Prefabricated Elements Case Study

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Smart Work Zone Deployment Initiative

Final Report
June 2007

Sponsored by
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and
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16. Abstract

Prefabricated elements have the opportunity to reduce the duration of closed lanes during highway reconstruction. Typically, an element that is prefabricated off-site and installed, rather than being constructed in-place, diminishes the duration of on-site construction activities and, therefore, minimizes the disruption and congestion of traffic due to shorter duration lane closures. This case study presents an analysis of the benefits and costs of using prefabricated pavement panels.

The case study involves a small panel replacement project, conducted by the Minnesota Department of Transportation, involving the installation of precast concrete pavement panels. The installation segment consisted of a 218 ft. continuous stretch of 12 ft. wide pavement. The objective of the test project was to evaluate the use of precast pavement panels to reduce construction time, thus reducing overall and continuous motorist delay due to a lane closure.

The results of the benefit-to-cost analysis conducted as part of this case study suggest that for small projects that consist of only a few panels, using prefabricated panels to reduce work zone user costs is cost-effective; however, as projects involve more prefabricated panels, the construction costs quickly escalate and become cost prohibitive.

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PREFABRICATED ELEMENTS CASE STUDY

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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We are grateful to several individuals. These include Tom Notbohm of the Wisconsin Department of Transportation; Jerry Roche of the Iowa Division of the Federal Highway Administration; Mark Bortle of the Iowa Department of Transportation; Daniel E. Sprengeler of the Iowa Department of Transportation; Tracy Scriba, Headquarter Office of the Federal Highway Administration; and Jim Brachtel, retired, from the Iowa Division of the Federal Highway Administration. We would also like to thank Cassandra Isackson of the Minnesota Department of Transportation Metro Division for providing us with the information for the case study.

1. INTRODUCTION

Prefabricated elements have the opportunity to reduce the duration of closed lanes during highway reconstruction. Typically, an element that is prefabricated off-site and installed, rather than being constructed in-place, diminishes the duration of on-site construction activities and, therefore, minimizes the disruption and congestion of traffic due to shorter duration lane closures. This case study presents an analysis of the benefits and costs of using prefabricated pavement panels. These panels are cast off-site and are ready for installation once the base is prepared. Since the concrete panels are already cured, the section can be opened for traffic immediately following placement of the panel and sealing. Using prefabricated panels eliminates the curing time required when cast-in-place panels are used. However, the precast panels are about eight times more expensive than traditional cast in-place panels, meaning that reduced user costs (work zone delays) are achieved at the expense of increased reconstruction costs. For small projects that consist of only a few panels, using prefabricated panels to reduce work zone user costs is cost-effective; however, as projects involve more prefabricated panels, the construction costs quickly escalate and become cost prohibitive.

For each case, the trade-off between user cost and the expense of prefabricated panels will be unique and dependent on traffic conditions and network characteristics in the neighborhood of the work zone (e.g., availability of diversion or detour routes). This case study presents a fairly simple example of the analysis required to make a decision on the economic feasibility of the use of a prefabricated panels. Because this is a relatively simple analysis, we have only accounted for the road user impacts on the roadway being reconstructed. We did not take into the account the broader network impacts of diverted vehicles on other routes or creating delays at other locations in the network, nor did we take into the account the higher safety costs associated with creating a queue on busy alternative routes.

The case study involves a small panel replacement project conducted by the Minnesota Department of Transportation. On Tuesday, June 21, 2005, the Minnesota Department of Transportation (Mn/DOT) conducted a test project involving the installation of precast concrete pavement panels on TH 62, between I-35W and TH 55, on the southeast side of the City of Minneapolis in the Twin Cities Metropolitan Area. The installation segment consisted of a 218 ft. continuous stretch of 12 ft. wide pavement on the outside lane of the eastbound direction near 40th Ave. The objective of the test project was to evaluate the use of precast pavement panels to reduce construction time, thus reducing overall and continuous motorist delay due to a lane closure. A Mn/DOT report was prepared on the project, summarizing the precast units and construction process, as well as providing a construction cost analysis and safety analysis (*1*).

2. PURPOSE

The purpose of this case study is to provide an example of an analysis of the use of prefabricated elements to reduce the duration of closed lanes during highway reconstruction. The objective of the analysis is to show a process to determine the benefits and costs of using prefabricated panels versus traditional concrete replacement for both a 218 ft. construction project and a single panel replacement. Through this process, the report will identify why the analysis is location specific and will outline the components that make the benefit-to-cost (B/C) analysis site specific. The end result of the analysis is not necessarily intended to show that precast concrete panels should or should not be used for all locations; rather, the intent is to show that this method has advantages in certain types of projects and locations and that the analysis should be conducted on a case-by-case basis for each specific project. The calculated results of this case study are not meant to be transferred directly and used as a mechanism to decide on the use of precast concrete panels in another location; rather, the process outlined in this report could be used for another location, with site-specific inputs, to make the analysis representative for that site's characteristics.

3. PRECAST CONCRETE PANELS

The precast concrete panels were fabricated at Wieser Concrete in Maiden Rock, Wisconsin. The panels are part of the Super-Slab system developed by Fort Miller Company, Inc. of Schuylerville, New York. Eighteen precast pavement units were installed on the project. Each unit was 12 ft. by 12 ft., with a depth of 9¼ inches.

The construction sequence for the project consisted of the following:

- Removing the old concrete pavement
- Fine grading the base
- Placing the precast panels, or grouting the panels
- Sealing the joints

The existing concrete was removed using conventional methods similar to those typically used in concrete replacement and reconstruction projects.

The fine grading of the base consisted of installing a leveling pad of fine-graded crushed limestone, or stone dust, and was quite time-consuming. The crushed limestone was compacted using a small vibratory roller. While other, more time-efficient, equipment is available for base compaction, it was not cost-effective for the contractor to mobilize these larger pieces of equipment due to the small size of the project.

