MTI Research Snaps:

DEVELOPMENT OF STATISTICAL MODELS TO PREDICT MATERIALS' UNIT PRICES FOR FUTURE MAINTENANCE AND REHABILITATION IN HIGHWAY LCCA

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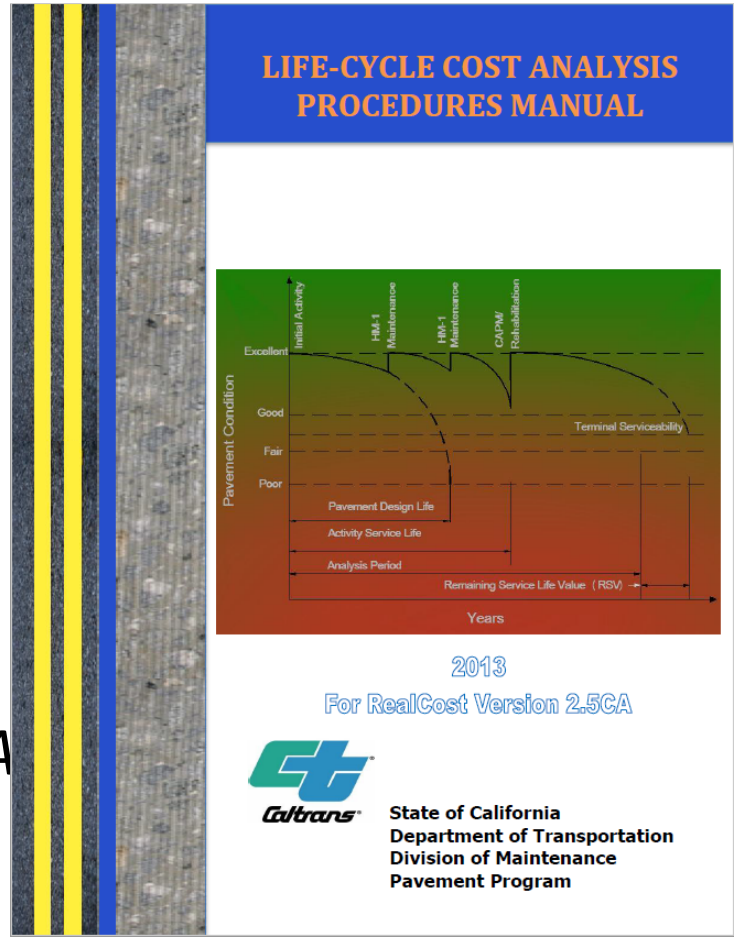
MINETA TRANSPORTATION INSTITUTE

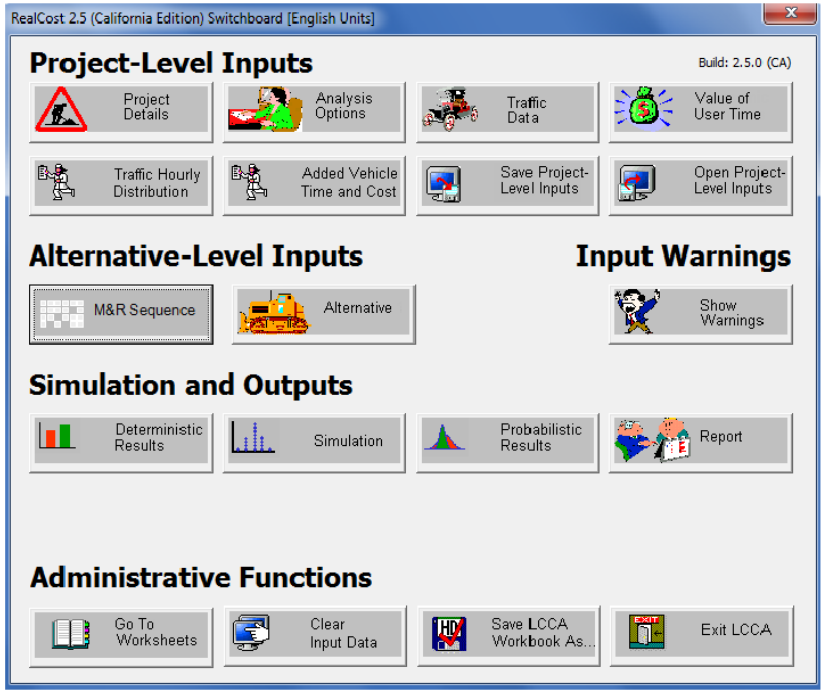
Overview

- Background
- Research Objective and Scope
- Data Collection and Analysis
- Model Development
- Case Study
- Summary and Conclusion
- Q&A

BACKGROUND

- Caltrans uses LCCA to compare the cost-effectiveness of design alternatives for highway projects.
- ***LCCA Procedure Manual (2013)***
- ***RealCost 2.5CA*** *– the California customized LCCA software (2013)*

