Journal of Traffic and Transportation Engineering 12 (2024) 107-118
doi: 10.17265/2328-2142/2024.03.001

DAVID PUBLISHING

Analysis of Historic Pavement and Bridge Conditions and Alternative Funding Levels for the Michigan Department of Transportation

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Abstract: In 1997 the Michigan Department of Transportation (MDOT) established an ambitious set of condition targets for its pavements and bridges, and the Department received increased revenue from a 4-cent-per-gallon increase in the state motor fuels tax to help meet its targets. However, over time, actual revenue was less than both what was initially estimated as needed to meet the targets and what was projected from the tax increase. Consequently, actual conditions were projected to fall short of the target levels, so the department issued bonds to address the shortfall through 2012. To support deliberations on future funding, in 2013 MDOT performed an analysis of historic conditions to determine what additional fuel tax revenues would have been required beginning in 1997 to: replace bond revenues used to fund pavement and bridge projects from 1997 to 2012; and enable MDOT to meet its condition targets. The analysis was performed using data on actual pavement and bridge funding and conditions; as well as predicted funding and conditions for different hypothetical increases in fuel taxes. The analysis concluded that, in addition to the actual increase of 4 cents per gallon, a fuel tax increase of another 10 cents per gallon would have been required in 1997 to replace bond revenue used for pavement and bridges and allow MDOT to meet its condition targets. The analysis results were used to help inform the discussion of Michigan's target asset conditions and funding, and demonstrate application of MDOT's pavement and bridge management systems for performing historic analyses.

Key words: Transportation asset management, transportation finance, performance measures, pavement management, bridge management.

1. Introduction

The Michigan Department of Transportation (MDOT) is responsible for maintaining approximately 9,650 miles of state trunkline highways and over 4,400 bridges. The Department is responsible for approximately 8 percent of Michigan's roadway network, but MDOT's portion of the network carries approximately 51 percent of total statewide traffic and accounts for 74 percent of the statewide bridge deck area [1].

Transportation asset management, defined in Michigan law (Public Act 51 Section 247.659a) as "an ongoing process of maintaining, upgrading, and operating physical assets cost-effectively, based on a continuous physical inventory and condition assessment," has been a priority for MDOT since the 1990's. In 1992 MDOT developed the Michigan Capital Preventive Maintenance Program to preserve pavement and bridge structures, delay future deterioration, and improve overall conditions cost-effectively and efficiently [2]. But without additional funding, by 1997 asset conditions deteriorated to the point that approximately 40 percent of the state network was rated as being in poor condition, and there was significant public concern over the poor condition of the state's roads [3]. In part based on analyses performed by MDOT, the state legislature approved a 4-cent increase in the state motor fuels tax, from 15 to 19 cents per gallon that took effect midway through 1997. MDOT made a series of significant additional changes at this time, including setting performance targets for

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pavements and bridges, and creating an annually-updated five-year program document. In 2003, the department made a further change, shifting away from system expansion to focus chiefly on preservation.

MDOT worked with the State Transportation Commission to establish performance targets to help direct investment of the additional funds raised by the tax increase. Specifically, the Department set a target of having 85 percent of non-freeway trunkline pavements and 95 percent of freeway pavements in good or fair condition. MDOT's goal was to achieve these targets within ten years, by 2007. Subsequently the two targets were combined, so the overall goal was to have 90 percent of the MDOT network in good or fair condition, though the analysis described here retains the original, two-tiered targets. Note a pavement section is classified in being in good or fair condition if it has a remaining service life (RSL) of 3 or more years. A bridge is classified as being in good or fair condition if it is not Structurally Deficient. That is, it should have National Bridge Inventory (NBI) deck, superstructure and substructure condition ratings of 5 or greater.

Following the 1997 tax increase, pavement and bridge conditions steadily improved. However, the revenue increase was somewhat less than that initially projected to reach the targets, and over time revenues fell below initial projections, largely due to poor economic conditions and increasing fuel efficiency. Consequently, MDOT increased its use of bonds to sustain its funding. Proctor, et. al. detail the use of bond funding in the recent report *The Road Not Taken – Michigan's Highway Funding Decisions: Lessons from the Past and Implications for the Future* [4], concluding the use of bonds allowed MDOT to improve its pavement and bridge conditions through 2007, but left MDOT with a significant debt, as well as debt payments of over $100 million annually for bonds issued to fund pavement and bridge-related preservation. A combination of additional preservation bonding and American Recovery and Reinvestment Act (ARRA) funds allowed MDOT to further improve pavement and bridge condition until 2012.

Based on 2012 funding levels, MDOT pavement and bridge conditions were predicted to decline over time, as inflation and debt payments continue to erode the Department's budget. Fig. 1, reproduced from [1] shows historic and predicted future pavement conditions for freeways made using actual data through 2011 and projections based on current funding levels for subsequent years. Fig. 2 shows historic and predicted future conditions for freeway bridges at current funding levels.

Both figures illustrate improving conditions in the late 1990's and early 2000's, and a projected decline in conditions in the future. The basic trends are similar for non-freeways, but MDOT is exceeding the target level of 85 percent good or fair for non-freeway pavements and bridges. The figures serve to illustrate two key concerns for MDOT. First, in the area of freeway pavements, MDOT has not yet reached its condition target, and is now moving away from rather than towards the target condition level. Second, moving forward at 2012 funding levels, asset conditions are projected to decline to levels not experienced by Michigan road users since the late 1990's.