The installation consisted of lifting the panels off of the truck with a crane and sequentially placing them, male end to female end, with a bond breaker between the slabs. The bond breaker is a small piece of foam that separates the units during installation to prevent damage when sliding the panels together. The installation continued, and the existing concrete was measured to determine where the saw cut should occur for a tight fit between the final panel and the existing concrete pavement. The termination point was saw cut and dowel bars were inserted into the existing concrete. The final precast panel had two female ends to fit over the dowel bars on both the neighboring precast panel and the existing pavement.

For this project, the precast panels were not tied to the adjacent 12-foot lane, due to the adjacent lane having joint spacing longer than twelve feet apart. Therefore, a one-inch contraction joint was used and sealed with a grout and joint sealer.

After the panels were placed, the joint slots, or dowel bar openings, were grouted with fast-setting grout.

4. TRAFFIC VOLUMES

The traffic volumes used in the B/C analysis of the prefabricated concrete panels compared to traditional concrete pavement were those in the Mn/DOT's *Metropolitan District Lane Closure Manual* (*2*).

Figure 1 contains the eastbound hourly and daily volumes as well as the allowable lane closures from TH 62 from TH 77 to TH 5. The volumes were counted in April and May 2003 by the Regional Traffic Management Center, detector station 325.

The method used here to determine queue lengths and volumes is a deterministic queuing model. Because this is only a case study example and the focus of the case study is on the economic analysis of a prefabricated element, we decided not conduct a more sophisticated study of the likely queues at this particular location. If this were an analysis to plan the actual use of precast panels, we would recommend using a work zone traffic operations model, such as Quickzone, or a traffic simulation model (for more information on modeling queues at lane closures see [*3*]). The manual uses allowable lane volumes based on the Highway Capacity Manual and experience. Each lane has an hourly volume of 1,800 vehicles. TH 62 is a four lane facility, so a single lane closure in one direction would reduce capacity to 1,800 vehicles per hour in that direction.[1] As shown in Figure 1, the directional volumes often exceed 1,800 vehicles. Therefore, a queue will develop in which the number of vehicles exceeding 1,800 in that given hour will be waiting; in addition, the queue could include vehicles from the previous hour that are still waiting.

[1] By comparison to what is found in the literature, 1,800 vehicles per hour through a lane closure is a relatively high estimate of capacity. However, to be consistent with Minnesota Department of Transportation practice, our analysis uses 1,800 vehicles per hour.

Allowable Lane Closure

Date Day Hours	MON	TUE	WED	THUR	FRI	Average Weekday	Allowable Lane Closure	SAT	SUN	Date Day Hours
12-01AM	203	239	253	282	318	259		467	467	12-01AM
01-02	136	158	164	185	225	174		350	356	01-02
02-03	87	101	105	122	136	110	1	196	191	02-03
03-04	86	100	102	114	127	106		139	141	03-04
04-05	260	226	232	266	262	249		178	159	04-05
05-06	983	902	930	961	851	925	0/1	409	318	05-06
06-07	2014	1941	1915	1992	1839	1940		708	599	06-07
07-08	2574	2655	2629	2599	2520	2595	0	988	674	07-08
08-09	2135	2229	2188	2260	2162	2195		1089	762	08-09
09-10	1664	1635	1745	1748	1711	1701		1418	997	09-10
10-11	1475	1444	1476	1473	1549	1483	0/1	1510	1317	10-11
11-12N	1627	1704	1673	1746	1852	1720		1819	1517	11-12N
12-01PM	1790	1846	1845	1875	2019	1875		2007	1898	12-01PM
01-02	1824	1862	1907	1945	2112	1930		1930	1936	01-02
02-03	1964	2010	2064	2076	2222	2067	0	1921	1923	02-03
03-04	2201	2235	2328	2314	2405	2297		1845	2032	03-04
04-05	2490	2555	2613	2591	2583	2566		1797	1940	04-05
05-06	2698	2668	2715	2803	2585	2694		1735	1903	05-06
06-07	1971	2035	2117	2147	2021	2058		1574	1540	06-07
07-08	1486	1553	1616	1560	1632	1569		1316	1467	07-08
08-09	1295	1472	1388	1424	1291	1374	0/1	1144	1221	08-09
09-10	1259	1276	1333	1384	1294	1309		1154	1034	09-10
10-11	801	862	904	926	1029	904		949	694	10-11
11-12M	506	544	549	585	712	579	1	712	419	11-12M
Totals:	33524	34252	34791	35378	35457	34680		27350	25501	

Allowable Lane Closure

0	= 0 lane closures allowed
0/1	= 0 lane closures within 500' of signal; otherwise 1 lane closure allowed
1	= 1 lane closure allowed
2	= 2 lane closure allowed

Figure 1. Allowable lane closure (Mn/DOT Metro District Lane Closure Manual)

For this analysis, it was assumed that each vehicle needed about 53 feet in the queue, thus allowing 100 vehicles per lane mile in a queue. Therefore, 200 vehicles can be in a queue for one mile using both lanes. The queue length was limited to one mile as a break-off point. Given the density of the highway network in the metropolitan area and the existence of parallel routes, an aggressive management program to divert traffic could limit the length of queues. A maximum of a one-mile-long queue was selected in this analysis because one mile would encompass an interchange upstream from the project site through which vehicles could access freeway design standard parallel routes.

Traffic volumes were both increased and decreased by 5% from the 2003 counts. A 5% decrease may represent a lower volume resulting from traveler diversion due to lane closure information provided by the Mn/DOT to the traveling public. With a 5% volume decrease, nine more hours per week were available for an allowed lane closure (52 hours compared to 61 for 2003 counts). A 5% increase may better represent traffic volumes (2006 traffic volumes) than the 2003 counts.

This component of the analysis is an example of inputs that are location-specific. Traffic volumes vary by facility in both AADT and hourly volumes. Other variations in facility traffic condition characteristics could include

- highly directional traffic at particular times of day,
- seasonal traffic fluctuations, and
- consistency of traffic volumes throughout the day.

Work zone lane capacity threshold values and allowable queue length or delay times vary between STAs. For this analysis, the Mn/DOT work zone lane capacity of 1,800 was used and the queue length was limited to one mile. Using a smaller work zone lane capacity and longer allowable queue, the delay would be considerably longer for a lane closure.

