the overall properties of concrete by incorporating SFM in concrete mixture; and Wang et al. (2022) found that using 1.50% of SFM in HMA mixtures rut depth was 0.93mm, which is lower than North Carolina interstate highway specification for rut depth of 4.5mm. Despite using face masks in the construction application improves the performance of infrastructure, no research on either the estimation of the initial costs associated with collection, processing, and application of face masks wastes in asphalt pavement, or the estimation of the long costs over the life cycle of the asphalt pavement is available.

The aim of this study is to simply and rapidly estimate the total cost associated with the collection, processing (i.e., shredding), and application of face mask in HMA pavements for various pavement sections. The total cost is calculated as the addition of three costs: cost of collection, cost of processing, and cost of asphalt mixture preparation. Once the total cost is calculated, it is compared to the total cost for conventional asphalt pavement. A case study considering market price and price from local waste

management facility and plastic processing companies in Greenville, NC are used. Life Cycle Cost Analysis (LCCA) is used to evaluate the long-term costs of mask modified asphalt pavement and the conventional asphalt pavement. Findings show cost of asphalt pavement with any plastic face masks can be simply and rapidly estimated using the methodology developed in this study. Additionally, due the less maintenance cost over the life cycle of 40 years of asphalt pavement, it will be beneficial to use face mask as an additive to the hot mix asphalt for the construction of asphalt pavement.

## 2. Methodology

### 2.1. Total cost

The total cost associated with the application of face mask in HMA-pavement is estimated as three-part costs: Cost of face mask collection ( $C_{FC}$ ), cost of face mask processing ( $C_{FP}$ ) (i.e., shredding), and cost of asphalt preparation with plastic ( $C_{AP}$ ). The cost of face mask collection ( $C_{FC}$ ) is based on prices from the waste management facility, which includes the labor cost required for setting up, pecking up, separation, and sanitization, transportation cost from and to the waste facility, materials cost required for sanitization, and the containers market price. Cost of face mask processing ( $C_{FP}$ ) is based on prices from a plastic processing company, which includes the transportation cost from the waste management facility to the plastic processing company, then from plastic processing company to the asphalt casting yard, and the cost of plastic waste processing. Cost of asphalt preparation with plastic ( $C_{AP}$ ) is based on the total weight of asphalt mixture and face mask modifier required for pavement sections, and the price of asphalt per ton, which will vary depending on the location. The total cost ( $TC$ ) is calculated as summation of the three costs as shown in Eq. (1).

$$TC = (C_{FC} + C_{FP}) * TNc + C_{AP} \quad (1)$$

where,  $C_{FC}$  is the cost of face mask collection,  $C_{FP}$  is the cost of face mask processing,  $TNc$  is the total number of containers, and  $C_{AP}$  is the cost of asphalt preparation.

#### 2.1.1. Cost of face mask collection ( $C_{FC}$ )

The  $C_{FC}$  is given in Eq. (2) shown below:

$$C_{FC} = P_c + C_L + \frac{C_T}{TNc} + C_{Sa} \quad (2)$$

where,  $P_c$  is the market price of waste container,  $C_L$  is labor cost,  $C_T$  is the transportation cost, and  $C_{Sa}$  is the cost of sanitization per container.  $C_L$  is calculated as  $C_L = N_L \times W_L \times t$ , where  $N_L$  is total number of labors required for setting up, picking up, separation and sanitization;  $W_L$  is wage of labor per hour, and  $t$  is the total number of hours.  $C_{Sa}$  is calculated as  $C_{Sa} = N_{Sa} \times P_{Sa}$ , where  $N_{Sa}$  is number of sanitizer bottles used, and  $P_{Sa}$  is unit market price of the sanitizer bottle.

$TNc$  is calculated as  $TNc = \frac{N_{cu}}{W_{cp}} \times W_p$ , where  $N_{cu}$  is number of containers used per cycle, and  $W_{cp}$  the weight of collected face mask per cycle and  $W_p$  is the weight of face mask required for construction. The ratio  $\frac{N_{cu}}{W_{cp}}$  represents total number of containers required to collect face mask per ton so that it is easier to calculate for different HMA pavement sections

#### 2.1.2. Cost of face mask processing ( $C_{FP}$ )

The  $C_{FP}$  is calculated based on the price provided by plastic processing company for each container with additional miscellaneous cost (i.e., fuel, toll) as shown in Eq. (3).

$$C_{FP} = (C_{CON}) + \alpha * (C_{CON}) \quad (3)$$

where,  $C_{CON}$  is cost of processing per container provided by plastic processing company as a package, and  $\alpha$  represents the miscellaneous costs per container, which is a percentage of the cost of processing per container.