To support deliberations on future funding, in 2013 MDOT performed an analysis to obtain insights on how conditions had varied over time, and what changes would have been needed in 1997 to enable MDOT to achieve its condition targets. Specifically, the analysis was conducted using MDOT's pavement and bridge management systems to determine the additional fuel tax revenues that would have been required beginning in 1997 to: replace bond revenues used to fund pavement and bridge projects from 1997 to 2012; and enable MDOT to meet its target pavement and condition levels. The following sections detail the analysis approach, results and conclusions.

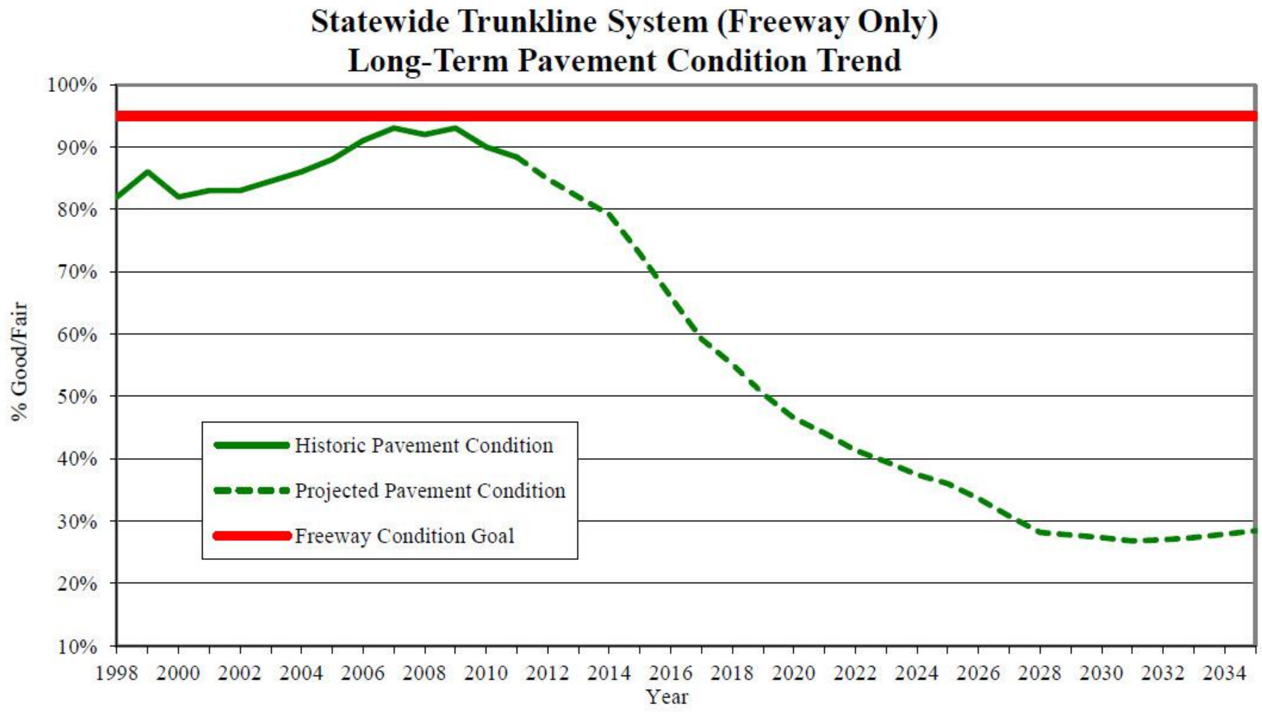

Fig. 1 MDOT freeway pavement conditions.
Source: MDOT (1).