5. BENEFIT AND COST COMPONENTS

To help quantify the benefits of using precast concrete pavement panels over traditional methods, a B/C ratio was used for each scenario. At first glance, the benefits of precast concrete pavement panels are difficult to see. The construction and material costs are significantly higher for precast panels than for traditional concrete replacement. However, the precast panels can be installed in considerably less time, reducing the length of time needed for construction and reducing the length of lane closures.

The user benefit in the calculation is the difference in road user delay costs between the construction schedule of precast concrete panels and traditional construction. For each scenario, the queue is determined hourly to calculate the road user costs. The cost of delay per vehicle is figured at $16.17 per hour. The value of time used per person per hour is $12.63 and is multiplied by the Minnesota automobile occupancy rate of 1.28 for peak travel periods (*4*). The peak automobile occupancy rate was used (instead of off-peak or daily values) because the delays due to a lane closure occur during the AM and PM peak travel periods. The total road user delay cost per day is the cost of delay multiplied by the total number of vehicles in queue for a certain day.

The cost portion of the B/C ratio is the owner cost, or the cost of construction. Construction costs were provided to show the large difference between the two construction techniques. The costs provided by Mn/DOT are shown in Tables 1 and 2.

Table 1. Cost of traditional repair

Item	Qty	Unit	Unit price	Cost
Full depth contraction joint repair	12	LF	$45.55	$546.60
Full depth panel replacement	283	SY	$69.20	$19,583.60
Reinforcement bars	90	LB	$6.00	$540.00
Dowel bars	96	EACH	$5.00	$480.00
Seal concrete pavement joints	15	LB	$3.80	$57.00
Joint repair	336	LF	$1.30	$436.80
Total traditional repair				**$ 21,644.00**

Table 2. Cost of precast concrete pavement panels

Item	Qty	Unit	Unit Price	Cost
Remove concrete pavement	2592	SF	$1.00	$2,592.00
Precast concrete panel	18	EACH	$9,040.00	$162,720.00
Seal concrete pavement joints	15	LB	$3.80	$57.00
Joint repair	336	LF	$1.30	$436.80
Total precast repair				**$ 165,805.80**

Mn/DOT noted in the report that, while the panel cost in the low bid was $9,040 per panel, the engineers estimate was $5,760 per panel. The panel cost included the costs associated with having the manufacturer on-site during construction and at the pre-construction meeting. The total costs included items related to pavement rehabilitation (excluding traffic control costs), diamond grinding, and striping.

As shown in Tables 1 and 2, the construction costs of prefabricated concrete panels are considerably higher than the costs of traditional concrete placement methods. However, this is also a location-specific input, for both traditional concrete placement methods and precast concrete pavement panel installation. Transportation costs can play a role in total construction cost as can material costs at the time of purchase. Fluctuation in both fuel and material prices can impact the total cost of the project, thus impacting the cost portion of the B/C analysis. Labor costs vary by location as well and are not figured in this analysis, but could be taken into account as another cost, or potential benefit, in the analysis. By using a more experienced crew, the schedule and lane closure duration could be reduced because of increased work efficiency over an inexperienced crew. However, a more experienced crew could also cost more to employ as they possess a more specialized skill than other laborers or contractors.

6. SCENARIO DESCRIPTIONS

To determine when it is appropriate to use higher construction cost prefabricated panels instead of lower cost cast-in-place panels, B/C ratios were calculated for different project lengths and different construction schedules. The results of these analyses were used to form a sensitivity analysis to determine the conditions under which it would be cost-beneficial to use prefabricated panels. To conduct the sensitivity analysis, the researchers investigated the user costs and construction costs of varying the length of panels from 1 panel to 18 panels (the length of the Mn/DOT experiment). From this range of panels, a number of panels was identified for this unique project, where the user benefits equaled the added construction costs.

6.1 Traditional Method

As a basis for comparison, a traditional concrete repair project, a standard full-depth panel replacement (Mn/DOT defines this as a Type D-1 repair), with characteristics similar to those of the precast concrete panel portion, was used. The report stated that a standard full-depth panel replacement with high early-strength concrete would result a continuous lane closure of about four days—one day to remove and replace the concrete and three days cure time. Therefore, the traditional concrete repair was used for comparison. This scenario included a continuous lane closure beginning during the AM peak hours of the first day and opening to traffic by the AM peak of the fifth day (e.g., lane closed by Monday 6:00 AM and reopened by Friday AM, thus not affecting the Friday AM peak). A generalized schedule follows.

- Day or night 1: Concrete replacement (barrier set after previous evening peak)
- Day 2: Concrete curing
- Day 3: Concrete curing
- Day 4: Concrete curing

It was assumed that concrete work could be performed for either the single panel or the full 218 ft. installation within the time allotted (four days), as curing duration lasts three days regardless of the number panels cast. Examples of the weekday and weekend schedules for both single panel and multiple panel projects are shown in Figure 2. The schedules display the times where construction and concrete curing is occurring (boxes with vertical lines) and allowable closure times that will not create queues. While traditional methods necessitate a four day closure, the schedule shows that the lane can be occupied for more time if needed preceding or following the lane construction because volumes are low (off-peak) and do not cause a queue. The queues were analyzed for projects with similar four-day schedules beginning on all seven days of the week, labeled as follows:

- Monday – Thursday (shown in Figure 2)
- Tuesday – Friday
- Wednesday – Saturday
- Thursday – Sunday
- Friday – Monday

- Saturday – Tuesday (shown in Figure 2)
- Sunday – Wednesday

Note that the day indicated is the first day that the lane closure occurs during a non-permitted closure time—usually the morning peak period.