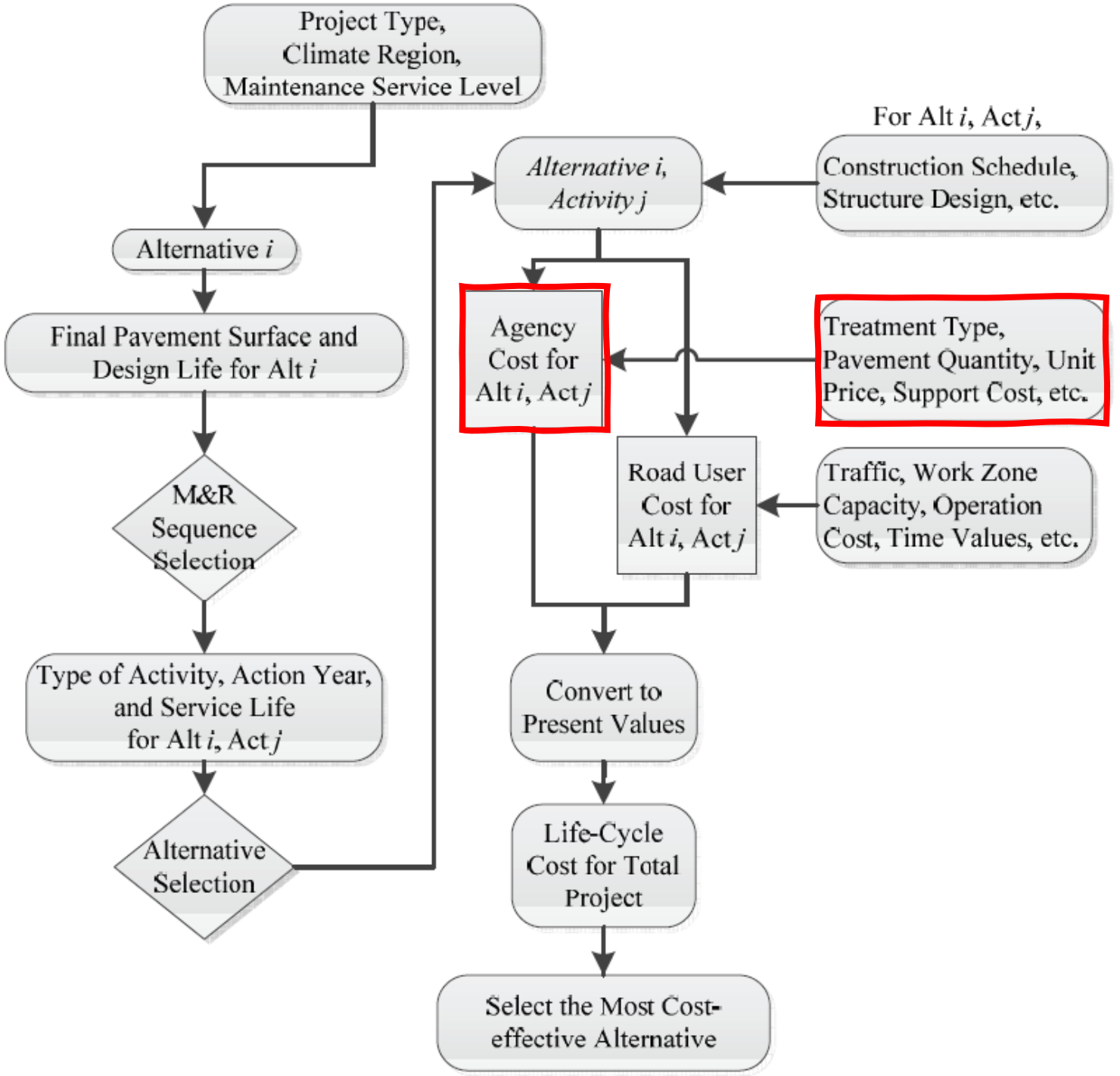




https://dot.ca.gov/programs/maintenance/pavement/concrete-pavement-and-pavement-foundations/life-cycle-cost-analysis

BACKGROUND

- **Caltrans LCCA Procedure**
- ***Life Cycle Cost***
  = Agency Cost + User Cost
- ***Major Inputs for Agency Cost***
  - ***Material types, quantities, unit prices, traffic handling cost, and support cost,***
- Material cost is up to 60 percent of agency cost.



RESEARCH OBJECTIVE AND SCOPE

- Current procedure uses uniform unit prices in calculating future maintenance and rehabilitation project cost.

- Research objectives are:
  - Investigate the trends of pavement unit prices in the past years.
  - Develop statistical models to better predict pavement unit prices for future M&R project to support LCCA for California highway projects.
  - Enhance the accuracy and practicality of the highway LCCA results.

DATA COLLECTION AND ANALYSIS

Pavement Material Items used in future M&R in LCCA

Pavement Item Description	Unit	Number of Projects	Data Period
Roadway Excavation	CY	4,151	1999-2018
Class 1 Aggregate Subbase (C1AS)	CY	29	1999-2018
Class 2 Aggregate Subbase (C2AS)	CY	210	1999-2018
Class 2 Aggregate Base (C2AB)	CY	800	2012-2018
Class 3 Aggregate Base (C3AB)	CY	160	2012-2018
Hot Mix Asphalt – Type A (HMA-A)	Ton	2,415	2008-2018
Hot Mix Asphalt - Open Graded (HMA-O)	Ton	57	2015-2018
Rubberized Hot Mix Asphalt – Gap Graded (RHMA)	Ton	681	2008-2018
Rubberized Hot Mix Asphalt - Open Graded (RHMA-O)	Ton	66	2015-2018
Jointed Plain Concrete Pavement (JPCP)	CY	200	2009-2019
Jointed Plain Concrete Pavement - Rapid Setting Concrete (JPCP-RSC)	CY	89	2014-2018
Lean Concrete Base (LCB)	CY	501	1999-2018
Lean Concrete Base – Rapid Setting Concrete (LCB-RSC)	CY	105	2013-2018

DATA COLLECTION AND ANALYSIS

Variation in Pavement Material Unit Price (JPCP and HMA-A) by Location

- No significant variation was statistically found in the unit prices of JPCP and HMA-A by District and Climate region in California.
- This research assumed project location does not affect the unit prices (at least JPCP and HMA-A).
- The unit prices were not separated by project location in the further steps.

ANOVA Test Results of District and Climate variables for JPCP and HMA in 2018

Variable	Type	Df	F-value	P-value
District	JPCP	7	0.801	0.596
District	HMA-A	11	1.517	0.124
Climate	JPCP	5	1.701	0.176
Climate	HMA-A	7	1.526	0.158

DATA COLLECTION AND ANALYSIS

Project Size (Material Quantity)

- The unit prices show a large variation depending on the size of the project (quantity of material used). Small projects which require low quantity of a material generally show higher unit prices than the larger project.

- For each pavement material, four project categories (small, medium, large, and extra-large size projects) were determined by the quartiles (25, 50, and 75 percentile) of the corresponding material quantities of the projects.