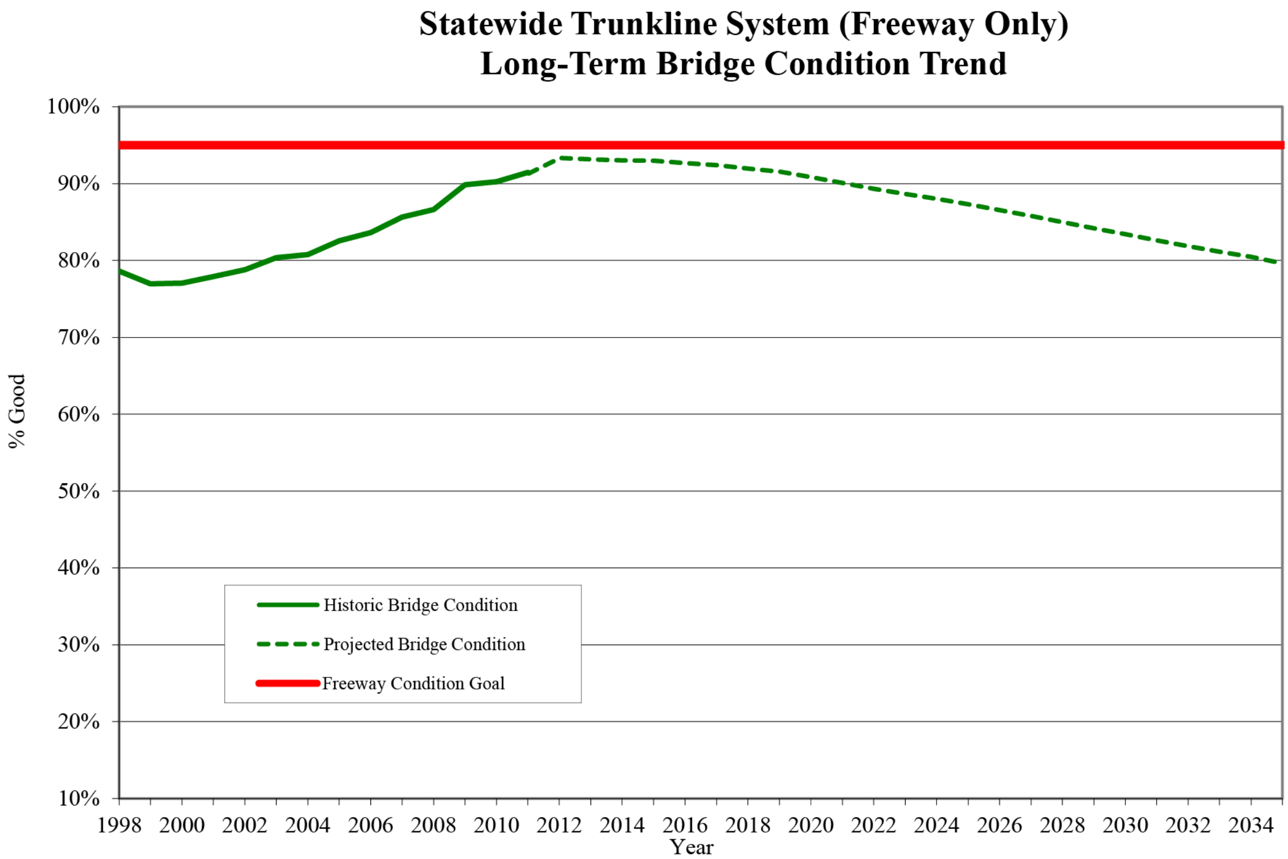

Fig. 2 MDOT freeway bridge conditions.
Source: MDOT (1).

2. Analysis Approach

Determining the additional fuel tax revenues that would have been required by MDOT to achieve its condition targets involved four primary analysis steps, described further in the following subsections:

- Projecting fuel tax revenue from a given tax increase
- Calculating bond revenue and repayment costs
- Predicting pavement and bridge conditions given a specified funding level
- Combining the revenue, bond and condition calculations

2.1 Projecting Fuel Tax Revenue

Revenue projections were developed using data on the revenues and split of revenues from the actual 4-cent increase, the gas price, and estimated fuel price elasticity of demand. Regarding the previous increase, MDOT staff first tabulated the total revenue from the increase received by the Michigan Transportation Fund (MTF). The revenue from the 4 cent increase in the fuel tax can be scaled to predict revenue that would have been realized from a further increase. However, the estimate needs to be adjusted for the price elasticity of demand. That is, the estimate needs to account for the fact that as the price of a good increases, the demand for that good tends to fall. A number of estimates of the fuel price elasticity of demand are available in the literature. For instance, Wong [5] reviews several studies of fuel price elasticity with estimates ranging from -0.1 to -1.1, with demand being more inelastic in the short-term. Poor [6] reviews over 30 sources on or related to fuel price elasticity, and notes that the value the Washington State Department of Transportation (WSDOT) uses for this parameter is -0.2. For the purpose of this analysis the WSDOT default of -0.2 was used, as this value is well within the range reported by Wong and Poor. The interpretation of this value is that for each percentage increase in the price of gasoline demand drops by 0.2 percent.

In order to calculate the impact of elasticity on tax revenues it is necessary to estimate the price of fuel. Average fuel prices were obtained from U.S. Energy Information Administration data (available at http://www.eia.gov/). For recent years a Midwestern price estimate has been available, but the average U.S. price was used, as the Midwestern estimate is not available for the full analysis period, and is in any case highly correlated with the U.S. value.

Together the above parameters support the calculation of MTF revenues from an additional increase in the fuel tax from 1997 to 2012. However, further calculations are required to determine the share of funds that would have been used for MDOT pavement and bridge preservation projects. MTF funds are divided between MDOT and Michigan counties and cities. From 1997 to 2004 MDOT received approximately 54% of the MTF total for the increased revenues. This figure declined to 48% in 2005, and approximately 42% from 2006 to 2012. Of the MDOT total, MDOT staff calculated that approximately 68% of the funds from the state fuel tax increase were used for non-capital uses not eligible for federal aid such as routine maintenance, administration and debt servicing. The remaining 32% was used for the capital program, with 40% of the capital program allocation used for pavement preservation and 17% for bridge preservation. For projecting the impact of additional funding, it was projected that the same splits would apply, though no additional funding would be required for non-capital uses. Thus, the analysis assumed that for each additional dollar of state fuel tax revenue received by MTF, approximately 17 to 22 cents would be used to match federal aid for pavement preservation, while 7 to 9 cents would be used to match federal aid for bridge preservation.

Table 1 illustrates the calculations for a hypothetical, additional increase of 4 cents per gallon. The table shows the average price of gasoline by year, actual MTF revenue from the previous increase, additional tax estimated accounting for elasticity, and predicted

Table 1 Predicted revenue from an additional 4-cent fuel tax (current dollars).

Year	Fuel Price ($/gallon)	Michigan Transportation Fund Revenue ($M)		Projected MDOT Capital Revenue from Additional Tax ($M)		
		Previous Increase	Projected from Additional Tax	Total	Pavement Only	Bridge Only
1997	1.19	32.3	31.1	16.9	6.7	2.9
1998	1.02	190.2	181.6	98.6	39.4	17.1
1999	1.12	196.0	187.9	101.9	40.7	17.7
2000	1.46	194.1	188.0	102.4	40.9	17.7
2001	1.38	196.5	190.0	102.9	41.1	17.8
2002	1.31	197.7	190.7	103.7	41.4	18.0
2003	1.52	197.0	191.0	103.7	41.4	18.0
2004	1.81	196.2	191.3	103.8	41.4	18.0
2005	2.24	194.2	190.2	91.5	36.6	15.9
2006	2.53	190.8	187.3	78.4	31.3	13.6
2007	2.77	186.0	182.9	76.5	30.6	13.3
2008	3.21	178.7	176.1	73.7	29.4	12.8
2009	2.31	178.1	174.6	73.0	29.1	12.6
2010	2.74	177.2	174.2	72.9	29.1	12.6
2011	3.48	175.1	172.8	72.3	28.9	12.5
2012	3.55	172.4	170.1	71.2	28.4	12.3
Total	N/A	2,852.5	2,779.8	1,343.4	536.4	232.8