2.1.3. Cost of asphalt preparation with plastic ( $C_{AP}$ )

The  $C_{AP}$  is calculated using two scenarios: preparation of HMA with face masks and without face masks as shown in Eq. (4).

$$C_{AP} = (TW_A - W_p) \times P_A \tag{4}$$

where  $TW_A$  is total weight of asphalt,  $W_p$  is the weight of face masks as percentage of  $TW_A$  and  $P_A$  is the price of asphalt paving per ton based on the prices from local asphalt paving companies.  $TW_A$  is calculated as  $TW_A = V_p \times W_A$ , where  $V_p$  is the volume of the asphalt pavement, and  $W_A$  is the unit weight of asphalt per ton.  $V_p$  is calculated as  $V_p = N_L \times L \times w \times T$ , where,  $N_L$  is number of lanes,  $L$  is length of asphalt pavement,  $w$  is width of asphalt pavement,  $T$  is thickness of asphalt pavement.  $W_p$  is calculated as  $W_p = \beta * TW_A$ , where  $\beta$  is the optimum ratio of  $W_p$  to  $TW_A$  that provides the best mechanical performance (e.g., rutting resistance). For the scenario without face masks,  $W_p$  equals zero.

2.1.4. Life cycle cost analysis (LCCA) of asphalt pavements

Life cycle cost analysis (LCCA) is used to evaluate the total present worth cost (TPWC) of asphalt pavement for the analysis period of 40 years. TPWC is calculated for  $j$  activity as shown in Eq. (5).

$$TPWC = \sum_{j=1}^J PWC_j \text{ for } j = 1, 2, 3, \dots, J \tag{5}$$

where  $PWC_j$  is the present worth cost (e.g., initial costs, rehabilitation costs, maintenance costs, residual value) for activity ( $j$ ) considered for the LCCA and is given as shown in Eq. (6)

$$PWC_j = \rho * IFC_j \tag{6}$$

where  $\rho$  is interest multiplier and is given as  $\rho = \frac{1}{(1+i)^y}$ , where  $i$  is interest rate and  $y$  is year when the activity is implemented, and  $IFC_j$  is inflated cost for activity ( $j$ ) and is given as shown in Eq. (7)

$$IFC_j = \gamma * IC_j \tag{7}$$

where  $\gamma$  is inflation multiplier and is given as  $\gamma = (1 + r)^y$ , where  $r$  is inflation rate,  $IC_j$  is initial cost for activity ( $j$ ). For pavement structure activities,  $IC_j$  equals to  $TC$  obtained calculated in Eq. (1). For the other activities (e.g., Rout and seal, mill and patch) and the residual,  $IC_j$  equals to the costs obtained according to normal preservation practices for asphalt pavements (FHWA, 2018).

3. Case study

Local prices obtained from local waste management facility, plastic processing companies, and asphalt construction company in the city of Greenville, NC are used for the application of the methodology. The prices include the containers, labor wage, transportation, sanitization, shredding, and asphalt prices. Table 1 shows the price source for each item considered in the study. Prices are based on four local sources (i.e., Pitt County Solid Waste Management Facility, local Lowes, Shred-It, ST Wooten Asphalt Plant) located in Greenville, NC. Authorities from these facilities were contacted and prices were provided. Container's price,

Table 1. Source of the prices.

Item	Unit Price	Source
95-gallon container	\$50	Pitt County Solid Waste Management
Labor Wage per hour	\$12	
Transportation Cost	\$175	
Sanitizer	\$3	Local Lowes Home Improvement
Shredding Cost	\$100	Shred-It
Asphalt paving cost	\$86	ST Wooten Asphalt Plant

minimum labor wage per hour, and transportation rate were provided by Pitt County Solid Waste Management Facility. Shredding price was provided by shredding company (Shred-It) as a package that includes pick up, preparation, shredding, drop off. Asphalt paving price was provided by a local asphalt plan, ST Wooten Asphalt Plant. Sanitizer price is based on a market price from local Lowes Home Improvement. While these prices may vary based on the geographic location, market price, local rating, and the number and size of the containers, it is recommended to check with the local facilities at the location where the study is taking place.