Maximum Quantities of the Pavement Materials Used in LCCA by Project Size

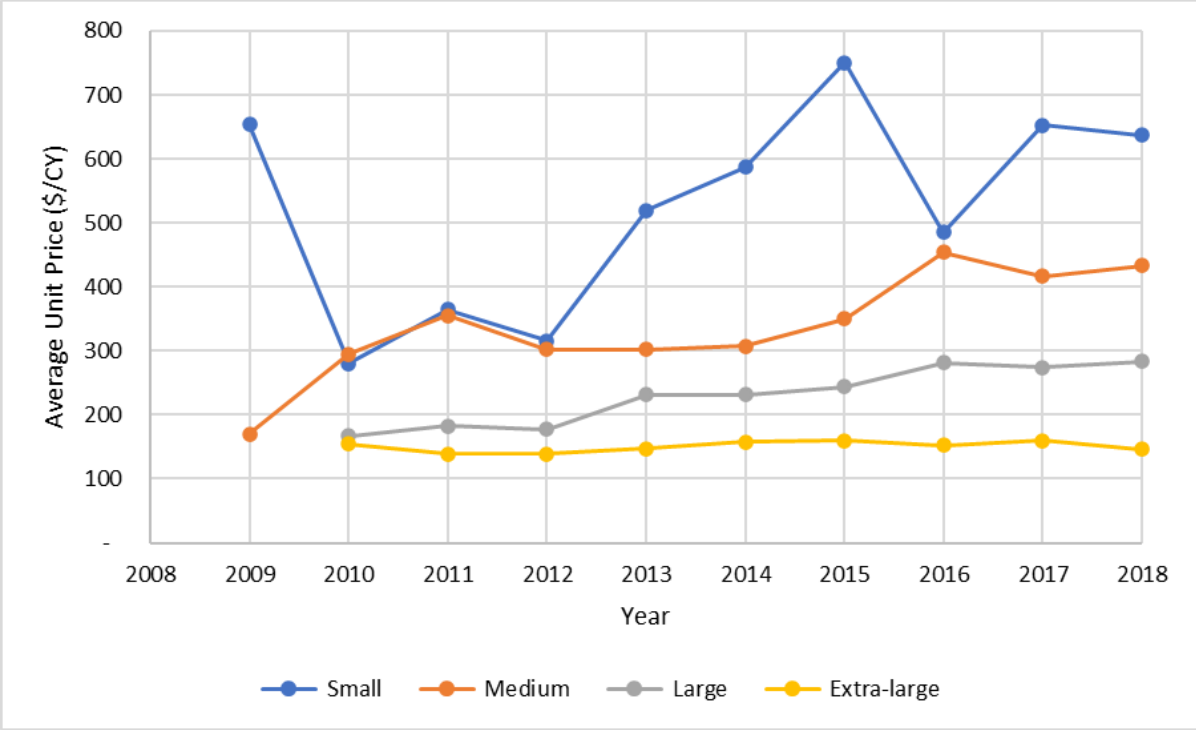
Material Type	Unit	Small	Medium	Large
Roadway Excavation	CY	300	1,500	9,000
Class 2 Aggregate Subbase	CY	300	1,500	8,500
Class 2 Aggregate Base	CY	200	1,000	3,000
Class 3 Aggregate Base	CY	100	500	2,000
Hot Mix Asphalt (Type A)	Ton	300	1,500	4,500
Hot Mix Asphalt (Open Graded Friction Course)	Ton	100	500	2,000
Rubberized Hot Mix Asphalt (Gap Graded)	Ton	2,500	7,500	16,000
Rubberized Hot Mix Asphalt (Open Graded Friction Course)	Ton	2,000	6,000	16,000
Jointed Plain Concrete Pavement	CY	200	1,500	12,000
Jointed Plain Concrete Pavement (Rapid Setting)	CY	200	500	1,500
Lean Concrete Base	CY	200	1,000	7,000
Lean Concrete Base (Rapid Setting)	CY	100	300	1,000

Average Unit Prices by Project Size (Material Quantity)

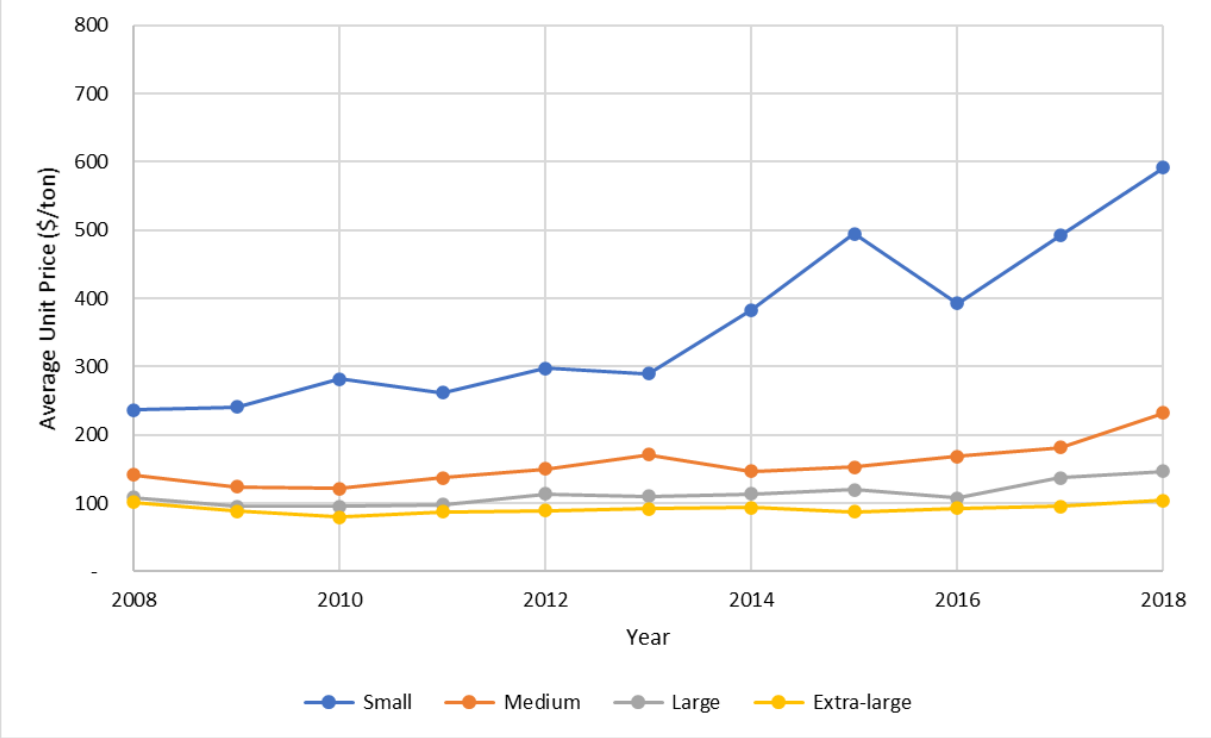
Material	Unit	Small (no. of projects)	Medium (no. of projects)	Large (no. of projects)	Extra-Large (no. of projects)
Roadway Excavation	CY	$267 (1,048)	$106 (979)	$60 (1,076)	$30 (1,048)
Class 2 Aggregate Subbase	CY	$163 (55)	$110 (51)	$51 (52)	$32 (52)
Class 2 Aggregate Base	CY	$358 (224)	$127 (226)	$95 (153)	$55 (204)
Hot Mix Asphalt (Type A)	Ton	$591 (662)	$232 (653)	$147 (513)	$104 (586)
Hot Mix Asphalt (Open Graded Friction Course)	Ton	$255 (10)	$179 (19)	$162 (14)	$109 (14)
Rubberized Hot Mix Asphalt (Gap Graded)	Ton	$210 (170)	$132 (183)	$118 (160)	$108 (167)
Rubberized Hot Mix Asphalt (Open Graded Friction Course)	Ton	$160 (18)	$147 (15)	$115 (15)	$120 (17)
Jointed Plain Concrete Pavement	CY	$637 (47)	$433 (51)	$283 (53)	$146 (51)
Jointed Plain Concrete Pavement (Rapid Setting)	CY	$1,091 (28)	$792 (16)	$658 (25)	$385 (20)
Lean Concrete Base	CY	$379 (134)	$292 (124)	$199 (118)	$145 (125)

