AF2901 Road and Railway Track Engineering

Life Cycle Cost Analysis

Iman Mirzadeh

Highway and Railway Engineering
Department of Transportation Science

Background

- A process for evaluating the total economic worth of a useable project segment by analyzing initial costs and discounted future costs, such as resurfacing costs, over the life of the project

- The concept was introduced in the 1930s as part of U.S. federal legislation regarding flood control

- From the beginning of 1950s it has begun to be used for the evaluation of highway projects

Fundamental concepts

- The value of money today and money that will be spent in the future are not equal.
  - This concept is referred to as the "time value of money".

- The time value of money results from two factors: (1) inflation, which is erosion in the value of money over time, and (2) opportunity cost.

- For cash or existing capital, opportunity cost is equivalent to the benefit the cash could have achieved had it been spent differently or invested. For borrowed money, opportunity cost is the cost of borrowing that money (e.g., the loan rate).

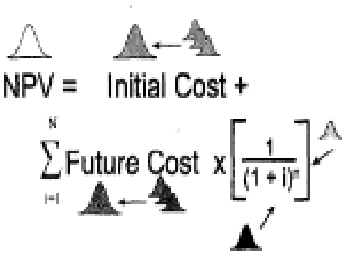
Fundamental concepts

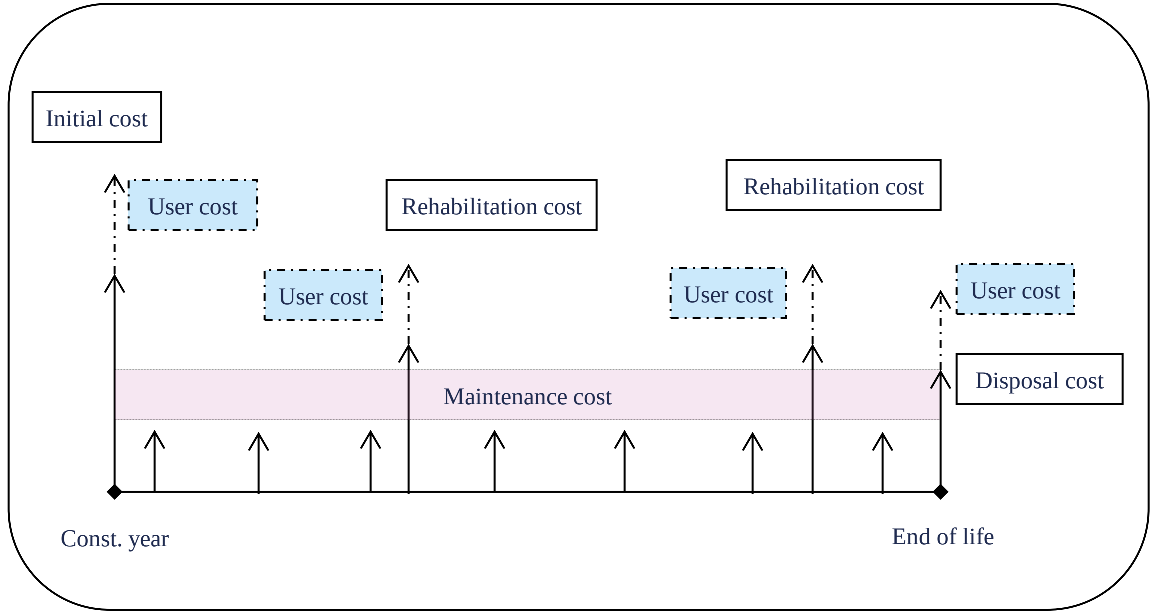
- Inflation reduces the value or purchasing power of money over time

- It is the result of the gradual increase in the cost of goods and services due to economic activity

$$\text{Dollars}_{\text{base year}} = \text{Dollars}_{\text{data year}} \times \frac{\text{Price Index}_{\text{base year}}}{\text{Price Index}_{\text{data year}}}$$

Net Present Value





$$NPV = Initial\ Cost + \sum_{n=0}^{L} \frac{Rehab\ Cost_n}{(1+i)^n} + Annual\ Operating\ Cost \times \frac{(1-(1+i)^{-n})}{i}$$

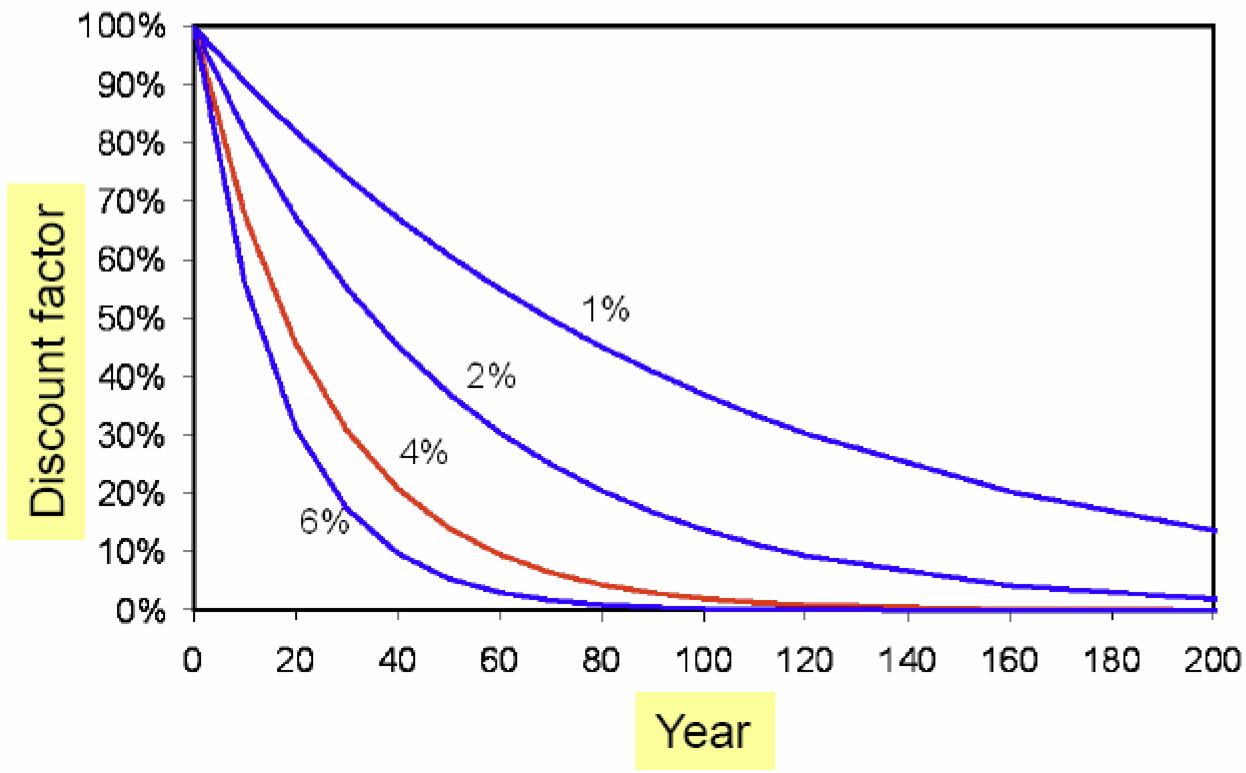
$$EAC = NPV \times \frac{i}{1-(1+i)^{-n}}$$