3.1. Cost of face mask collection

Three collection points are chosen with four large containers of 95 gal (Capacity of 0.40 Tons of masks) at each location resulting in total of 12 containers for this case study. Masks collected from the 12 containers is transformed to the waste management facility for separation and sanitization. The ratio  $\frac{N_{CU}}{W_{CP}}$  represents a total number of 2.5 containers require to collect 1 ton of face masks. For sanitization, one bottle (32 oz) hydrogen peroxide ( $H_2O_2$ ) with 0.5% concentration is applied for each container. Each container takes an average of 1 h to set up, pick and sanitize resulting in total of 12 h. Four labors with \$12/hour wage per labor are used to carry out the process. Based on Eq. (2), cost of mask collection ( $C_{FC}$ ) was calculated using market price of \$50 for a 95-gal container, market price of \$3 for sanitization bottle, \$12/hour wage for labor, and \$175 transportation cost (provided by Pitt County solid waste management facility) for the total of 12 containers, resulting in ( $C_{FC}$ ) equals to \$80 per container. Table 2 shows the cost associated with face mask collection ( $C_{FC}$ ).

3.2. Cost of face masks shredding

To process the face masks for using in the asphalt preparation, shredding is used in this case study. A shredding company, Stericycle/ Shred-it, is contacted to carry out the process of shredding of the disinfected face masks. No labor cost is needed for shredding since the shredding company offered a package that includes the pickup from the recycling center, removal of ear loops and nose strips, shredding of the face masks and transportation to the casting yard. Based on Eq. (3), cost of mask shredding ( $C_{FP}$ ) was calculated using \$100 cost for preparation and shredding per container. Additionally, a miscellaneous cost  $\alpha = 0.08$  per container is considered resulting in  $C_{FP}$  equals to \$108 per container. Table 3 shows the cost associated with face mask shredding ( $C_{FP}$ ).

3.3. Cost of asphalt preparation with face masks

$C_{AP}$  is calculated in this case study using two scenarios (pavement structure with face masks and without face masks). To calculate the weight of face masks ( $W_p$ ), value of  $\beta$  equals to 0.015 which is the ratio  $W_p$  to  $TW_A$  that provides the best rutting resistance in hot-mix asphalt mixture (HMA) (Wang et al., 2022). A dry mixing process was used for this study, where face masks were directly added to the mix with coarse and fine aggregate. For scenario without face masks,  $W_p$  equals zero. Based on Eq. (4), multiple costs of  $C_{AP}$  are calculated for various pavement sections. This includes six number of lanes (i.e., 1, 2, 3, 4, 5, 6), four lane lengths (i.e., 100 m, 250 m, 500 m, 1000 m), and fixed lane width and thickness of 3.66 m and 0.05 m, respectively. The asphalt price of \$86 per ton and unit weight of 2.4 ton per cubic meter provided by St. Wooten Corporation are used. Table 4 shows the cost associated with asphalt preparation ( $C_{AP}$ ) considering face masks as plastic modifier.

3.4. Total cost

$TC$  for the two scenarios (i.e., with and without masks) is calculated by substituting the calculations of Eqs. (2), (3), and (4) in Eq. (1). Table 5

**Table 2.** Cost of face mask collection.

$N_{CU}$	$P_C$	$TP_C$	$N_L$	t (hr.)	$W_L$	$C_L$	$C_T$	$N_{Sa}$	$P_{Sa}$	$C_{Sa}$	$W_{EC}$ (T)	$W_{CP}$ (T)	$N_{CT}$	$C_{PC}$
12	\$50	\$600	4	12	\$12	\$144	\$175	12	\$3	\$36	0.4	4.8	2.5	\$80

\*Note:  $N_{CU}$  = number of containers used per cycle.  
 $P_C$  = market price of container.  
 $TP_C$  = total market price of containers used per cycle.  
 $N_L$  = number of laborers.  
t = total number of hours.  
 $W_L$  = wage of labor per hour.  
 $C_L$  = labor cost.  
 $C_T$  = transportation cost.  
 $N_{Sa}$  = number of sanitizer bottle used.  
 $P_{Sa}$  = price of each sanitizer bottle.  
 $C_{Sa}$  = cost of sanitizer.  
 $W_{EC}$  = weight of masks in each container.  
 $W_{CP}$  = weight of collected masks per cycle.  
 $N_{CT}$  = number of containers require to collect 1-ton masks.  
 $C_{PC}$  = cost of mask shredding per container.