additional MDOT capital revenue (total, pavement and bridge). All values are in current dollars. In this example, an additional four-cent increase is projected to yield somewhat less additional revenue than that projected for the previous increase (95 to 99 percent, depending on the year). After 1997 (the year the tax was implemented) the additional funds are expected to equate to $29 to $41 million of additional funds for pavement and $13 to $18 million additional for bridge, with revenues declining significantly after 2004.

2.2 Calculating Bond Revenue

MDOT staff prepared estimates of the revenues received from bonds from 1997 to 2012 for pavement and bridge preservation, and the cost of payments of principal and interest on those bonds made over the period of analysis. Table 2 summarizes the bonds issued and subsequent repayment costs in current year dollars, including only the portion of the bonds used for pavement and bridge preservation. The table shows that over the period from 1997 to 2012 MDOT used $1.49 billion of bond funding (in current dollars) for pavement and bridge preservation, and over this same period paid approximately $571 million in interest and principal on those bonds, with the bulk of the repayment costs incurred from 2010 to 2012. Proctor [4] provides additional detail and analysis on these numbers.

2.3 Predicting Pavement and Bridge Conditions

The MDOT management systems Roadway Quality Forecasting System (RQFS) and Bridge Condition Forecasting System (BCFS) were used to predict the pavement and bridge conditions that would result from a variety of different budgets. Both systems were designed to predict future conditions and costs, rather than to perform a "back casting" analysis. Thus, a number of adjustments and assumptions were required in interpreting system results to support the required analysis.

RQFS is a strategy analysis tool developed and used by MDOT to project results of pavement rehabilitation policies. MDOT has documented the basic modeling approach of RQFS previously [3, 7]. The primary performance measure in the system is RSL, calculated based on pavement distress data. The system is run with

Table 2 Use of bonds for pavement and bridge preservation (current dollars).

Year	Bonds Issued ($M)			Repayment Costs ($M)		
	Pavement	Bridge	Total	Pavement	Bridge	Total
1997	0.0	0.0	0.0	0.0	0.0	0.0
1998	0.0	0.0	0.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0	0.0	0.0
2001	198.4	0.6	199.0	0.0	0.0	0.0
2002	174.7	9.3	184.0	11.9	0.3	12.2
2003	17.3	0.0	17.3	20.9	0.4	21.3
2004	165.9	6.3	172.2	20.9	0.4	21.3
2005	75.6	0.0	75.6	22.3	0.5	22.8
2006	321.9	6.9	328.7	13.4	0.3	13.7
2007	296.6	0.3	296.9	21.7	0.5	22.1
2008	39.7	0.0	39.7	71.8	1.5	73.3
2009	92.4	0.0	92.4	74.2	1.6	75.8
2010	63.9	1.3	65.2	103.3	2.2	105.5
2011	0.0	0.0	0.0	98.7	2.1	100.8
2012	14.7	6.5	21.2	100.4	2.1	102.6
Total	1,461.0	31.2	1,492.2	559.5	12.0	571.5

a given rehabilitation policy, or "mix of fixes." The policy establishes thresholds for reactive maintenance, capital preventive maintenance, rehabilitation and reconstruction. The system predicts the treatments that will be performed at a network level given the policy, and the resulting conditions for MDOT freeways and non-freeways. The system does not support specification of an overall budget. To test the impact of a given budget it is necessary to adjust the model assumptions (e.g., amount of programmed work and the rehabilitation policy). Also, although MDOT can run the system using data from a previous year, it is feasible to go back only as far as 1998. Also, funding for 1997 was largely unaffected by the gas tax increase, as the increase went into effect midway through the fiscal year. Thus, RQFS was run assuming 1997 funds were unchanged, and any increased funding would be applied from 1998 to 2012.

Two scenarios were run in RQFS to test the impact of different budget assumptions. In both scenarios the pattern of funding was similar to that which actually occurred (excluding revenue from bonds), but the overall funding was varied. Fig. 3 shows the predicted percent good/fair for freeways and non-freeways by year for each scenario. The scenarios were characterized in terms of their overall funding in constant dollars (including 1997 expenditures not modeled by RQFS), and the resulting conditions for freeways and non-freeways in 2007 and 2012. A set of linear models was derived for predicting the freeway and non-freeway percent good/fair as a function of total funding.

In deriving the models a multiplier of the constant dollar budget was calculated such that the resulting linear models correctly predict the actual condition results given the actual constant dollar budget for pavement. Table 3 summarizes the resulting models. For instance, for freeway pavement in 2012 the slope of the resulting model is 8.05E-11 and the intercept is 0.163. Thus, given an $8 billion total budget for pavement from 1997 to 2012, the model predicts the resulting percent good/fair for freeway would be 8.05E-11 * 8.00E+9 + 0.163 = 0.808, or approximately 81 percent. The table shows that in deriving the models relatively large multipliers were

calculated for the budgets modeled by RQFS to match actual results: 0.418 for the 2007 model and 0.531 for the 2012 model, indicating it was necessary