DATA COLLECTION AND ANALYSIS

Joint Plain Concrete Pavement (JPCP)



Hot Mix Asphalt Type A (HMA-A)



DATA COLLECTION AND ANALYSIS

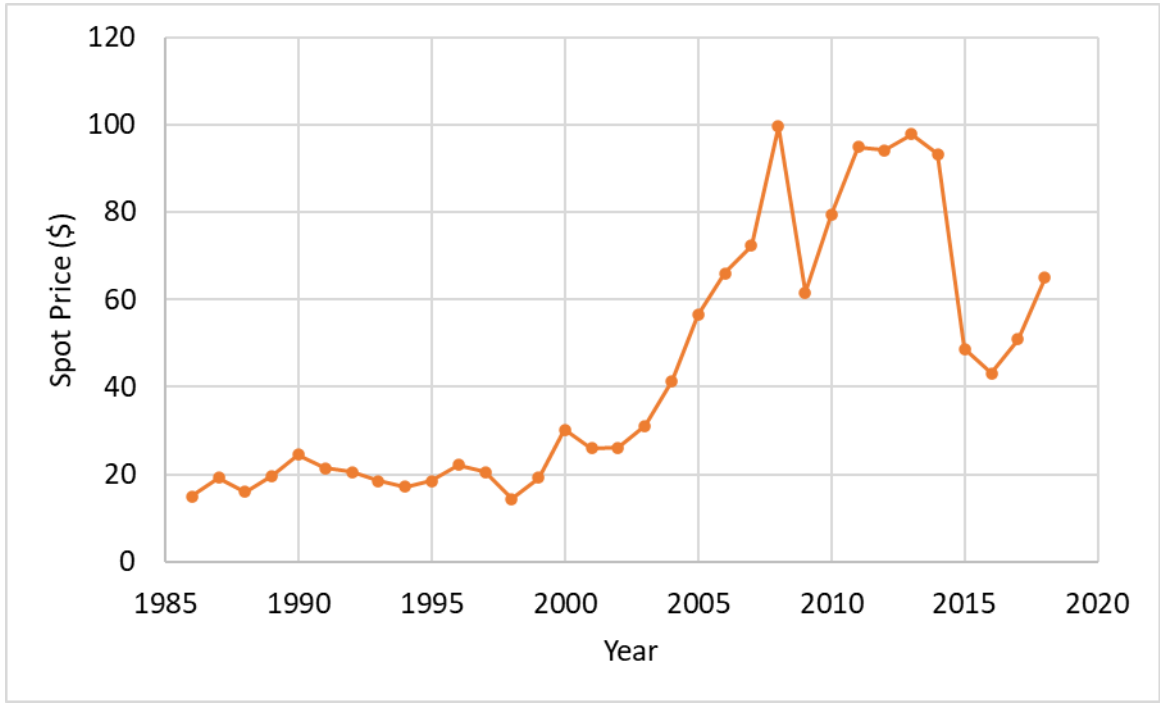
Socio-economy Parameters

Socio-economy Parameters	Data Period
Gasoline/diesel price	1995-2018
Crude oil price	1986-2018
Population	1970-2018
Consumer price index	1998-2018
State expenditure in Transportation	1989-2018
Vehicle registration	1997-2018
Vehicle miles traveled	1997-2018
Inflation rate	1980-2018
Industry cement price	1998-2018
California minimum wage	1980-2018

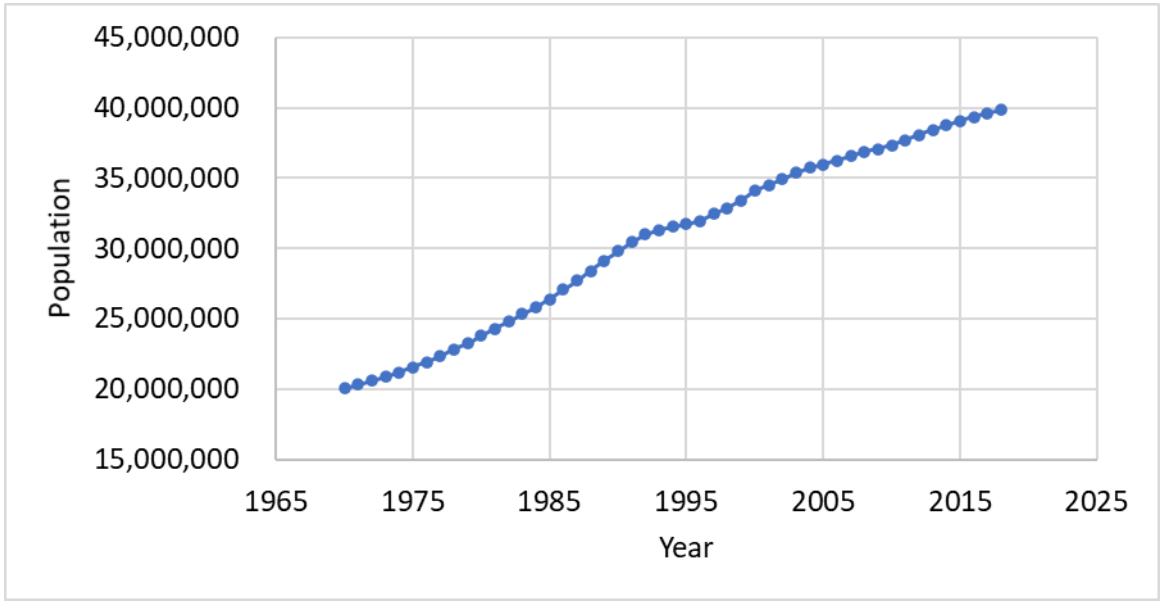
DATA COLLECTION AND ANALYSIS

Socio-economy Parameters

National Crude Oil Price ($/barrel)