**Table 3.** Cost of mask shredding.

No. of container	Unit cost of preparation and shredding/container	Cost of preparation and shredding	Miscellaneous cost	Mask weight (Ton)	Cost of preparation and shredding per container
12	\$100	\$1200	\$96	4.80	\$108

**Table 4.** Cost of asphalt preparation with face masks.

L(m)	W(m)	T(m)	$V_P$ (m <sup>3</sup> )	$TW_A$ (Ton)	$W_P$ (Ton)	$TW_{EP}$ (Ton)	$TN_C$	$TC_{PC}$	$TC_{PP}$	$P_A$	$C_{APM}$	$C_{APWM}$
1000	3.66	0.05	183	439	7	432	16	\$1,311	\$1779	\$86	\$37,754	\$37,238
500	3.66	0.05	92	220	3	217	8	\$655	\$889	\$86	\$18,920	\$18,576
250	3.66	0.05	46	110	2	108	4	\$328	\$445	\$86	\$10,074	\$9,460
100	3.66	0.05	18	44	1	43	2	\$131	\$178	\$86	\$3,784	3,698

\*Note: L = length of pavement section.  
W = width of pavement section.  
T = thickness of pavement section.  
 $V_P$  = volume of pavement section.  
 $TW_A$  = total weight of asphalt.  
 $W_P$  = total weight of masks.  
 $TW_A$  = total weight of asphalt excluding masks.  
 $TN_C$  = total number of containers.  
 $TC_{PC}$  = total cost of masks collection.  
 $TC_{PP}$  = total cost of masks processing.  
 $P_A$  = price of asphalt per ton.  
 $C_{APM}$  = cost of asphalt preparation with masks.  
 $C_{APWM}$  = cost of asphalt preparation without masks.

**Table 5.** Total pavement structure cost with and without face masks for different pavement sections.

No of Lanes	$TC_{WM}$ (1000m)	$TC_M$ (1000m)	$TC_{WM}$ (500m)	$TC_M$ (500m)	$TC_{WM}$ (250m)	$TC_M$ (250m)	$TC_{WM}$ (100m)	$TC_M$ (100m)
1	\$37,771	\$40,844	\$18,886	\$20,464	\$9,443	\$10,847	\$3,777	\$4,029
2	\$75,542	\$81,688	\$37,771	\$40,928	\$18,886	\$21,694	\$7,554	\$8,058
3	\$113,314	\$122,532	\$56,657	\$61,392	\$28,328	\$32,541	\$11,331	\$12,087
4	\$151,085	\$163,376	\$75,542	\$81,856	\$37,771	\$43,388	\$15,108	\$16,116
5	\$188,856	\$204,220	\$94,428	\$102,320	\$47,214	\$54,235	\$18,886	\$20,145
6	\$226,627	\$245,064	\$113,314	\$122,784	\$56,657	\$65,082	\$22,663	\$24,174

\*Note:  $TC_{WM}$  = total cost without masks.  
 $TC_M$  = total cost with masks.