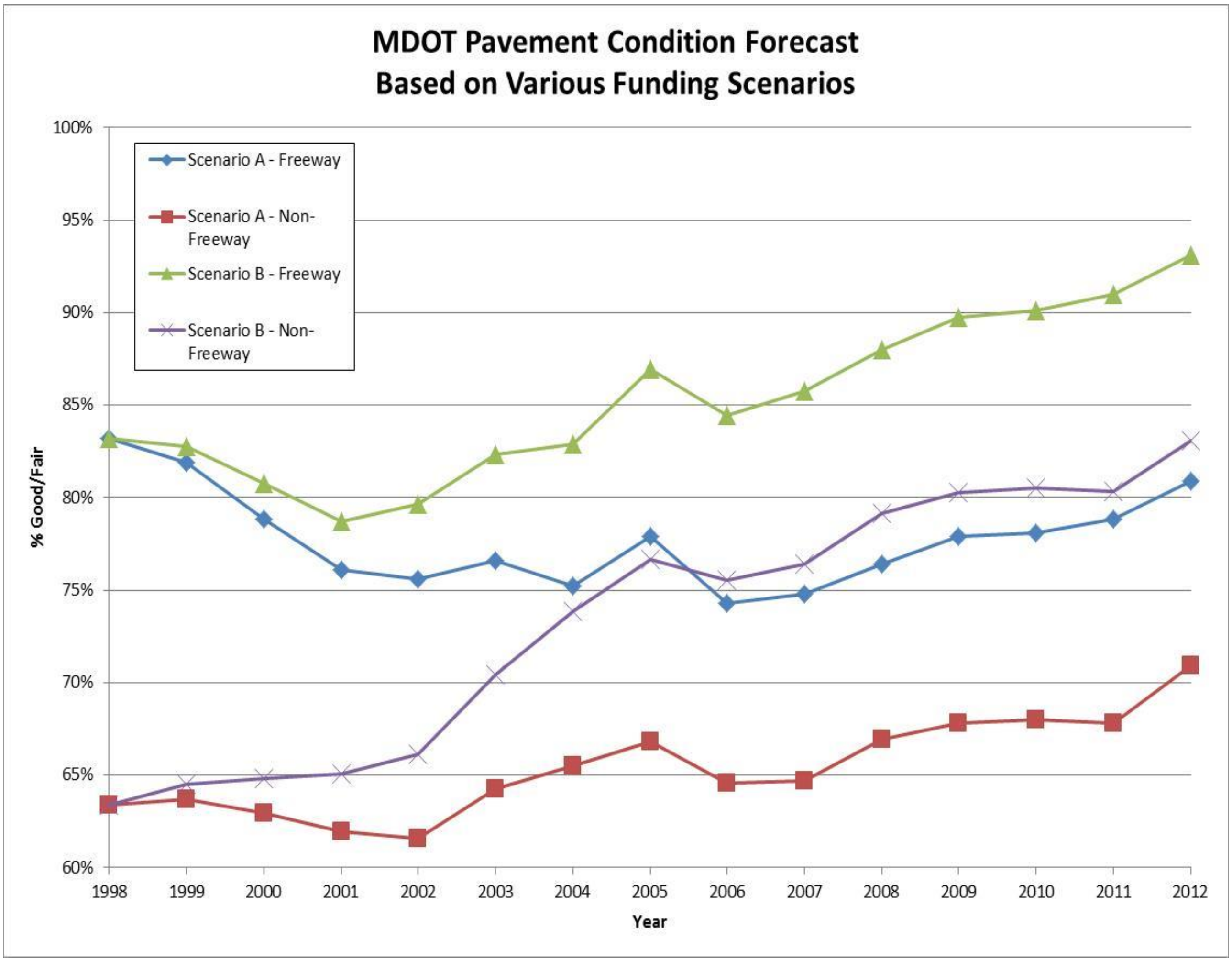

Fig. 3 ROFS projections for percent good/fair for selected scenarios.

Table 3 Pavement best-fit models.

Parameter	**Value by Model**	
	2007	**2012**
Freeway - m (slope)	1.23E-10	8.05E-11
Freeway - b (intercept)	0.251	0.164
Non-Freeway - m (slope)	1.31E-10	8.02E-11
Non-Freeway - b (intercept)	0.118	0.067
Calibration Factor	0.418	0.531

to approximately halve the budget predicted by RQFS to match actual observations. These adjustments are described further in the Results section.

A similar approach was used for predicting bridge conditions. MDOT uses BCFS for testing network-level bridge investment strategies. BCFS has two components. The first component calculates a transition probability matrix that predicts the likelihood of transition from one condition rating to another based on MDOT's historic NBI inspection data. The system uses the minimum of the deck, superstructure, substructure and culvert ratings for characterizing the condition rating of each bridge. The second component of the system simulates the effects of capital preventive maintenance, rehabilitation and replacement work, given an initial distribution of condition ratings, overall budget by year, and split of the budget by the three categories of work. The system uses an average cost per bridge for each work type and incorporates a set of business rules for predicting the application of the different treatments and their effects given a set of bridge condition ratings. Additional information on the system has been published by MDOT and the Federal Highway Administration (FHWA) [3, 8].

Three scenarios were run in BCFS to test the impact of different budget assumptions. For each scenario it was necessary to run the system twice – from 1997 to 2006, and from 2007 to 2012, in the latter case using the predicted 2006 results as an input. Breaking the scenarios into two pieces was necessary as the system is designed for a 10-year analysis, but doing this allowed for specification of different deterioration rates for the two periods, consistent with the actual data. In the scenarios the pattern of funding was similar to that which actually occurred, but the overall funding was varied. Fig. 4 shows the predicted percent good/fair for freeways and non-freeways by year for each scenario.