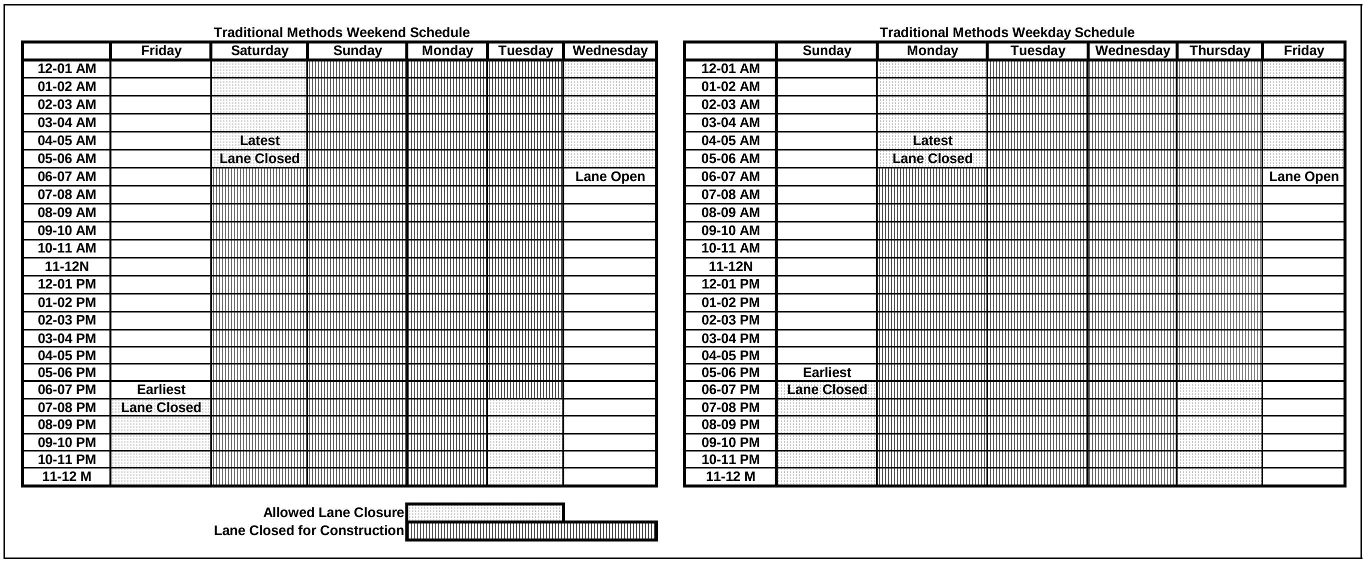

Figure 2. Weekend and weekday construction schedules using traditional construction methods

To stay consistent with the report prepared by Mn/DOT, the schedule provided in their report for the traditional concrete placement was used. The cure time is a variable that will differ between each STA or location because of possible accelerator additives that STAs might use for certain projects. Therefore, the traditional concrete placement schedule can vary widely between STAs and the actual schedule could be dramatically reduced, thus affecting the final benefit-to-cost analysis results. Similarly, the project scheduling may vary on start times during different days of the week in order to avoid high traffic volumes on certain days of the week.

6.2 218 ft. Precast Panel Replacement

The schedule that Mn/DOT actually used for the 18 panel installation involved a four day installation. The following schedule is similar to the one used in the report:

- Day 1: Set barrier (Sunday)
- Day 2: Removals and stone dust placement (Monday)
- Day 3: Place panels and grout (Tuesday)
- Day 4: Seal joints and repair shoulders (Wednesday)

While Mn/DOT's project actually took four days to complete, it was not considered to be a typical project using prefabricated panels. The report stated that the contractor was not under any incentive to finish the project at a certain time. The contractor was also delayed due to an afternoon storm that halted base compaction. In addition, the contractor and the workers were unfamiliar with this type of operation and spent a longer amount of time on each task at the beginning than they did when finishing, due to increased familiarity with the task. The report stated that the schedule could be drastically reduced for this length of project when the contractor is more familiar with the precast pavement panel installation process. Therefore, the report stated that a reasonable timeline could be two days plus a night of closure, as follows, instead of four continuous days of closure:

- Day 1: Set barrier and perform removals
- Day 2: Set and grout panels
  - Open to traffic in PM peak if allowable
- Night of Day 2: Seal joints and repair shoulders

Figure 3 displays both the weekend and weekday construction schedules for precast pavement panel installation for a 218 ft., 18 panel project. The weekend schedule begins after the Friday PM peak period and must be completed by the Monday AM peak period. Night work can be performed before the Monday AM peak period if needed without causing a queue, but the Mn/DOT report does not state that this period of night work is needed. The weekday schedule incorporates the same four day schedule; however, the lane is opened to traffic for the Tuesday peak PM period and closed again for night work to finish the installation.