Discount factor

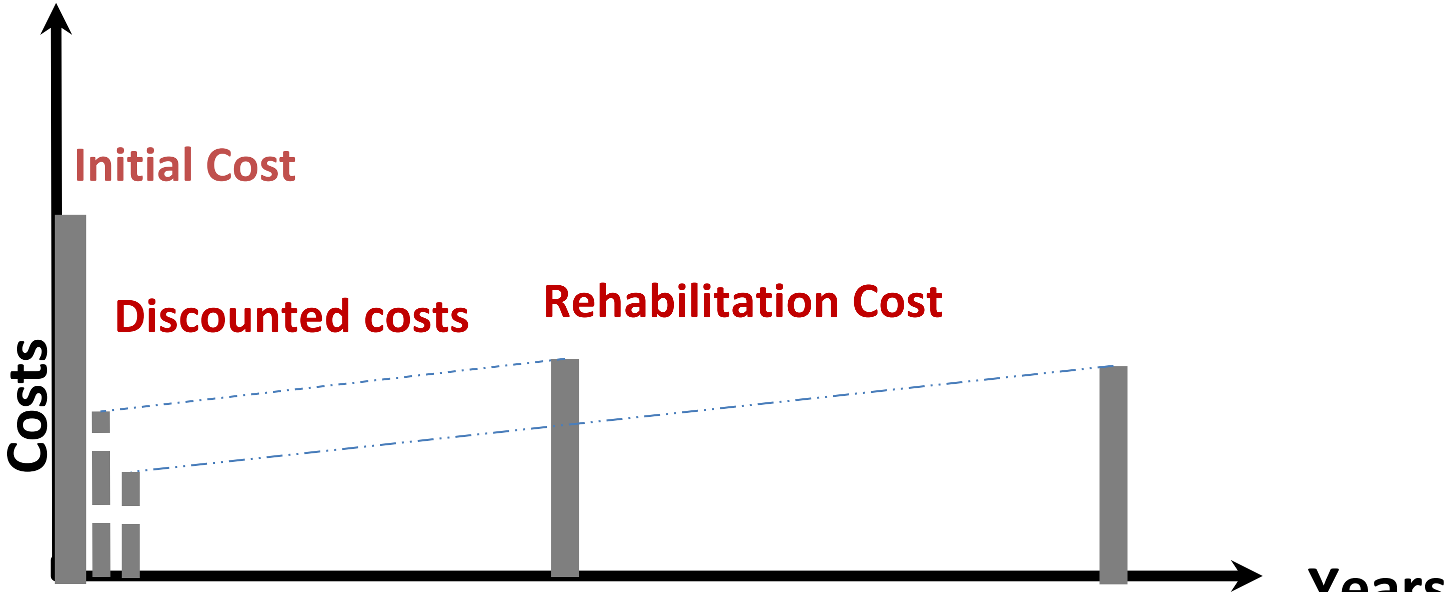
$$NPV = Value \cdot \frac{1}{(1+r)^n}$$

where
r = rate of return
n = number of years

Discount factor (DF)



Net Present Value



$$r = \frac{1 + i}{1 + j} - 1$$

where:

Discount	=	calculated discount rate,
interest	=	expected interest rate, and
inflation	=	expected inflation rate.

Pavement LCC

- Costs for Production, Transportations, Laying

Const. Agency

- Costs for Production, Transportations, Milling, Remixing, Laying

Rehab. Agency

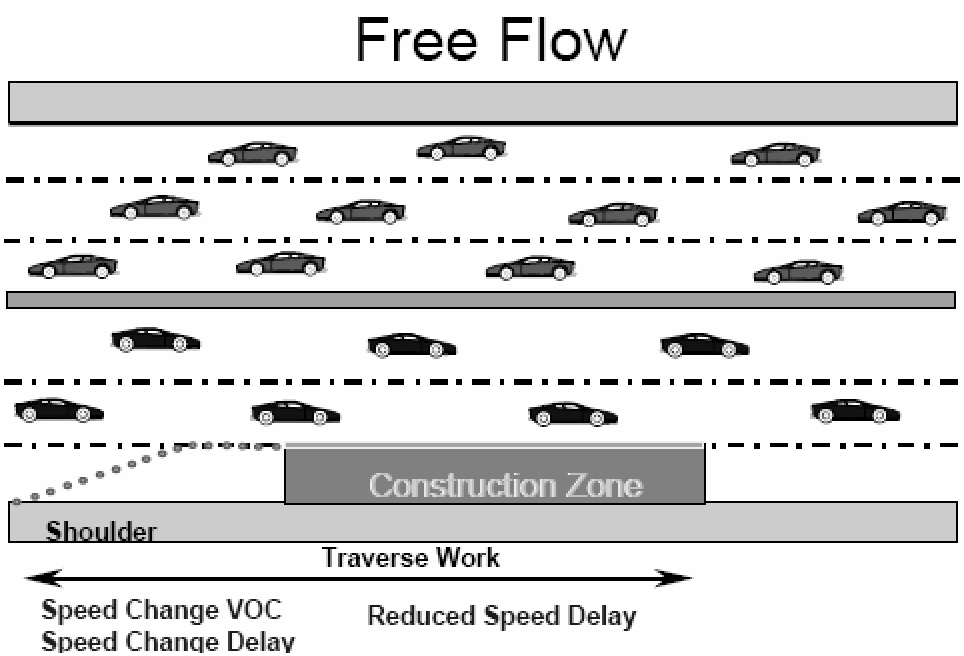
- Costs Related to Delay , and Energy Consumption, …

Road Users

Road user costs

- For early construction completion, maintenance and rehabilitations
- Delay-of-use
- Time delay
- Fuel consumption
- Driver discomfort
- Vehicle operating costs
- Accidents