The approach described above for pavement was used to develop linear models for predicting bridge freeway and non-freeway percent good/fair in 2007 and 2012 given a total preservation budget expressed in constant dollars. Table 4 summarizes the resulting models. The table shows that a very modest adjustment was made to the budgets modeled by BCFS to match actual results, with calibration factors of 1.055 for the 2007 models and 1.082 for the 2012 models. These adjustments are described further in the Results section.

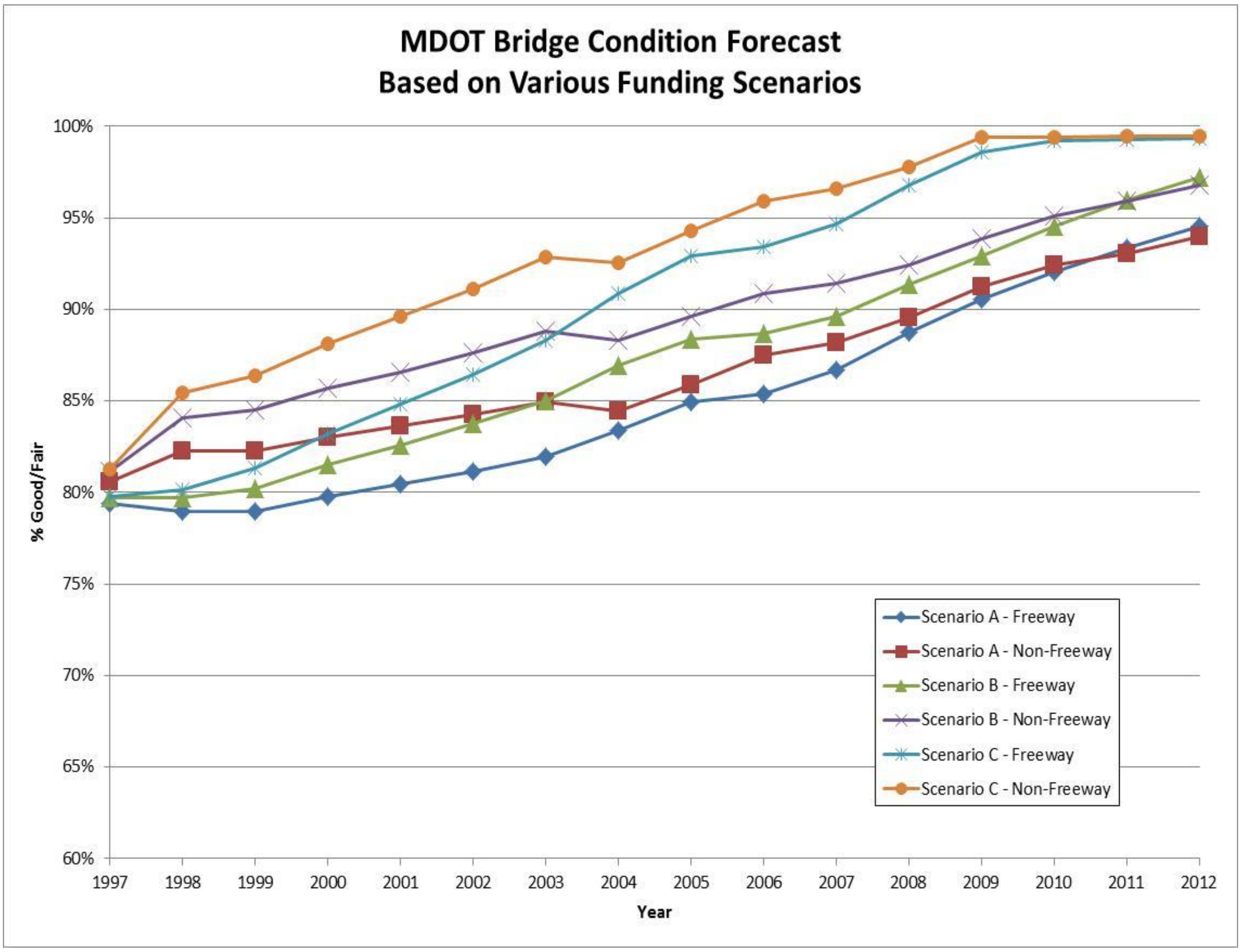

Fig. 4 BCFS projections for percent good/fair for selected scenarios.

Table 4 Bridge best-fit models.

Parameter	Value by Model	
	2007	2012
Freeway - m (slope)	1.38E-10	6.26E-11
Freeway - b (intercept)	0.574	0.741
Non-Freeway - m (slope)	1.46E-10	7.19E-11
Non-Freeway - b (intercept)	0.573	0.704
Calibration Factor	1.055	1.082

2.4 Combining the Calculations

The last step in the analysis was to combine the revenue, bond, pavement and bridge results. This was accomplished as follows:

Actual pavement and bridge preservation expenditures by year were adjusted to approximate the spending that would have occurred without bond revenues and repayment costs. In other words, revenues from bonds were subtracted from and repayment costs were added to actual preservation expenditures.

The fuel tax increase was specified, resulting in predicted additional revenue for pavement and bridge preservation. The resulting pavement and bridge funding (actual – bonds + additional funding) was calculated by year.

Total pavement and bridge funding was calculated, adjusting the year-by-year values for inflation. FHWA construction cost indices were used for this calculation. Note FHWA's calculations of the National Highway Construction Cost Index (NHCCI) are published for years 2003 and forward. FHWA's composite construction index was used for prior years. This index predicted a 14.7 percent increase in prices from 1997 to 2003, versus a 9.6 percent increase for the Bureau of Labor Statistics (BLS) Producer Price Index and a 14.6 percent increase in the Consumer Price Index for this period. Fig. 5 shows the two FHWA indices and resulting value used for inflation adjustments.