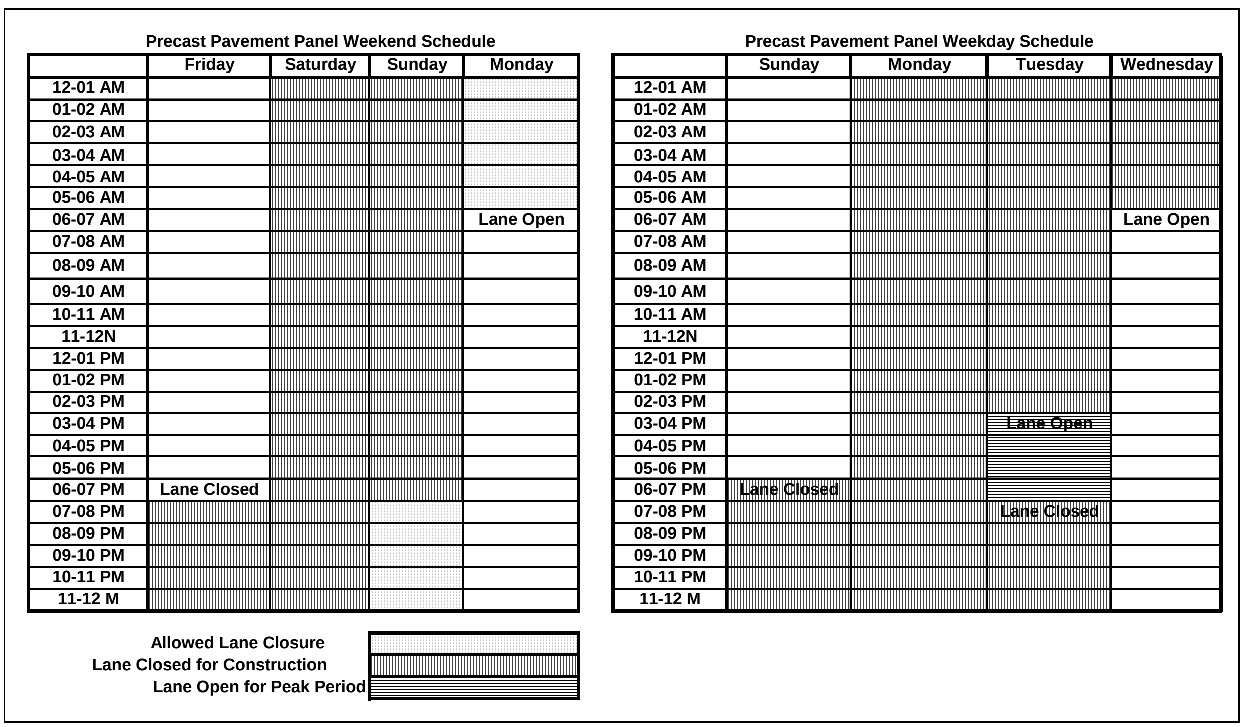

Figure 3. Weekend and weekday construction schedules using precast pavement panels for 18 panels

The possibility of opening the closed lane for the PM peak period exists with this type of schedule. In order to show a few different schedules, the weekend schedule does not include the Sunday PM peak lane opening. It was assumed that the weekend could be utilized to maximize closure time because traffic volumes are not as high as those during the week. If the project has circumstances that require a longer continuous closure, the weekend schedule could be utilized. The weekday closure does have a Tuesday PM peak opening because of the high volumes during this time. The schedule of work will have less flexibility because the tasks to allow a temporary lane opening need to be completed by lane opening time. With the weekend schedule, the work needs to be completed by the Monday AM peak.

6.3 Single Panel Replacement

Time savings and resulting lowered user delay costs are realized in single panel applications. Mn/DOT's report states that on smaller, repair-type applications, such as one or two panel replacements, it would be possible to open the lane to traffic within one day. The schedule could include the following:

- Panel removal and replacement during the day, including grouting
  - Lane opened for peak PM period
- Joints and shoulder sealed during the night

Therefore, a scenario was developed for a single panel replacement. This assumed that a lane closure was set during an allowable lane closure time (either the night before construction or that morning), so work can begin that morning. The work needs to begin early enough to allow for the panel to be replaced and grouted (and allow the grout to set) so the lane can be opened for the peak PM hours. The lane could then be closed to perform joint and shoulder sealing and reopened by the following day's AM peak. Figure 4 shows two precast pavement panel construction schedule examples, where the replacement is performed on a Monday or a Thursday.

Single Precast Pavement Panel Replacement Schedule Examples

	Sunday	Monday	Tuesday
12-01 AM			
01-02 AM			
02-03 AM			
03-04 AM			
04-05 AM		Latest	
05-06 AM		Lane Closed	
06-07 AM			Lane Open
07-08 AM			
08-09 AM			
09-10 AM			
10-11 AM			
11-12N			
12-01 PM			
01-02 PM			
02-03 PM			
03-04 PM		Lane Open	
04-05 PM			
05-06 PM	Earliest		
06-07 PM	Lane Closed		
07-08 PM		Lane Closed	
08-09 PM			
09-10 PM			
10-11 PM			
11-12 M			

	Wednesday	Thursday	Friday
12-01 AM			
01-02 AM			
02-03 AM			
03-04 AM			
04-05 AM		Latest	
05-06 AM		Lane Closed	
06-07 AM			Lane Open
07-08 AM			
08-09 AM			
09-10 AM			
10-11 AM			
11-12N			
12-01 PM			
01-02 PM			
02-03 PM			
03-04 PM		Lane Open	
04-05 PM			
05-06 PM			
06-07 PM	Earliest		
07-08 PM	Lane Closed	Lane Closed	
08-09 PM			
09-10 PM			
10-11 PM			
11-12 M			

Allowed Lane Closure
Lane Closed for Construction
Lane Open for Peak Period

Figure 4. Single precast pavement panel replacement schedule examples

7. BENEFIT-TO-COST ANALYSIS

The benefit-to-cost analysis compares the traditional schedule for concrete replacement or reconstruction with precast concrete panel installation, for both a multiple panel project and single panel replacement. Table 3 summarizes the lane closure schedules, notable characteristics of the schedules and the figure numbers for the graphical representations of the schedule displayed in the previous sections.

Table 3. Summary of scenarios

Method	Schedule of work	Characteristics	Figure reference
Traditional	Friday PM to Wednesday AM Sunday PM to Friday AM*	• Continuous work period of up to 107 hours • Work period occurs during AM and PM peak periods for four continuous days	Figure 2
218 ft. Precast panel installation	*Mn/DOT report schedule* Sunday PM to Wednesday	• Schedule used in report • Lane opened when allowed on Wednesday • Continuous work from lane closure to completion of work	Not shown
	Weekend Friday PM to Monday AM	• Avoids weekday peak periods • Continuous work period of up to 59 hours	Figure 3
	Weekday Sunday PM to Wednesday AM	• Opened for Tuesday PM peak • Continuous work period of up to 45 hours	Figure 3
Single panel installation	Sunday PM to Tuesday AM	• Opened before Monday PM peak and closed to finish after peak period ends	Figure 4
	Wednesday PM to Friday AM	• Opened for Thursday PM peak and closed to finish work after peak period ends	Figure 4

7.1 218 ft. Construction Project (18 Panel Replacement)

The precast pavement panel replacement project schedules used include the following:

- Mn/DOT schedule in the report
- Weekend (shown in Figure 3)
- Weekday (shown in Figure 3)

The precast schedules were compared with the traditional construction schedules shown in Figure 2, beginning on each day of the week. Figure 3 illustrates what the likely schedule would have been had the contractor been more experienced in roadway reconstruction with precast panels.