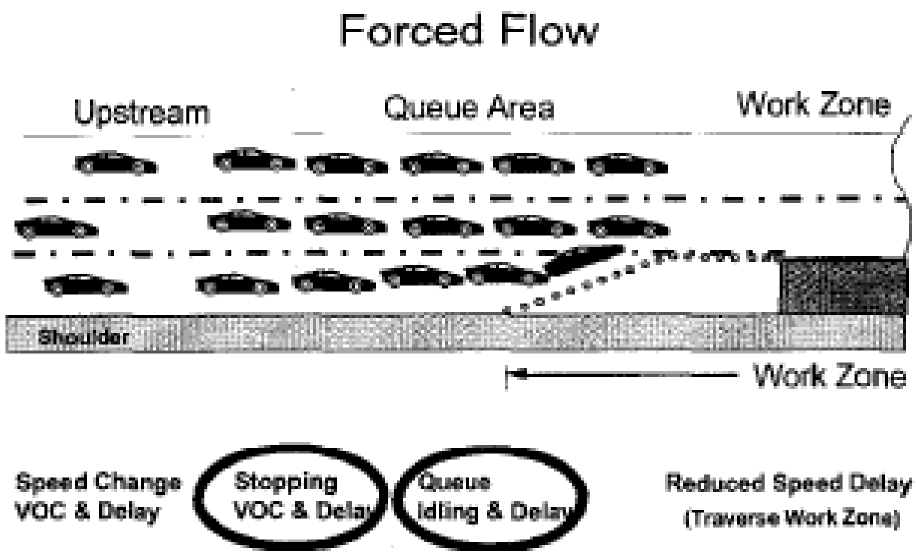
Road user costs



- *Maximum capacity for 2-lane directional freeway* = 2200
- Lane width = 3,5 m
- No. Of lanes in each direction = 2
- Heavy vehicles proportion = % 12

→ *Free Flow Capacity = 2075 vphpl*

Road user costs



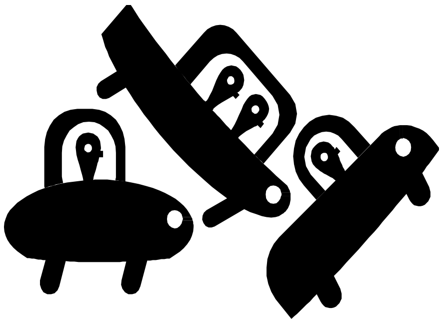
Directional Lanes		Number of Studies	Average Capacity	
Normal Operations	Work Zone Operations		Vehicles Per Hour	Vehicles per Lane per Hour
3	1	7	1,170	1,170
2	1	8	1,340	1,340
5	2	8	2,740	1,370
4	2	4	2,960	1,480
3	2	9	2,980	1,490
4	3	4	4,560	1,520

Road user costs

Accident Costs:

AC = L x ADT x N x (Aa-An) x ca

- L = Length of affected road way
- ADT = Average daily traffic (vehicles per day)
- N = number of days of maintenance activity
- Aa = Accident rate during maintenance activity
- An = Normal accident rate
- ca = Cost per accident



Life-Cycle Cost Analysis

RealCost

USER MANUAL

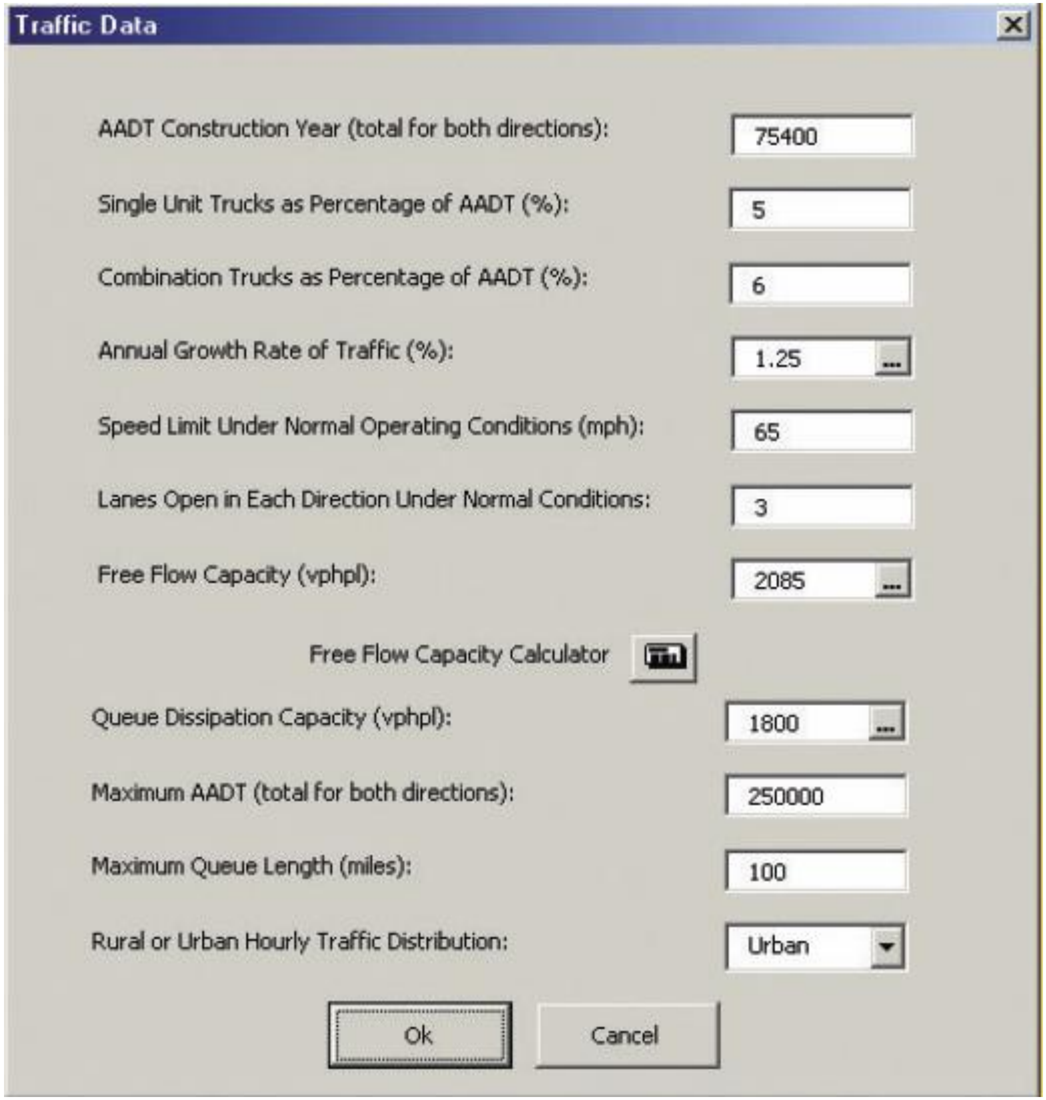
U.S. Department of Transportation
Federal Highway Administration