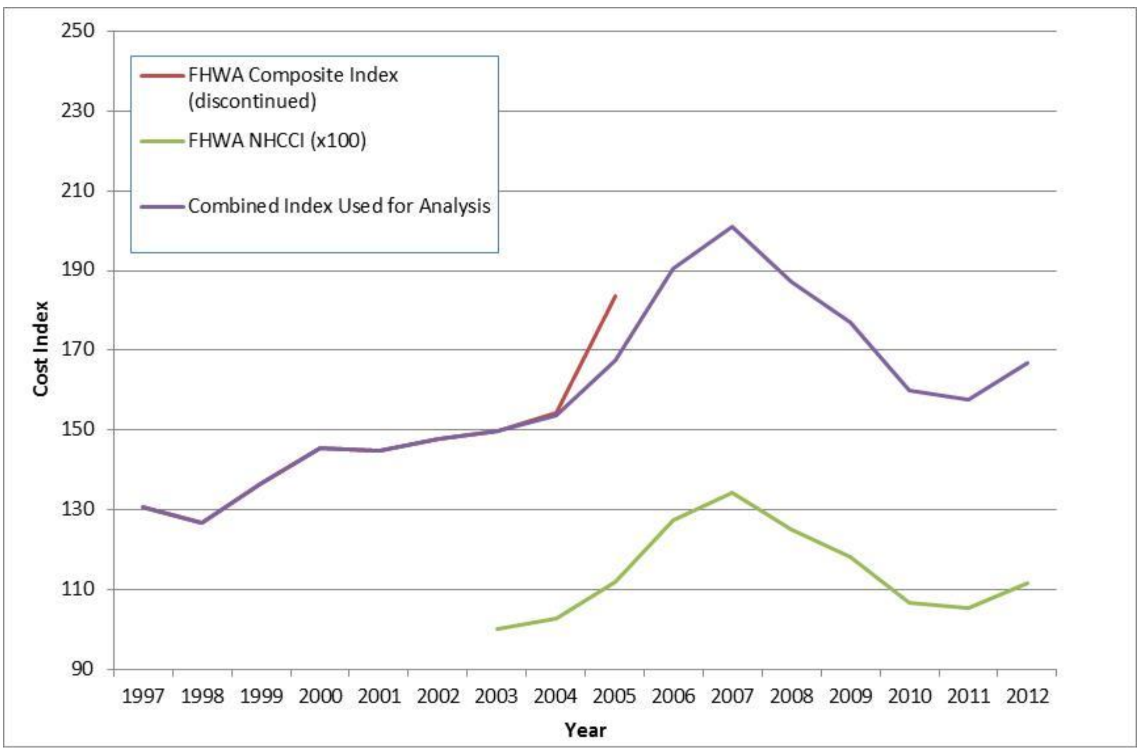

Fig. 5 Cost indices used for the analysis

Pavement and bridge conditions were projected given the resulting overall pavement and bridge budgets using the models specified in Tables 3 and 4. Note that if the funding was sufficient for meeting the targets for one asset type, but not sufficient for meeting the targets for the other asset type, funds were "rebalanced," shifting the funds in excess of that required to meet MDOT's targets from one asset type to the other.

The process was repeated, testing different hypothetical tax increases to determine the tax increases that would have been required to: a) replace funding from bonds; and b) both replace funding from bonds and achieve MDOT's pavement and bridge targets.

3. Analysis Results

Table 5 summarizes the results of the analysis. The table shows the total pavement and bridge budgets, and percent good/fair predicted by asset group for 2007 and 2012. Results are shown for four funding scenarios: actual funding; actual funding but without additional bond revenues; and additional fuel tax increases of 5 cents and 10 cents without bonds. In the table, condition results are shaded where predicted to meet MDOT targets of 95 percent good/fair for freeways and 85 percent for non-freeways. Figure 6 shows predicted conditions for 2012 graphically. Note the results are not highly sensitive to alternative assumptions regarding inflation or fuel price elasticity.

The table shows that MDOT met its goals for non-freeway conditions in both 2007 and 2012, and met its goals for freeway bridges in 2012. However, for freeway pavements conditions fell slightly short of the goal in 2007, and since then have declined further. Without bonds, pavement conditions would have been significantly worse, with a drop of approximately 6 percentage points for freeway pavements projected for 2012, and 18 percentage points for non-freeway pavements. An additional fuel tax of approximately 5 cents would have been required beginning in 1997 to generate the equivalent amount of revenue for pavement and bridge preservation as bonds did during the period from 1997 to 2012. However, an increase of 10 cents (in addition to the actual increase of 4 cents) would have been required to enable MDOT to meet is target condition levels, as illustrated in the last column of the table and in Fig. 6.

One concern in analyzing the results was that a substantial adjustment was required to expenditures predicted by RQFS to match model results to actual observations. MDOT staff performed further analysis to better characterize this issue. Through this analysis MDOT determined that two primary factors contributed to the discrepancy. One factor is that the projections for RQFS assume an average inflation rate

Table 5 Summary results.