California Population



DATA COLLECTION AND ANALYSIS

Correlation among Socio-economy Parameters

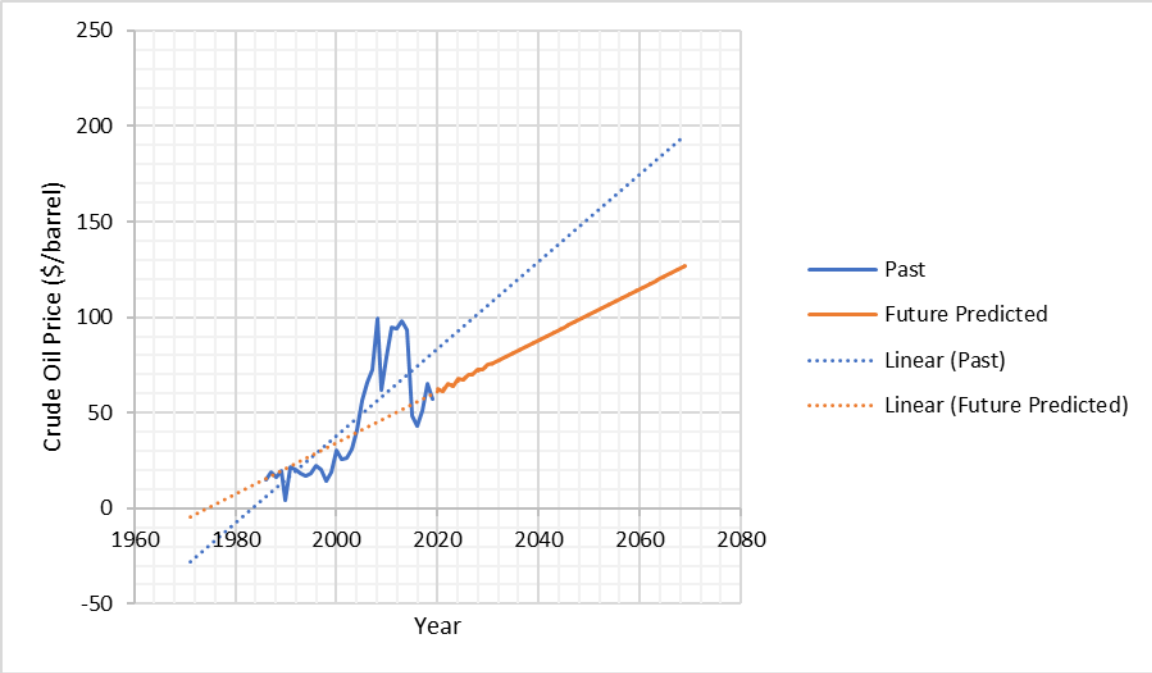
Selected Parameter	Correlated Parameters (Correlation Rate)
Crude Oil Price	*Gasoline Prices* (0.93) and *Diesel Prices (0.94)*
Population	*Vehicle Miles Traveled (0.90)*, *Consumer Price Index (CPI)(0.99)*, and *Minimum Wage (0.94)*
State Expenditure in Transportation	None
Total Vehicle Registration	None

MODEL DEVELOPMENT

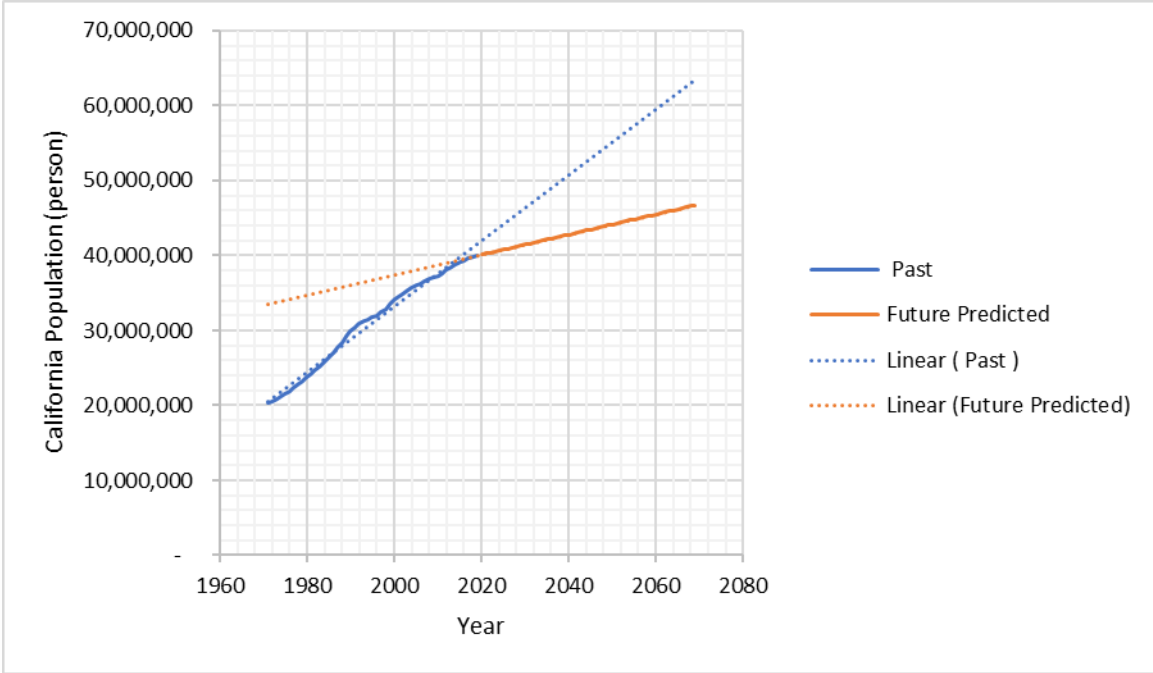
Time Series Analysis of Socio-economic variables

- Autoregressive Integrated Moving Average (ARIMA) method was applied in time series analysis.