Table 4 shows the construction and road user costs for each scenario. The construction costs are the owner costs and the road user costs is the time value of the delays associated with cast-in-place panels as compared with precast panels. The road user costs are also determined for a 5% traffic volume decrease below historical volumes and a 5% increase above historical traffic volumes.

Table 4. Construction and road user costs for 218 linear ft. panel replacement

	Days of lane closure	Construction costs	Road user costs for different traffic volumes: 2003 volumes	5% volume decrease	5% volume increase
Precast		Owner cost	Road user costs	Road user costs	Road user costs
Mn/DOT project	Sun. PM–Wed.	$165,806	$85,342	$67,818	$102,527
Weekend	Fri. PM–Mon. AM	$165,806	$36,310	$20,564	$41,596
Weekday	Sun. PM–Wed. AM (Tues. PM peak open)	$165,806	$42,130	$31,250	$52,977
Traditional		Owner cost	Road user costs	Road user costs	Road user costs
	Mon.–Thurs.	$21,644	$117,918	$93,700	$139,241
	Tues. –Fri.	$21,644	$123,705	$99,585	$145,886
	Wed. –Sat.	$21,644	$114,296	$86,733	$134,197
	Thurs. –Sun.	$21,644	$101,767	$74,624	$117,643
	Fri. –Mon.	$21,644	$96,287	$71,035	$113,617
	Sat. –Thurs.	$21,644	$91,372	$64,746	$108,008
	Sun. –Wed.	$21,644	$103,093	$79,345	$122,089

Table 4 shows that the road user costs of the actual schedule that Mn/DOT reported during their first trial with precast panels, labeled "Mn/DOT Project." The actual time it took Mn/DOT to place the precast panels and open the roadway for traffic was about twice as long as schedules described in Figure 3, also labeled "Precast Weekend" and "Precast Weekday" in Table 4. The road user costs for the "Mn/DOT Project" schedule are shown only for reference because they do not represent a realistic estimate of closure duration, given an experienced contractor.

7.1.1 Weekend Lane Closures

Table 5 provides the B/C ratios of a precast concrete panel weekend schedule (described in Figure 3) versus a traditional method schedule (described in Figure 2) that begins on the day indicated (e.g., Thursday in the table means that the traditional method project construction begins Thursday at 6 AM, while the lane closure may be implemented Wednesday evening or night). In all cases, the incremental reduction in user costs is less than the increased costs of reconstructing with prefabricated panels versus conventional methods; therefore, the B/C ratio is less than one.

Table 5. B/C ratios for weekend schedules of a 218 ft. panel replacement

Day of the week construction begins (precast weekend)	B/C ratio for 2003 volumes	B/C ratio for 5% volume decrease	B/C ratio for 5% volume increase
Thursday	0.45	0.37	0.53
Friday	0.42	0.35	0.50
Saturday	0.38	0.31	0.46
Sunday	0.46	0.41	0.56

Figure 5 displays the B/C ratios graphically. Figure 5 also shows the differences in ratios depending on when the traditional construction schedule begins. Regardless of the schedule, the additional costs of construction exceed the road user cost reductions due to shorter lane closure times.

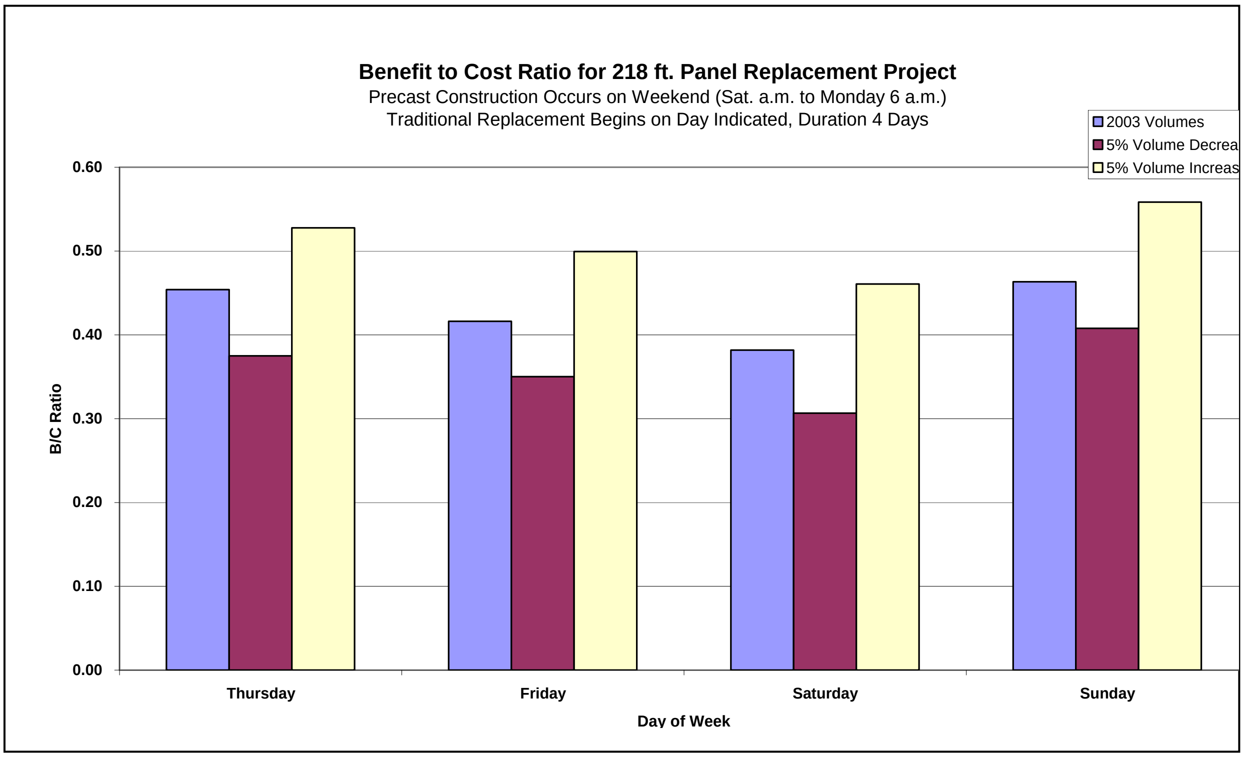

Figure 5. B/C ratio for 218 ft. panel replacement, weekend schedules

7.1.2 Weekday Lane Closures

Table 6 provides the B/C ratios of a precast concrete panel weekday schedule (described in Figure 3) versus a traditional method weekday schedule (described in Figure 2) that begins on the day indicated (i.e. Monday in the table means that the traditional method project construction begins Monday 6 AM, while the lane closure may be set Sunday evening or night). Again, for both assumed schedules, the reduced road user costs of using the prefabricated panels is less than the added costs of construction; hence, B/C ratios are less than one.