RealCost v. 2.1

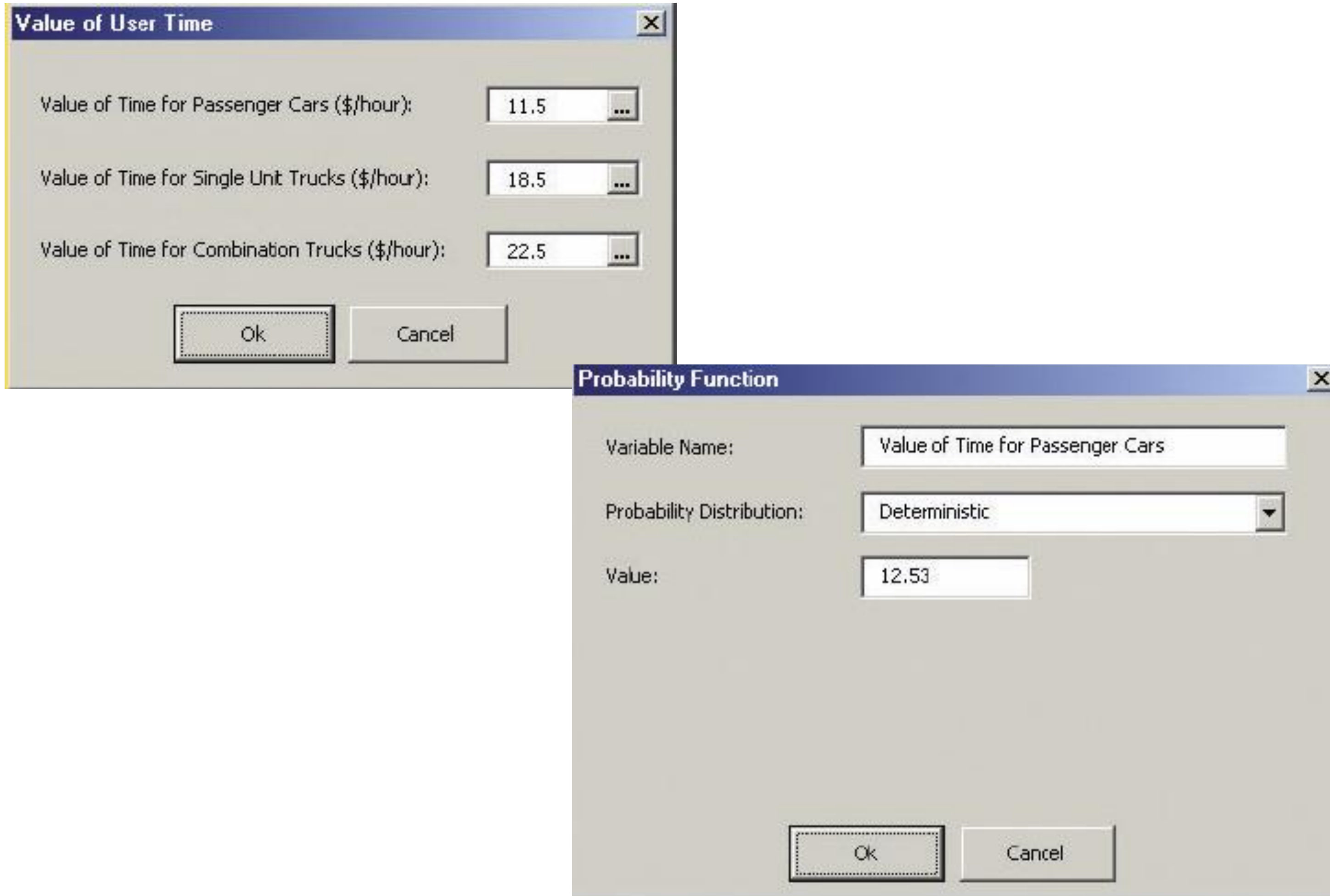
Office of Asset Management

May 2004

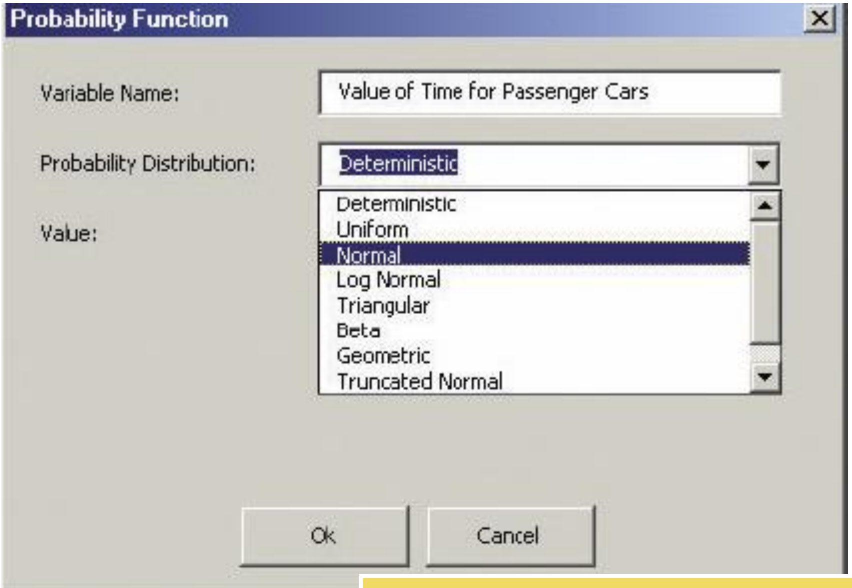
Real Cost

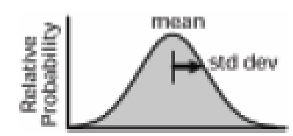
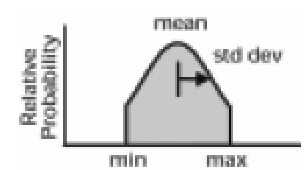
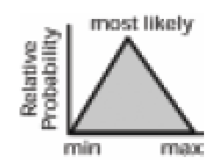
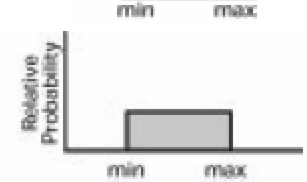

Traffic Data
AADT Construction Year (total for both directions):
75400
Single Unit Trucks as Percentage of AADT (%):
5
Combination Trucks as Percentage of AADT (%):
6
Annual Growth Rate of Traffic (%):
1.25
Speed Limit Under Normal Operating Conditions (mph):
65
Lanes Open in Each Direction Under Normal Conditions:
3
Free Flow Capacity (vphpl):
2085
Free Flow Capacity Calculator
Queue Dissipation Capacity (vphpl):
1800
Maximum AADT (total for both directions):
250000
Maximum Queue Length (miles):
100
Rural or Urban Hourly Traffic Distribution:
Urban
Ok
Cancel