Crude Oil Price



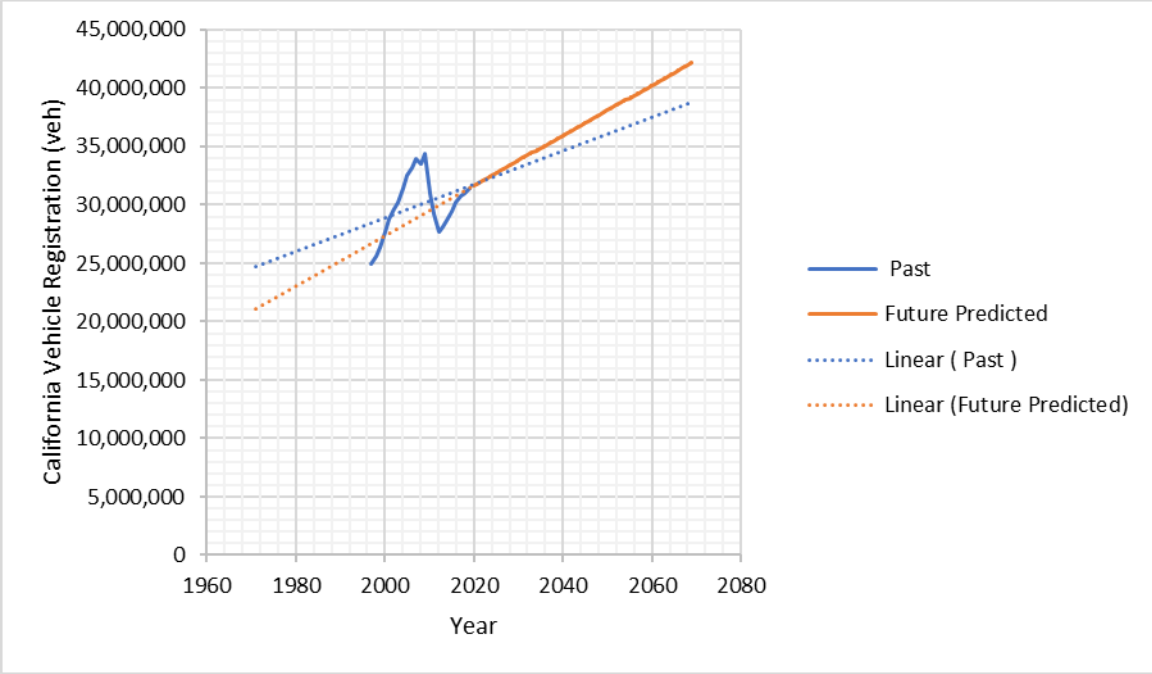
California Population



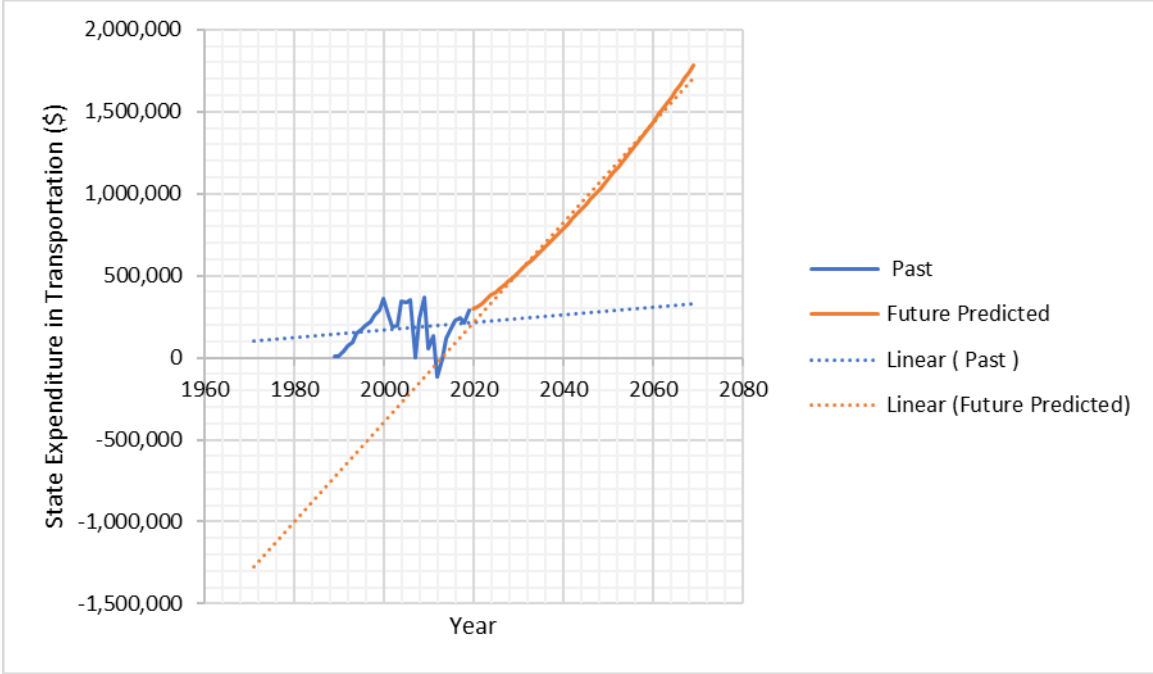
MODEL DEVELOPMENT

Time Series Analysis of Socio-economic variables

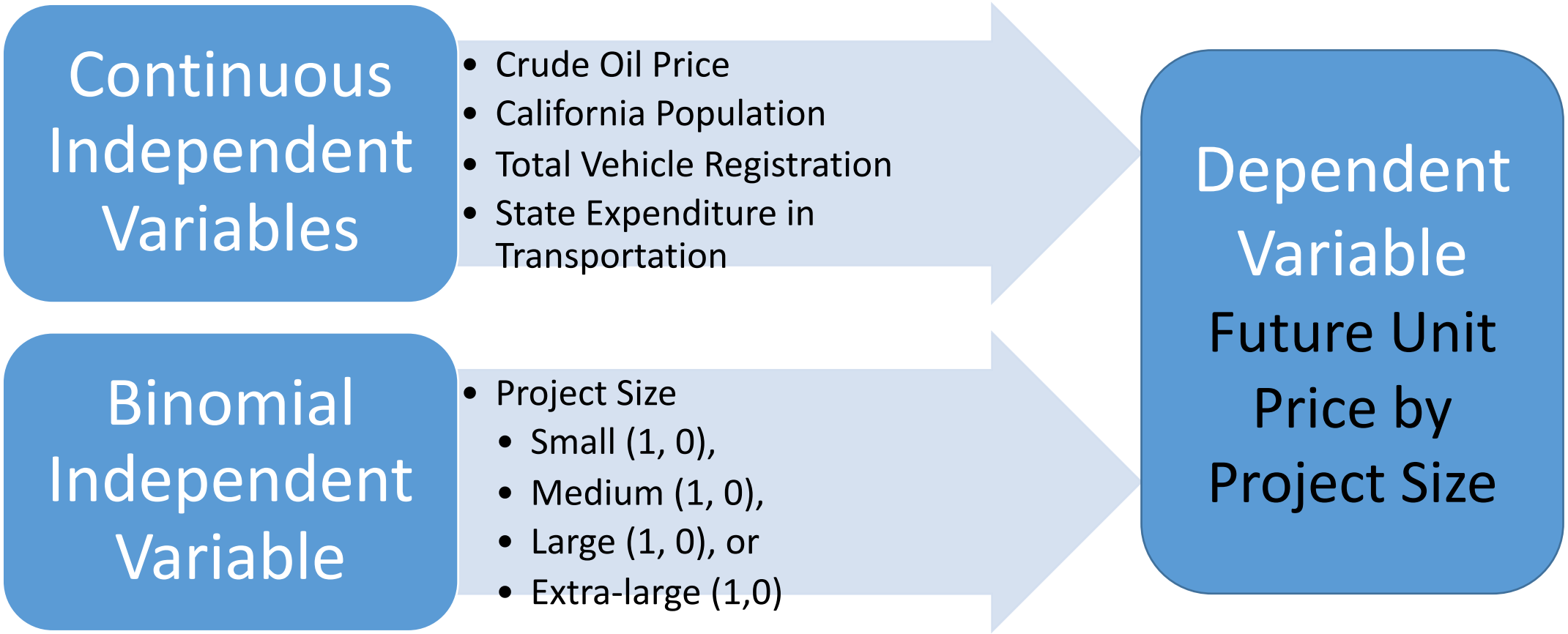
California Vehicle Registration



State Expenditure in Transportation



MODEL DEVELOPMENT
Multiple Regression Analysis

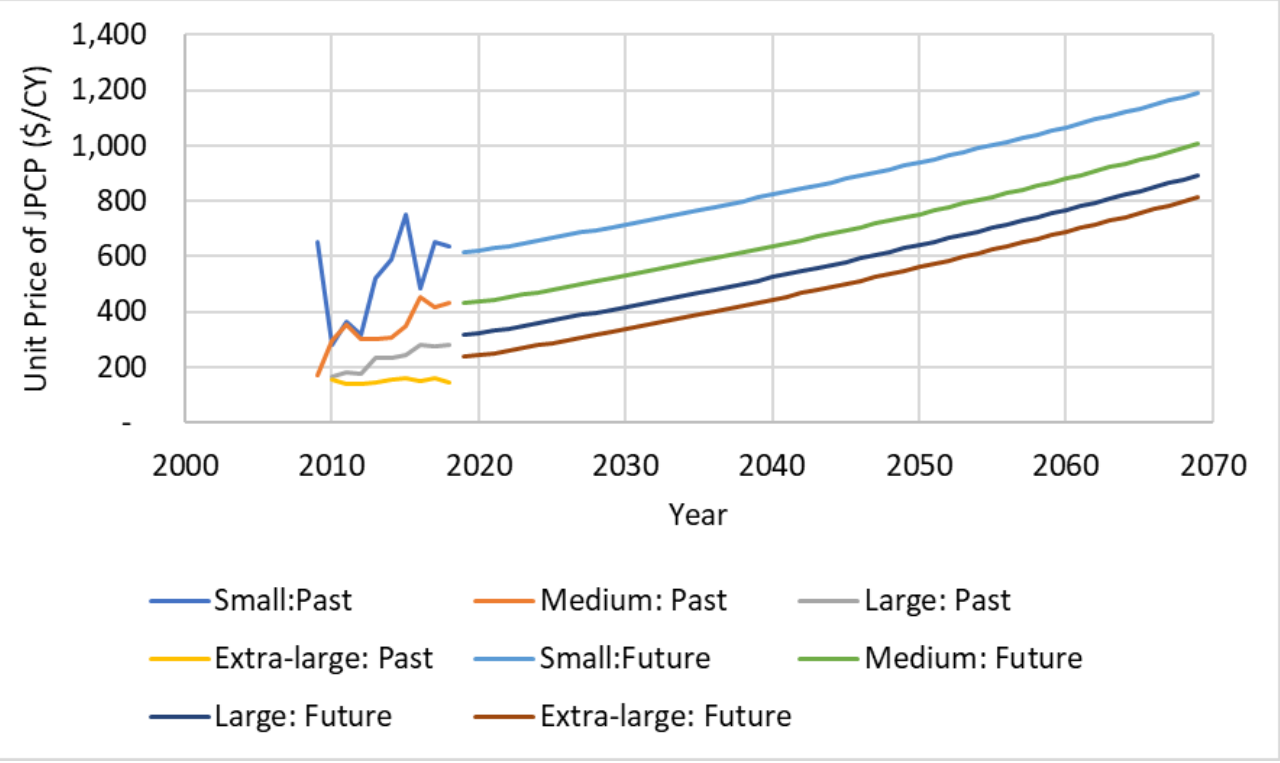


MODEL DEVELOPMENT
Multiple Regression Analysis Results

Material	R-squared Value	Intercept	Crude Oil	Population	Vehicle Registration	Transportation Expenditure	Medium Size Project	Large Size Project	Extra-Large Size Project
Roadway Excavation	0.8735	-1.407e+3	4.682e-02	2.860e-05	1.721e-05	-1.753e-04	-1.209e+02	-1.506e+02	-1.718e+02
Class 2 Aggregate Subbase	0.5089	9.401e+00	1.555e-01	3.873e-06	1.087e-06	-7.012e-05	-1.169e+02	-1.404e+02	-1.562e+02
Class 2 Aggregate Base	0.8163	-1.657e+03	-3.703e-02	2.392e-05	3.297e-05	-2.541e-04	-1.121e+02	-1.410e+02	-1.707e+02
Class 3 Aggregate Base	0.7094	-3.464e+03	6.149e-01	1.052e-04	-1.666e-05	-1.618e-04	-4.682e+01	-1.066e+02	-1.282e+02