Table 6. B/C ratios for weekday schedules of a 218 ft. panel replacement

Day of the week construction begins (precast weekday)	B/C ratio for 2003 volumes	B/C ratio for 5% volume decrease	B/C ratio for 5% volume increase
Monday	0.53	0.43	0.60
Tuesday	0.57	0.47	0.64

Figure 6 graphically displays the B/C ratios on a 218 ft. (18 panel) project. This figure shows that, when comparing a weekday project, it matters little if the traditional method project begins on Monday or Tuesday.

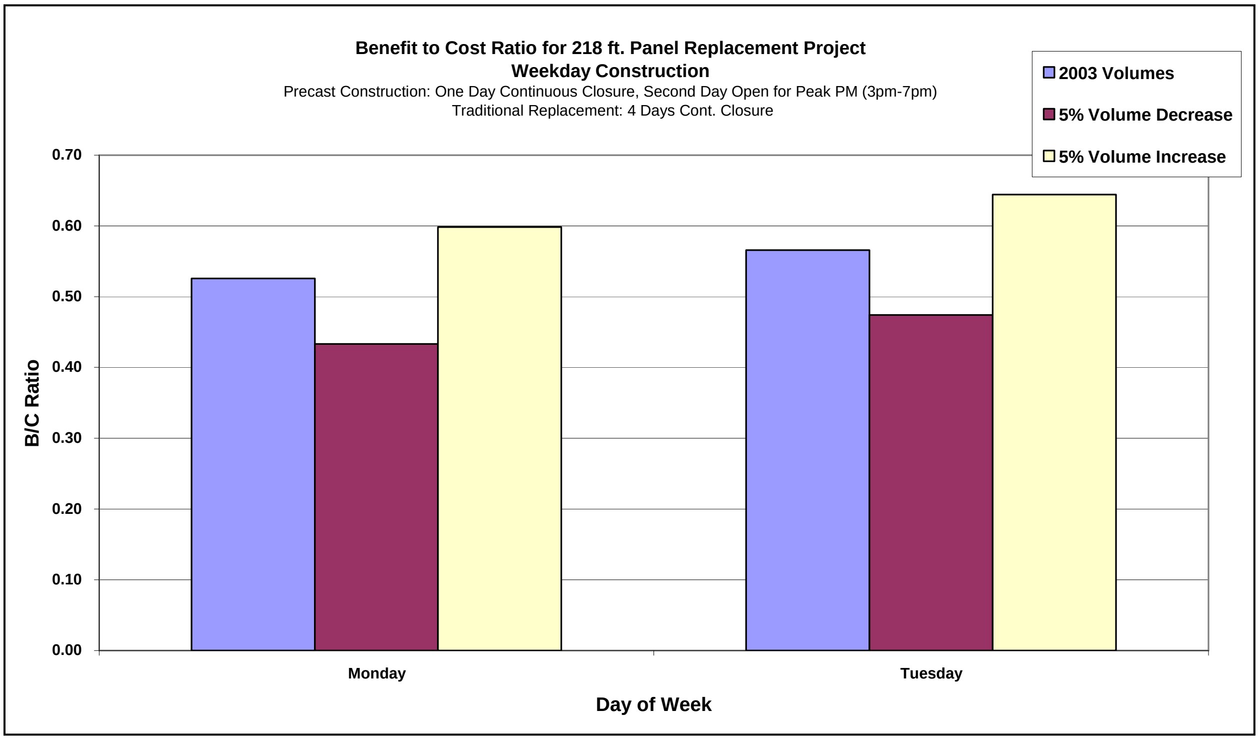

Figure 6. B/C Ratio on 218 ft. replacement project, weekday schedules

For both weekday and weekend lane closure schedules, the B/C ratios were less than 1.0. The weekday construction had a slightly higher B/C ratio, around 0.5. The overall low ratios are mostly due to the high construction and material costs of precast concrete pavement panels. Both precast schedules were shorter in duration compared to a traditional method, as the precast construction schedules included one less day (three day lane closure) than the schedule of the traditional method (four day lane closure). The reduction in road user costs was not large enough to compensate for the high precast panel cost; thus, the B/C ratios were all less than 1.0. Therefore, the benefits are not realized in the initial installation of precast panels on long-distance projects.

7.2 Single Panel

For a single panel replacement project, the road user costs were determined using a precast concrete panel method and a traditional concrete placement method. Examples of a single precast concrete pavement panel schedule are shown in Figure 4 and traditional concrete placement schedules are shown in Figure 2. Table 7 displays the construction costs, or owner costs, and the road user costs of a single panel installation for the 2003 traffic volumes and volumes that are a 5% increase and 5% decrease of the 2003 volumes. The traditional road user costs are the same as those used for the 218 ft. schedule using traditional concrete placement because the concrete still needs one day for replacement and a three-day cure time, thus necessitating a four-day closure.