Real cost

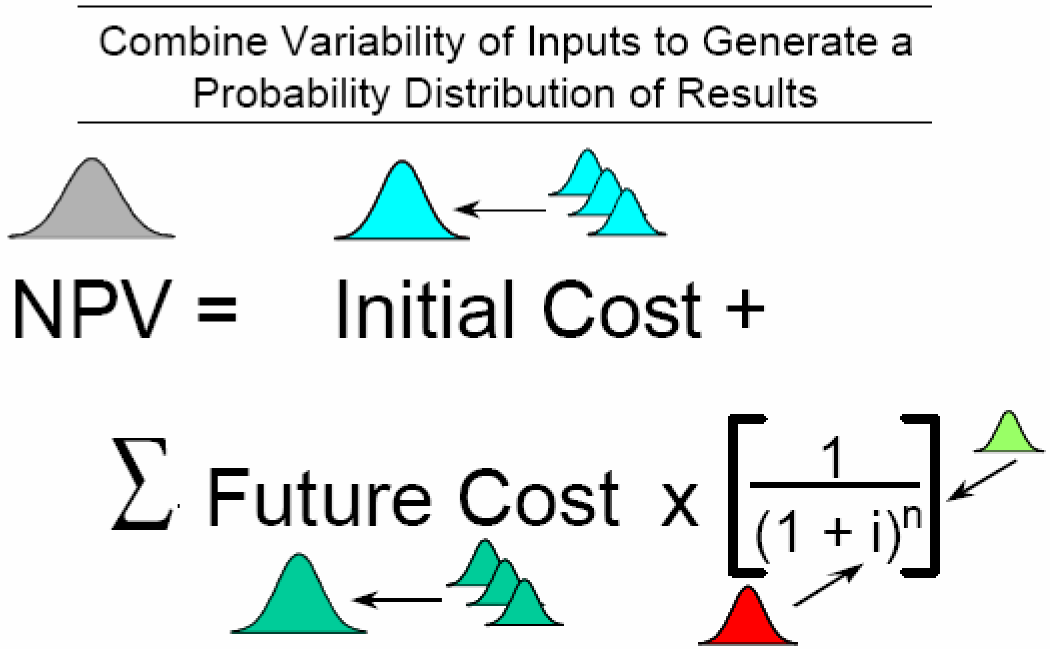


Value of User Time
Value of Time for Passenger Cars ($/hour):
11.5
Value of Time for Single Unit Trucks ($/hour):
18.5
Value of Time for Combination Trucks ($/hour):
22.5
Ok
Cancel
Probability Function
Variable Name:
Value of Time for Passenger Cars
Probability Distribution:
Deterministic
Value:
12.53
Ok
Cancel

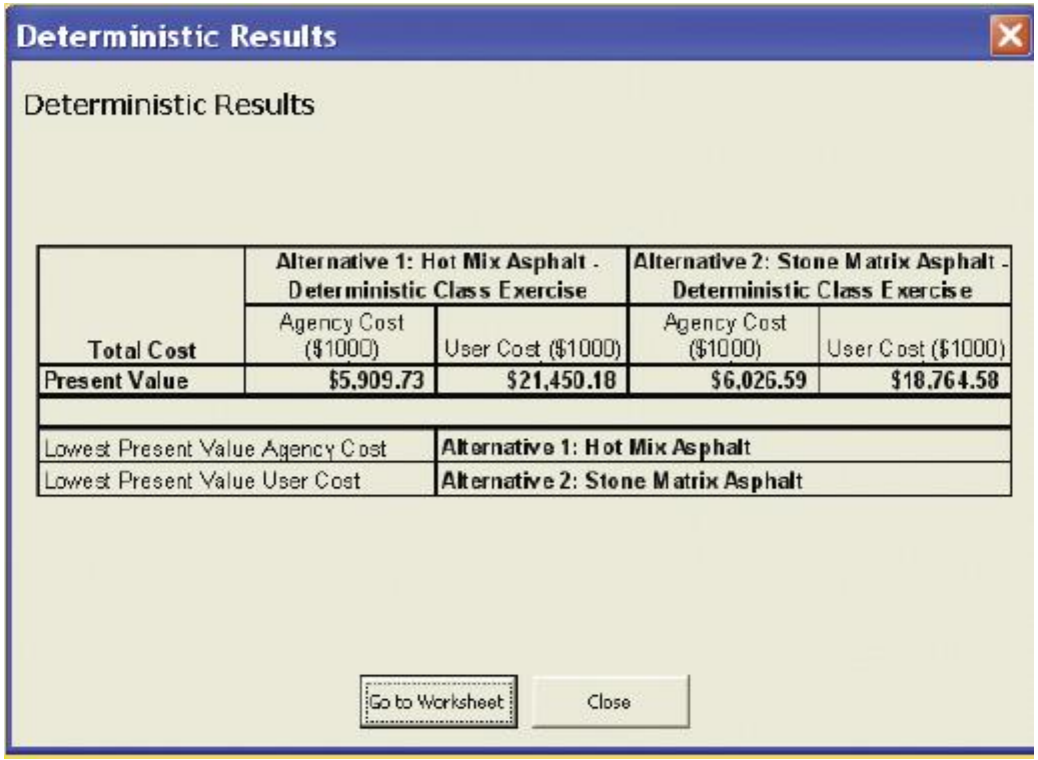


Distribution Type	Spreadsheet Formula	Illustration
Normal	lccanormal (mean, std dev)	
Truncated Normal	lccatnormal (mean, std dev, lower bound, upper bound)	
Triangular	lccatriang (minimum, most likely, maximum)	
Uniform	lccauniform (minimum, maximum)	

NPV Computation using Monte Carlo



Deterministic Results


Deterministic Results

Deterministic Results

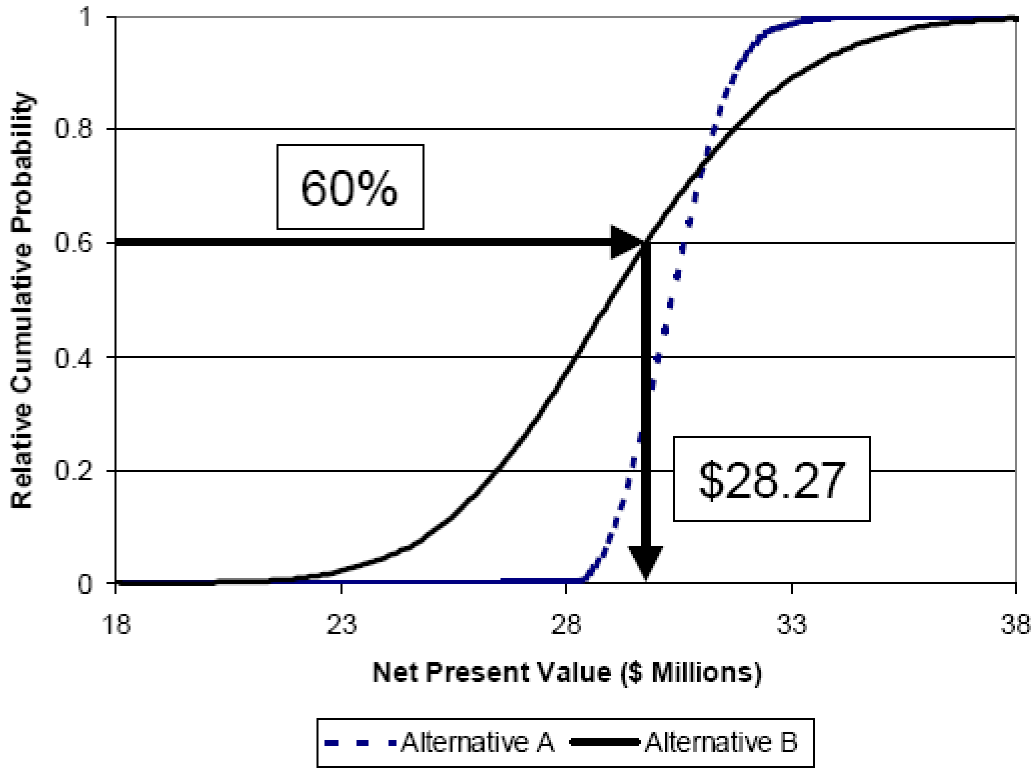
Total Cost	Alternative 1: Hot Mix Asphalt - Deterministic Class Exercise		Alternative 2: Stone Matrix Asphalt - Deterministic Class Exercise	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Present Value	**$5,909.73**	**$21,450.18**	**$6,026.59**	**$18,764.58**