Hot Mix Asphalt (Type A)	0.8283	-2.073e+03	4.123e-01	5.257e-05	1.315e-05	-9.127e-05	-2.033e+02	-2.471e+02	-2.685e+02
Hot Mix Asphalt-Open Graded	0.7868	-2.243e+05	-7.413e+01	8.125e-03	-3.031e-03	NA	-2.360e+02	-2.802e+02	-3.170e+02
Rubberized Hot Mix Asphalt (Gap Graded)	0.6767	-9.921e+02	6.691e-01	2.256e-05	8.544e-06	-7.062e-05	-6.238e+01	-7.182e+01	-7.619e+01
Rubberized Hot Mix Asphalt - Open Graded	0.5788	-2.033e+05	-6.540e+01	7.380e-03	-2.778e-03	NA	-4.310e+01	-5.080e+01	-6.036e+01
Jointed Plain Concrete Pavement	0.769	-8.828e+02	-1.094e-01	4.208e-05	-8.043e-06	2.580e-04	-1.858e+02	-2.984e+02	-3.781e+02
Jointed Plain Concrete Pavement (Rapid Setting Concrete)	0.802	-1.659e+04	5.697e+00	6.807e-04	-3.448e-04	4.023e-03	-3.214e+02	-4.063e+02	-5.453e+02
Lean Concrete Base	0.4005	1.094e+02	2.682e-01	-3.969e-06	1.437e-05	-1.310e-04	-1.520e+02	-1.993e+02	-2.541e+02
Lean Concrete Base Rapid Setting	0.6675	-1.027e+04	-4.374e+00	3.721e-04	-1.116e-04	-7.896e-04	-6.503e+01	-2.035e+02	-2.715e+02

MODEL DEVELOPMENT
Multiple Regression Analysis Results

Joint Plain Concrete Pavement (JPCP)