Description	Asset Group	Actual Funding	Actual - Bonds	Actual-Bonds+ Additional Fuel Tax	
				5 cents	10 cents
Total Budget, 1997-2012 (Constant $M)	Pavement	8,573	7,710	8,738	9,705
	Bridge	3,289	3,257	3,257	3,306
	Total	11,862	10,967	11,996	13,012
2007 % Good/Fair	Pavement - Freeway	93.0%	83.9%	90.5%	96.6%
	Pavement - Non-Freeway	91.2%	74.4%	81.5%	87.9%
	Bridge - Freeway	87.9%	87.6%	90.8%	94.5%
	Bridge - Non-Freeway	89.4%	89.2%	92.6%	96.5%
2012 % Good/Fair	Pavement - Freeway	85.4%	78.5%	86.7%	94.5%
	Pavement - Non-Freeway	87.1%	68.5%	76.7%	84.5%
	Bridge - Freeway	94.6%	94.5%	94.5%	94.8%
	Bridge - Non-Freeway	94.2%	93.8%	93.8%	94.2%

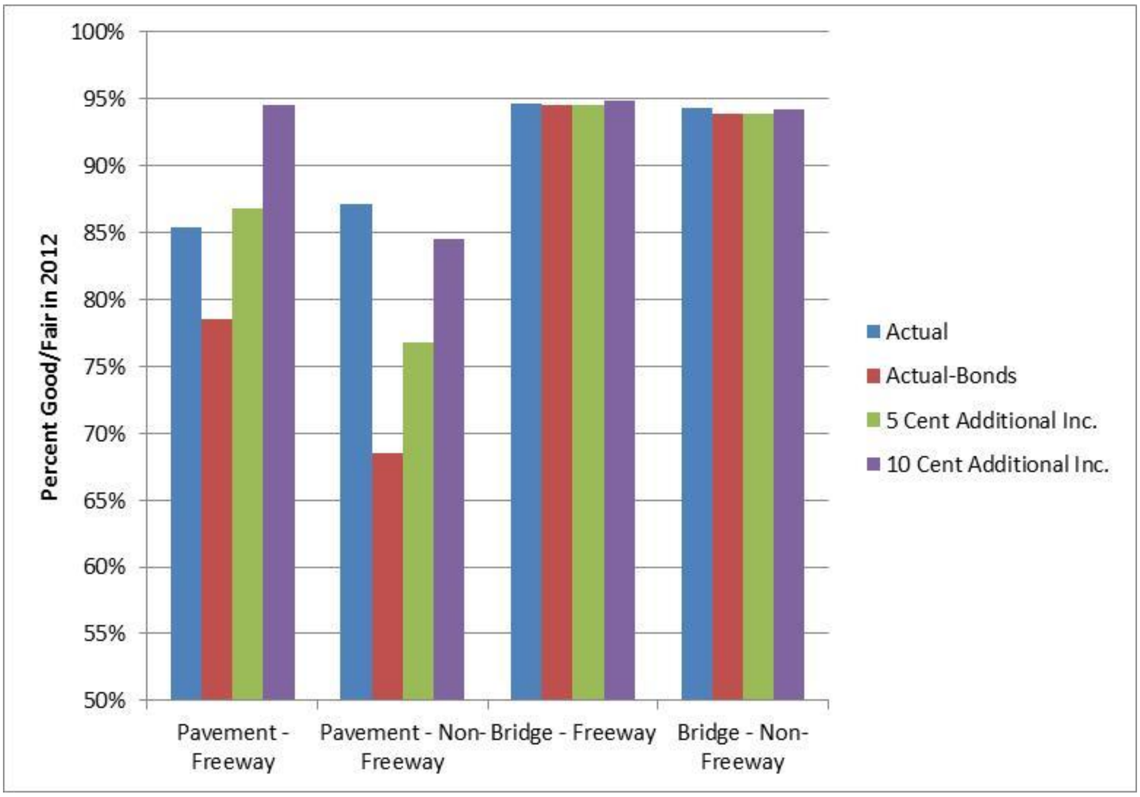

Fig. 6 Predicted percent good/fair in 2012 by asset group.

of 5 percent per year, consistent with MDOT experience. RQFS and BCFS runs were performed using 2012 costs, but in the case of RQFS these costs were then inflated to account for predicted future inflation. A second factor is that RQFS assumes a somewhat different mix of fixes moving forward, with greater emphasis on rehabilitation and reconstruction, than MDOT actually used in the past. MDOT staff demonstrated that when RQFS is run with the actual mix of fixes used by MDOT it closely approximates actual conditions. Based on the supplemental analysis, the approach of applying a multiplier to modeled expenditures was deemed to be reasonable for calibrating model to actual results, though further analysis may be warranted of RQFS modeling assumptions regarding future costs and treatments.

In contrast to the case of RQFS, for BCFS very little adjustment was required to the system's projections. This stems from the fact BCFS projections were made in 2012 dollars without additional inflation assumed, and from the fact that BCFS appears well-tailored for performing the sort of historic analysis described here. Since BCFS fits a set of deterioration models based on observed data, it can be readily calibrated to work with historic data.

4. Conclusions

The analysis described here yielded a number of conclusions. First, it provided Michigan decision-makers considering future transportation funding options with information on historic conditions and the impact of previous decisions regarding funding. Results of the analysis, coupled with additional information on revenues, impact of bonding, and other considerations, were summarized in [4] and distributed to decision-makers and the public. Second, the analysis served as a useful test of MDOT's management systems that will aid in making future systems improvements. A particular issue illustrated by the analysis is that while RQFS is a powerful tool for testing future strategies, it is not designed for historic analysis or rapidly testing different budget assumptions.

MDOT is now exploring the potential for coupling results from RQFS with a spreadsheet tool patterned on the analytical approach used by BCFS to leverage the strengths of both systems. Third, the analysis demonstrated an approach for using pavement and bridge management systems to perform what-if analyses and test different funding assumptions with historic data. Pavement and bridge management systems may not be designed for such “back casting” analyses, but historic analysis can be used to help test modeling assumptions and parameters, and provide insights into future decisions.

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