Lowest Present Value Agency Cost	**Alternative 1: Hot Mix Asphalt**
Lowest Present Value User Cost	**Alternative 2: Stone Matrix Asphalt**

Go to Worksheet

Close

Probabilistic Results



Fundamental concepts

- The inflation indexes are suggested to be chosen from broad (e.g., Gross Domestic Product chain deflator) to intermediate (e.g., a Consumer Price Index) to narrow sector (e.g., highway construction or resurfacing cost such as road construction index (Vägindex)) depend on how results are to be interpreted

Description	Near-Term Value (Years 0-5)	Long-Term Value (Years 6+)
"Nominal" U of C Discount Rate	6%	7%
Inflation	1.5%	3.0%
"Real" U of C Discount Rate (Adjusted to take out inflation)	4.4%	3.9%

$$r = \frac{1+i}{1+j} - 1$$

Vägindex

- Recognizing that the broader indices may not adequately reflect the development of future costs related to road construction, the Swedish Transport Administration adopted a road construction cost index entitled the 'Vägindex' (STA, 2012)

- The use of the Vägindex was criticized by the Swedish National Audit Office (NAO, 2010)

Vägindex

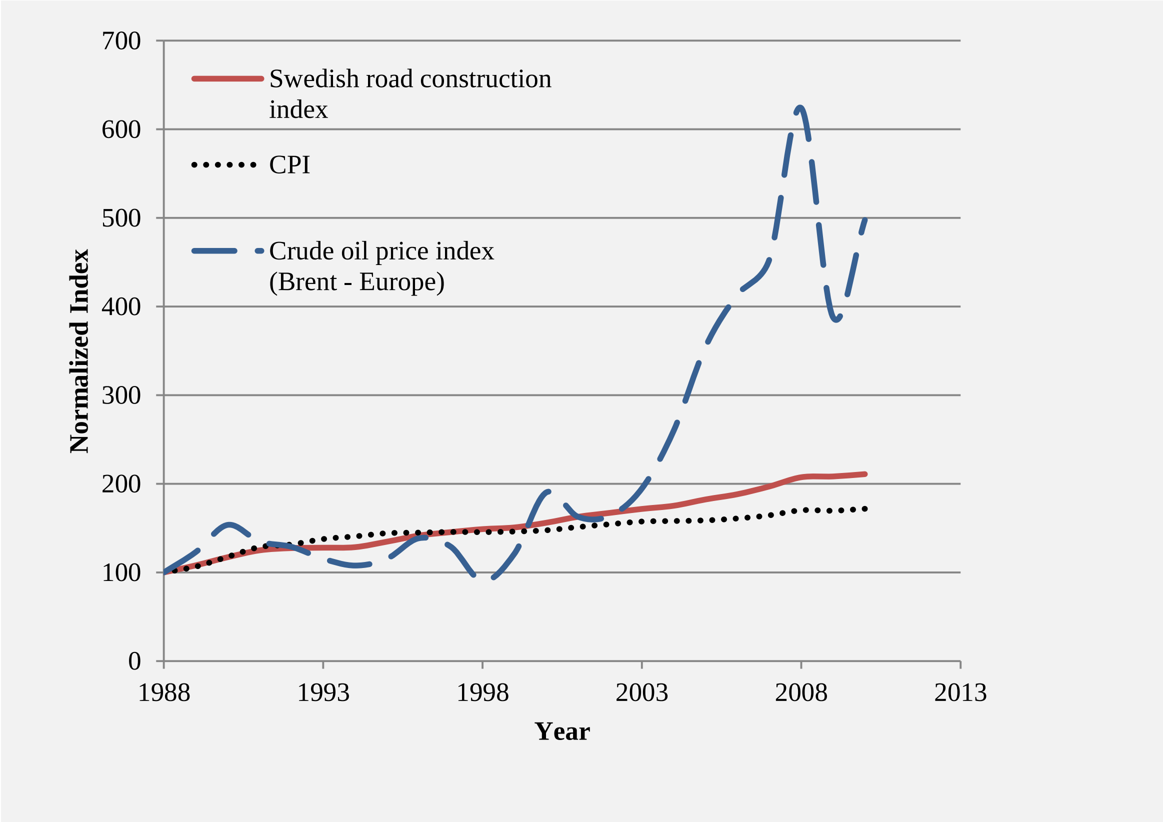
- Cost trends in the road construction sector are not comparable with that of the general economy

- The use of Vägindex does not adequately reflect the cost increases resulting from the relatively high price trends in the construction industry

- The widespread use of Vägindex is likely to reduce the awareness of potential future costs at the Swedish Transport Administration since fundamental cost drivers may be disguised

Inflation indices

- Trafikvärket (2009) and SCB (2012)

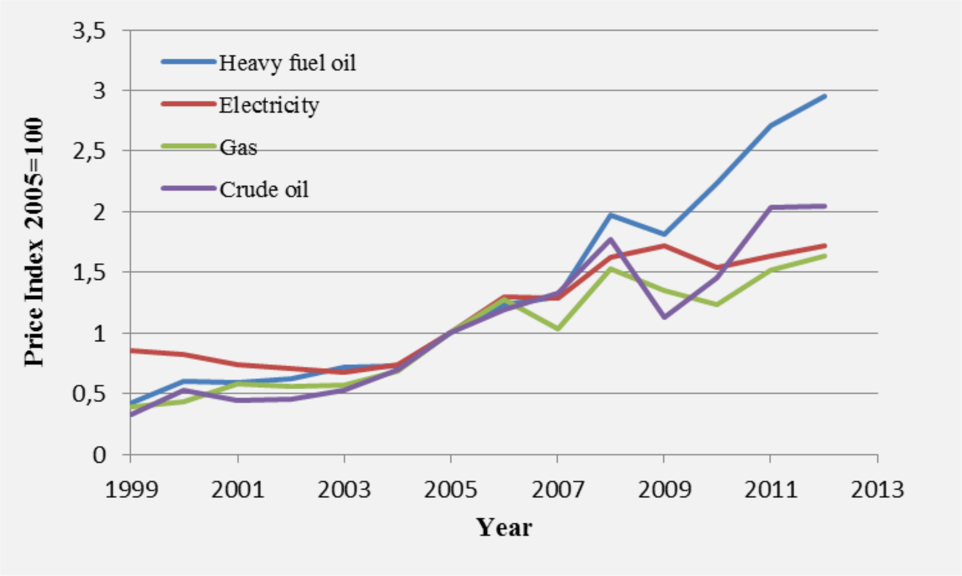


Inflation indices

- A significant part of the costs associated with asphalt pavements is related to the cost of oil products such as bitumen, fuel oil and transportation fuel.