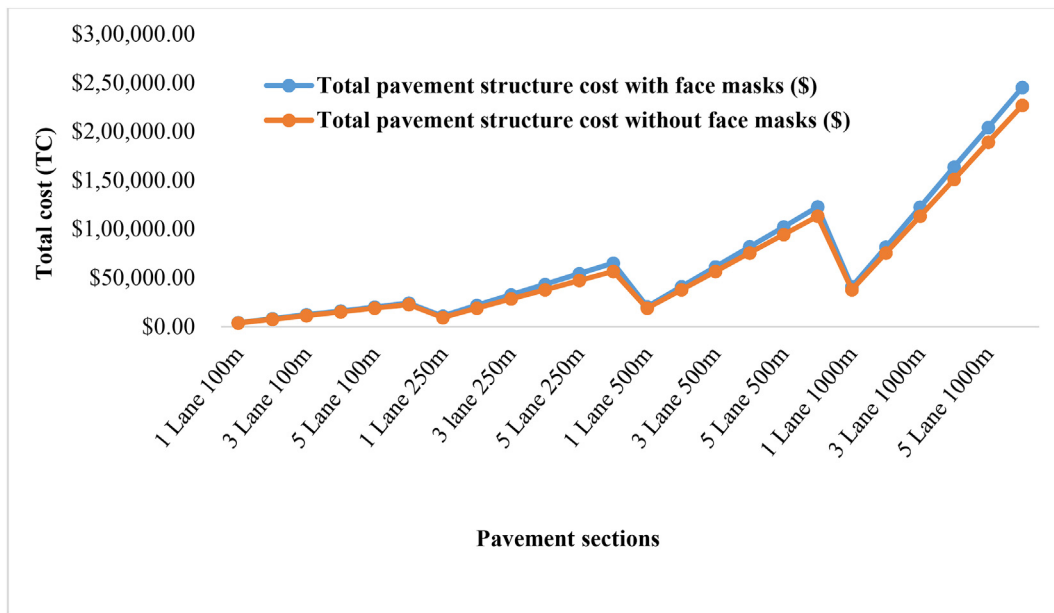


Figure 1. Total cost of multiple pavement sections considering the two scenarios.

shows the total cost (TC) for different pavement sections considering two scenarios, with and without face masks.

Figure 1 shows TC for the two scenarios for number of lanes of 1, 2, 3, 4, 5 and 6, lengths of 100 m, 250 m, 500 m and 1000 m, and width and thickness of 3.66 m and 0.05 m, respectively.

There is no large difference in TC for both scenarios for pavement sections with lengths of 100m, 250m, and 500m for the number of lanes 1, 2, 3, 4, and 5. However, a small deviation in TC demonstrating higher TC with face masks than without face masks begins at section 6 Lane 250m and increases at sections 5 Lane 500m, 6 Lane 500m, 5 Lane 1000m and, and 6 Lane 1000m, respectively. Although TC with face mask is slightly higher at larger sections, it is expected that less maintenance will be required for the pavement constructed with facemasks because adding 1.5% of SFM to the hot-mix asphalt mix allowed lowest level of rutting (Wang et al., 2022).

### 3.5. Life cycle cost analysis (LCCA)

In assessing long-term investment options, life cycle cost analysis is frequently used to assess costs throughout the life cycle of the investment. In addition to considering probable costs throughout the life of each pavement option, the method is deemed fair and balanced. This is because it determines which of the several pavement options will provide the greatest value in the long run (Gu and Tran, 2019). For the case study, LCCA is used to evaluate the long-term costs of mask modified asphalt pavement and the conventional asphalt pavement. For the LCCA analysis, 1-lane 1000m asphalt pavement is considered to evaluate the cost benefit between face mask pavement and conventional pavement. Table 6 shows activities (i.e., Pavement structure, rehabilitation, maintenance) and initial costs required for the life cycle analysis. Since previous study has shown that the rutting and stiffens are improved by using face mask as an additive to the HMA (Wang et al., 2022), the associated maintenance costs are not considered. Based on normal preservation practices for asphalt pavements (FHWA, 2018), pavement rehabilitation 50 mm milling and 50 mm resurfacing costs are used, for first and second maintenance 125 mm rout and seal coat are used for transverse and centerline crack, and for third maintenance 40 mm milling and 40 mm patch costs are assumed for 5% of the total pavement surface. The LCCA is conducted for a 40 years of analysis period considering 4.75% interest, and 7% of inflation rate.

Table 6. Life cycle analysis activities and initial costs.

Phases	Activities	Initial costs (\$/lane-km)
Pavement structure		
	Mask modified asphalt pavement	\$40,844
	Conventional asphalt pavement	\$37,771
Rehabilitation		
	Mill 50 mm and resurface 50 mm	
	Mask modified asphalt pavement	\$54,700
	Conventional asphalt pavement	\$50,700
Maintenance		
First		
	Rout and seal 125 m of transverse cracks	\$750.00
	Rout and seal 125 m of centerline cracks	
Second		
	Rout and seal 250 m of transverse cracks	
	Rout and seal 125 m of centerline cracks	\$1,150.00
Third		
	Mill 40 mm and patch 40 mm (5% of area)	\$2,660.00

Tables 7 and 8 show the present worth costs of mask modified asphalt pavement, and conventional asphalt pavement for 40 years, where the total present worth cost after 40 years is \$58,979.30 and \$83,335 for mask modified and conventional asphalt pavement, respectively. Despite the higher initial costs for the mask modified asphalt pavement, it is clear that an amount of \$24,355.70 will be saved over the life cycle of asphalt pavement. Therefore, the added benefits of using masks modified asphalt pavement are higher than those of conventional asphalt pavement.