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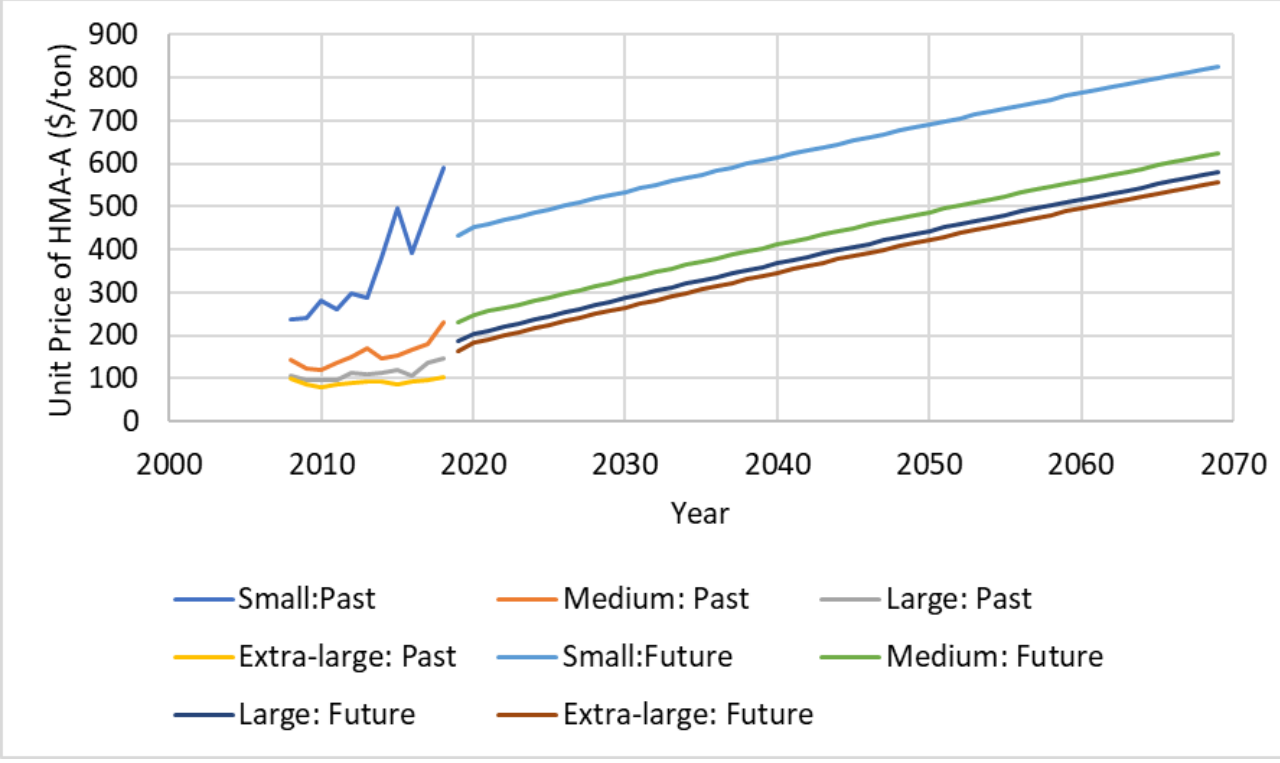

CASE STUDY

- Two separate LCCA were executed by using
  (1) the uniform unit prices without consideration of the project size and activity years;
  (2) the predicted unit prices by project size in the corresponding activity years

- LCCA for Rehabilitation Project of 9.6 lane-miles in 2020

Alternative 1:
HMA Rehab 0.65 ft,
20-year design life

Alternative 2:
JPCP Rehab 1.0 ft,
40-year design life

CASE STUDY RESULTS

HMA Unit Prices for future M&R Project (NPV: Net Present Value, 4% discount rate)

Year	Uniform Unit Price of HMA ($ton)	Predicted Unit Price of HMA ($/ton)	Uniform Unit Price of HMA, NPV ($ton)	Predicted Unit Price of HMA, NPV ($ton)
2020	183	183	183	183
2038	183	404	90	199
2043	183	370	74	150
2061	183	568	37	114
2066	183	537	30	88

JPCP Unit Prices for future M&R Project

Year	Uniform Unit Price of JPCP ($CY)	Predicted Unit Price of JPCP ($/CY)	Uniform Unit Price of JPCP, NPV ($ton)	Predicted Unit Price of JPCP, NPV ($ton)
2020	243	243	243	243
2065	460	836	42	143

SUMMARY AND CONCLUSION

- Trends in material unit prices were explored by project location (district and climate region) and project size.
  - No significant difference in unit price by location
  - Difference in unit prices by project size was observed especially for small-size projects

- Multiple regression models were developed to estimate the annual unit prices of each pavement material by project size for the next 50 years (2020-2069)
  - In LCCA, long-term prediction includes uncertainties due to the unexpected economic trends and industry demand-supply conditions.
  - The models were good with reasonable predictions that overcome sudden changes due to economic downturns (e.g. 2008 recession).

- The R-squared values for different variables were in the range of 0.5 and 0.9.
  - Prediction models for ***Roadway Excavation***, ***Class 2 and 3 Aggregate Base***, ***HMA-A***, ***RHMA***, ***JPCP***, and ***LCB*** were adequate showing reasonable results with good prediction.
  - Prediction models for ***Class 2 Aggregate Subbase, HMA-O, RHMA-O, JPCP-RSC*** showed results which were contrary to normal expectations and were not recommended for use.

SUMMARY AND CONCLUSION

- Economic recessions and a global pandemic can have a significant unexpected influence on variations in material unit prices and project costs in the future.

- Nevertheless, the data-driven scientific approach as described in this research reduces risk caused by such uncertainties and enables practically reasonable predictions for the future.

- The developed models can be implemented into enhancing the current LCCA procedure to predict more realistic unit prices and project costs for the future M&R activities.

Thank you for joining us for:

DEVELOPMENT OF A STATISTICAL MODEL TO PREDICT MATERIALS' UNIT PRICES FOR FUTURE MAINTENANCE AND REHABILITATION IN HIGHWAY LCCA

The full report will be posted at MTI website soon.

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CASE STUDY
Comparison of the LCCA Results

Life Cycle Agency Cost for Alternative 1: HMA Rehabilitation (NPV: Net Present Value, 4% discount rate)

Year	Agency Cost with Uniform Unit Price of HMA ($1,000)	Agency Cost with Predicted Unit Price of HMA ($1,000)	Agency Cost with Uniform Unit Price of HMA, NPV ($,1000)	Agency Cost with Predicted Unit Price of HMA, NPV ($1,000)
2020	11,341	11,341	11,341	11,341
2038	741	1,551	366	766
2043	11,341	21,481	7,147	13,445
2061	741	2,106	148	422
2066	11,341	22,470	2,900	7,724
Total Agency Cost in Life Cycle	35,505	58,949	24,598	31,218

Life Cycle Agency Cost for Alternative 2: JPCP Rehabilitation (NPV: Net Present Value, 4% discount rate)

Year	Agency Cost with Uniform Unit Price of JPCP ($)	Agency Cost with Predicted Unit Price of JPCP ($)	Agency Cost with Uniform Unit Price of JPCP, NPV ($)	Agency Cost with Predicted Unit Price of JPCP, NPV ($)
2020	11,794	11,794	11,794	11,794
2065	241	338	41	58
Total Agency Cost in Life Cycle	12,035	12,131	11,835	11,852