- Therefore, application of one generalized inflation index based on Vägindex or CPI on the total cost may lead to a false estimation of future costs

Crude oil index



- Products refined from crude oil, such as transportation fuels, gas oil and fuel oil, are obviously closely linked to the price of crude oil and follow oil price fluctuations
- There is a lag between the change in the price of oil and that of other fuels
- The lag is shortest for oil products, like fuel oil
- For electricity the lag is delayed

Energy cost calculation

	Crude oil (MJ)	Energy source A (MJ)	Energy source B (MJ)	Cost of Energy (€)
Bitumen	qc_1	-	-	E_1
Modifier	qc_2	-	-	E_2
Aggregate production	-	qa_3	qb_3	E_3
Bitumen production	-	qa_4	qb_4	E_4
Modifier production	-	qa_5	qb_5	E_5
Asphalt production	-	qa_6	qb_6	E_6
Transportation	-	qa_7	qb_7	E_7
Laying asphalt	-	qa_8	qb_8	E_8
Compacting asphalt	-	qa_9	qb_9	E_9
User's energy loss	-	qa_{10}	qb_{10}	E_{10}

$$E_k = c_k \times P_c + a_k \times P_a + b_k \times P_b + \ldots$$

Where:

Pc, Pa, Pb are the unit cost (€/MJ) of crude oil, energy source A and energy source B

Energy & time related variables

	Item	Time Spent (Hr.)	Value of time (€/Hr.)	Cost of time (€)
Labor& Equipment	Transportation	t_1	C_L	T_1
	Laying asphalt	t_2	C_L	T_2
	Compacting asphalt	t_3	C_L	T_3
	Milling and resurfacing	t_4	C_L	T_4
Road users	*User's time loss*	t_5	C_u	T_5

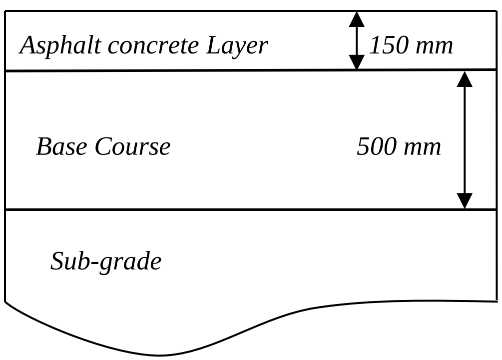
$$NPV = \left[\sum_{k=0}^{n} E_k \times (1+j_C)^y + \sum_{k=0}^{n} T_k \times (1+j)^y \right] \times \left(\frac{1}{1+i} \right)^y$$

$$EAC = TNPV \times \frac{i}{1-(1+i)^{-d}}$$

- y : the number years after the construction
- j_c : the yearly crude oil inflation rate
- j : the yearly inflation according to CPI
- i :the rate of interest
- d : the design life of the pavement

Case study

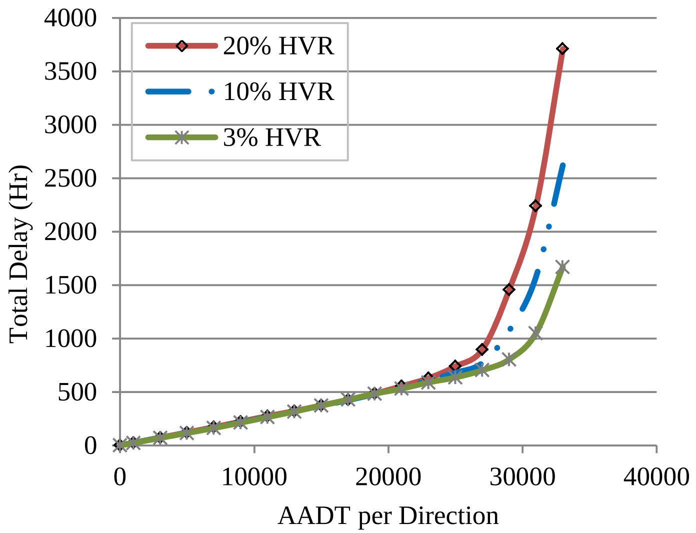
- 25 years design life
- Rehabilitation at the 15th year

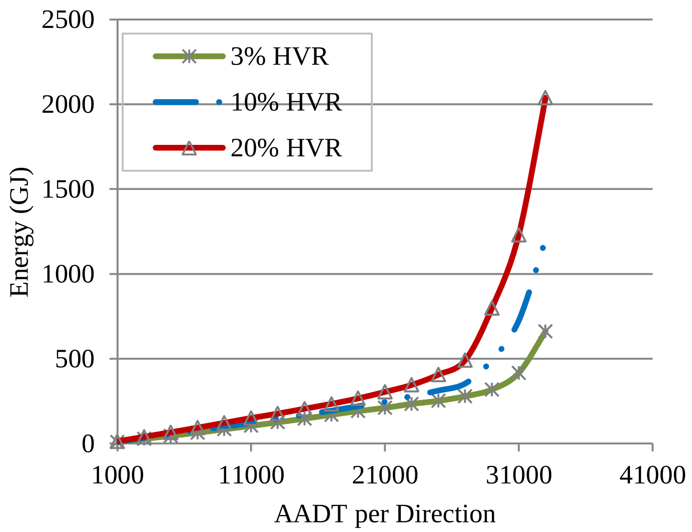


Transport Material	From_To	Distance[4] (km)
Binder	Refinery[2]_ Mixing plant[1]	100
Aggregate	Quarry site[1]_ Mixing plant	5
Asphalt	Mixing plant _ Construction site[3]	50