## 4. Conclusions and recommendations

A simplified and rapid estimation of TC associated with collection, processing and application of face mask in asphalt pavement was developed. LCCA of using the face mask were also investigated over 40 years life cycle of pavement. The detailed methodology for the calculation of the total cost and a simplified not in-depth methodology for the LCCA were explained. TC was calculated for different pavement sections considering two scenarios, with and without face masks. The results

**Table 7.** Total present worth cost for mask modified asphalt pavement.

$y$	$j$	Activity	$IC_j$	$\gamma$	$IFC_j$	$\rho$	$PWC_j$	
0	1	Pavement structure	\$40,844.00	1.00	\$40,844.00	1.00	\$40,844.00	
10	2	Rout and seal	\$750.00	1.96	\$1,470.00	0.63	\$926.10	
15	3	Rout and seal	\$1,150.00	2.75	\$3,162.50	0.50	\$1,581.25	
21	4	Mill and patch	\$2,660.00	4.14	\$11,012.40	0.38	\$4,184.71	
32	5	Mill and resurface	\$54,700.00	8.72	\$476,984.00	0.23	\$109,706.32	
40	6	Residual value	-\$41,025	14.97	-\$614,144.25	0.16	-\$98,263.08	
							<i>TPWC</i>	\$58,979.30

**Table 8.** Total present worth cost for conventional asphalt pavement.

$y$	$j$	Activity	$IC_j$	$\gamma$	$IFC_j$	$\rho$	$PWC_j$	
0	1	Pavement structure	\$37,771.00	1.00	\$37,771.00	1.00	\$37,771.00	
5	2	Rout and seal	\$750.00	1.40	\$1,050.00	0.79	\$829.50	
10	3	Rout and seal	\$750.00	1.96	\$1,470.00	0.63	\$926.10	
15	4	Mill and patch	\$2,660.00	2.75	\$7,315.00	0.50	\$3,657.50	
20	5	Rout and seal	\$1,150.00	3.87	\$4,450.50	0.40	\$1,780.20	
25	6	Mill and resurface	\$50,700.00	5.43	\$275,301.00	0.31	\$85,343.31	
35	7	Rout and seal	\$750.00	10.68	\$8,010.00	0.20	\$1,602.00	
40	8	Residual value	-\$20,280.00	14.97	-\$303,591.60	0.16	-\$48,574.66	
							<i>TPWC</i>	\$83,335.00

reveal that the difference in TC is not significant between the two scenarios for pavement sections with lengths less than 500m and number of lanes less than 6. The difference in TC begins for 5 and 6 Lanes with lengths greater than 500 m. The LCCA indicates that there is a 29% maintenance cost reduction over the 40 years life cycle of the asphalt pavement. This reduction is a result of rutting and stiffens improvement. Therefore, the LCCA results suggest that using facemask as a modifier in HMA is economically more efficient than the conventional asphalt. However, LCCA presented in this study is not performed in-depth and does not consider changes in design, construction, materials that are intended to improve the environmental or societal impacts of a pavement project. Additionally, it does not account for the variability in initial costs over time or the uncertainty in the timing and costs of planned maintenance and rehabilitation activities. The results and conclusions presented in this study can not be generalized to other plastic types or distress. Therefore, a more in-depth life cycle cost analysis is needed. This includes exploring the previous issues, the chemical, physical, and mechanical performances of the face mask in the asphalt pavement for long and short terms, and accounting for variability and uncertainty in the initial costs and costs of maintenance and rehabilitation. Consideration of other distress (e.g., block cracking, longitudinal cracking, edge cracking, top-down cracking, moisture damage) and other plastic wastes is encouraged and needed to validate the results of this study and to give insight on the short- and long-term costs for pavement section under different distress and plastic types.

## Declarations

### Author contribution statement

Carol Massarra; Md. Hasibul Hasan Rahat: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

George Wang; Husam Sadek: Conceived and designed the experiments; Analyzed and interpreted the data.

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### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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