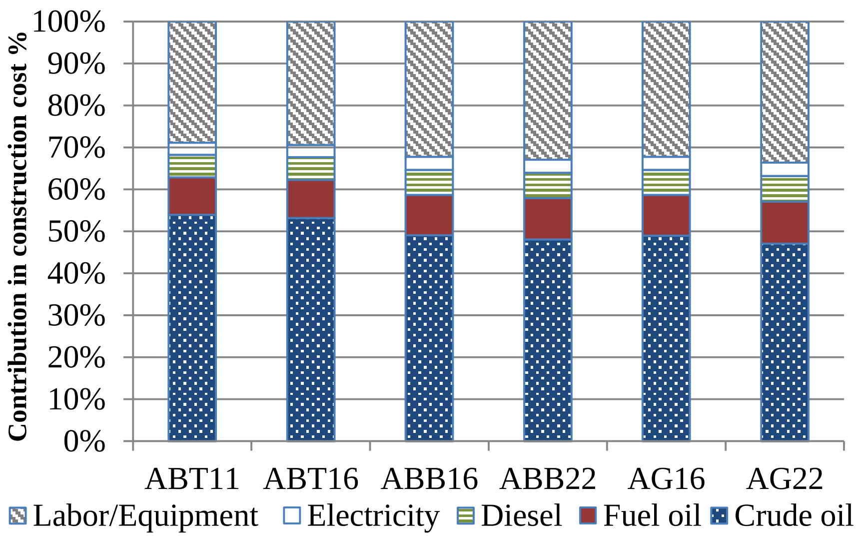
Road user costs

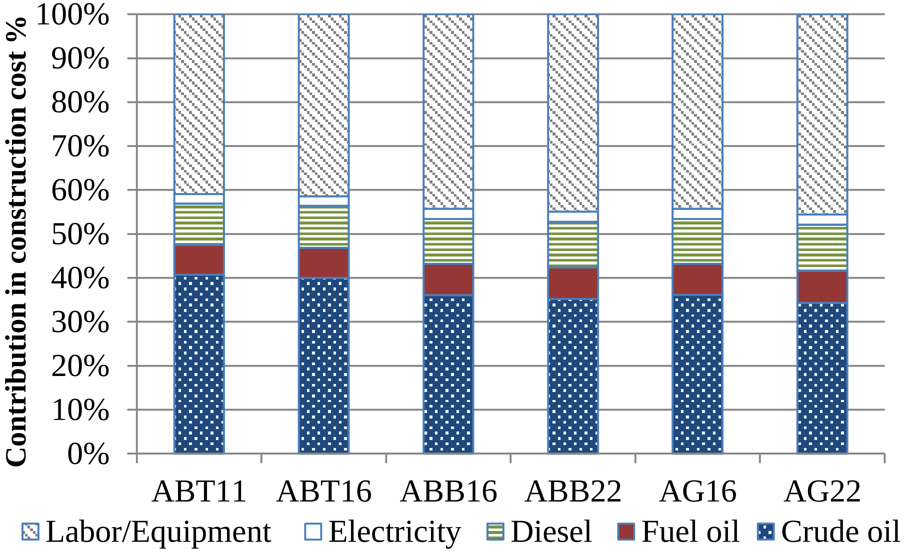
- Microsimulation Models
  - VTI model (AIMSUN 5.1 by Transport Simulation Systems)





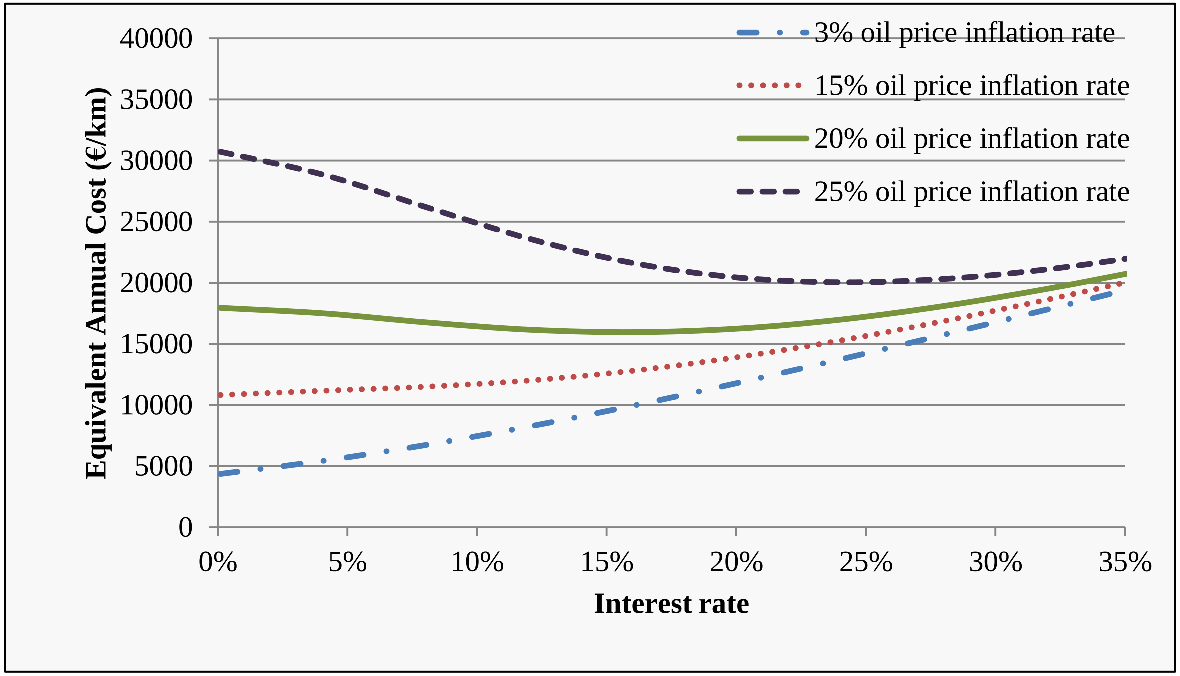
Contribution of cost drivers





Discount rate sensitivity analysis

- The general inflation rate for the time related cost was assumed to be 3%
- The average crude oil inflation rate for the last 10 years has been about 20%



Summary

- A transparent framework was presented for asphalt pavement LCC by applying energy and time as a basis for calculations which underlined main financial risks pertaining to asphalt paving works

- By applying the energy and time units as basis for cost calculations, the framework imposed separate inflation indices on the energy related costs and the labor/road user related costs

- The framework is capable of reflecting the price trends in the energy sector. Therefore, it can increase the awareness for the future costs related to maintenance and rehabilitation activities

Summary & Conclusion

- The prices of different energy sources in Europe during the recent years more or less have followed the fluctuation of the oil price

- Therefore, the crude oil inflation index was chosen as the inflation index for all energy sources

- The country general inflation index was used for the time related items

Summary & Conclusion

- The sensitivity analysis regarding the transportation distances showed that the transportation distances has a high impact on the total cost of asphalt pavement

- Therefore, it is believed that the transportation distance is one of the most important factors regarding the high variation in the price of laid asphalt pavements in Sweden

Summary & Conclusion

- In Sweden price of oil products are mostly affected by the global economy rather than the national economy

- Despite the price index of oil products which had a high fluctuation in different time periods, the cost fluctuation related to labor and equipment has been steady and followed the CPI

- Therefore, energy and time related costs are in this framework treated with different inflation indices in order to perform a better financial risk assessment regarding the future costs

Summary & Conclusion

- The calculated discount rate based on this model for the last 20 years was -4% which means the future costs in this period have been more expensive due to discounting

- Therefore, by assuming the similar pattern for the coming future, it is highly beneficial to minimize future costs

- This can be done by increasing the material quality to have a better performance regarding cracking and rutting in order to require less rehabilitation in the future

- The amount of future user costs regarding energy used by vehicles can also be decreased by using pavements with a lower rolling resistance

Thank you!