Table 7. Construction and road user costs for single concrete panel replacement

			Road user costs for different traffic volumes		
	Dates of lane closure	**Construction costs**	**2003 volumes**	**5% volume decrease**	**5% volume increase**
Precast		Owner cost	Road user costs	Road user costs	Road user costs
	Monday	$9,210	$17,395	$12,594	$22,989
	Tuesday	$9,210	$18,268	$12,189	$23,522
	Wednesday	$9,210	$20,321	$13,935	$24,848
	Thursday	$9,210	$22,875	$16,183	$26,400
	Friday	$9,210	$22,665	$18,478	$27,790
	Saturday	$9,210	$13,240	$8,617	$14,711
	Sunday	$9,210	$11,284	$5,060	$12,820
Traditional		Owner cost	Road user costs	Road user costs	Road user costs
	Mon.–Thurs.	$3,449	$117,918	$93,700	$139,241
	Tues. –Fri.	$3,449	$123,705	$99,585	$145,886
	Wed. –Sat.	$3,449	$114,296	$86,733	$134,197
	Thurs. –Sun.	$3,449	$101,767	$74,624	$117,643
	Fri. –Mon.	$3,449	$96,287	$71,035	$113,617
	Sat. –Thurs.	$3,449	$91,372	$64,746	$108,008
	Sun. –Wed.	$3,449	$103,093	$79,345	$122,089

Table 7 also shows the variation of user costs between different days of the week due to traffic demand. The difference in user costs between precast and traditional methods is high, due to the continuous closure required by the traditional method. As expected, the weekend user costs are the lowest for single-day construction, while Thursday and Friday have the highest costs. For a four-day continuous closure (using traditional construction), the schedule that utilizes a closure on the weekend and continues to Monday or Tuesday provides the lowest user costs.

The B/C ratios were calculated for two different combinations. First, the B/C ratios were calculated where both precast panel and traditional construction start on the same day (e.g., both begin on Monday with precast open by Tuesday peak AM and traditional open by Friday AM). The calculated B/C ratio values are shown in Table 8 and graphically displayed in Figure 7.

Table 8. B/C ratio for single panel replacement beginning on same day

Day of week construction begins	B/C ratio for 2003 volumes	B/C ratio for 5% volume decrease	B/C ratio for 5% volume increase
Monday	17.45	14.08	20.18
Tuesday	18.30	15.17	21.24
Wednesday	16.31	12.64	18.98
Thursday	13.70	10.15	15.84
Friday	12.78	9.12	14.90
Saturday	13.56	9.74	16.20
Sunday	15.94	12.90	18.97

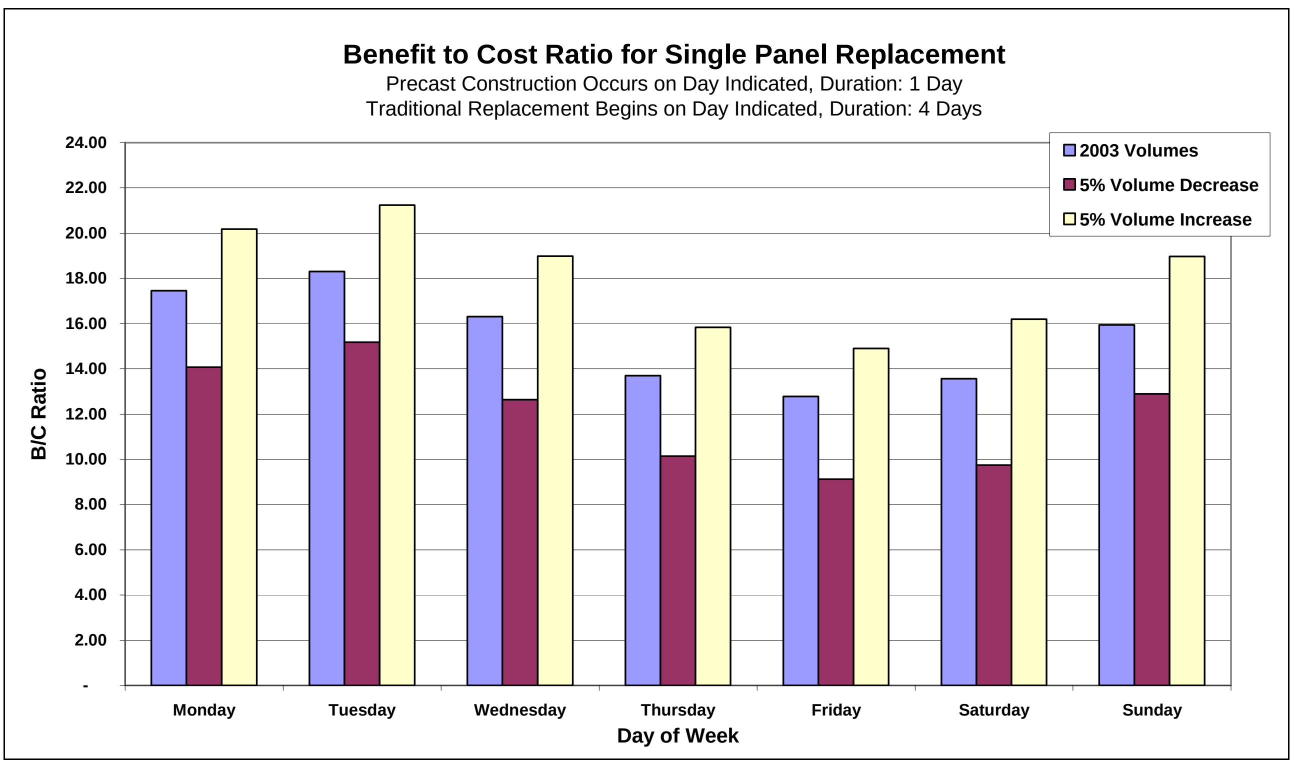

Figure 7. Single panel replacement beginning on same day

The second combination for which B/C ratios were calculated was where the precast concrete panel replacement is performed on the last cure day of a traditional panel replacement (e.g., traditional replacement begins Monday AM and opens to traffic by Friday AM, while precast is performed on Thursday and opened to traffic by Friday AM). The B/C ratio values are shown in Table 9 and graphically displayed in Figure 8.

Table 9. B/C ratio for single panel replacement with projects ending on same day

Day of week construction ends	B/C ratio for 2003 volumes	B/C ratio for 5% volume decrease	B/C ratio for 5% volume increase
Monday	16.50	13.46	19.59
Tuesday	17.54	14.08	20.50
Wednesday	17.54	13.56	20.74
Thursday	15.71	12.08	18.20
Friday	13.70	10.15	15.73
Saturday	12.69	9.12	14.67
Sunday	14.37	11.35	16.88

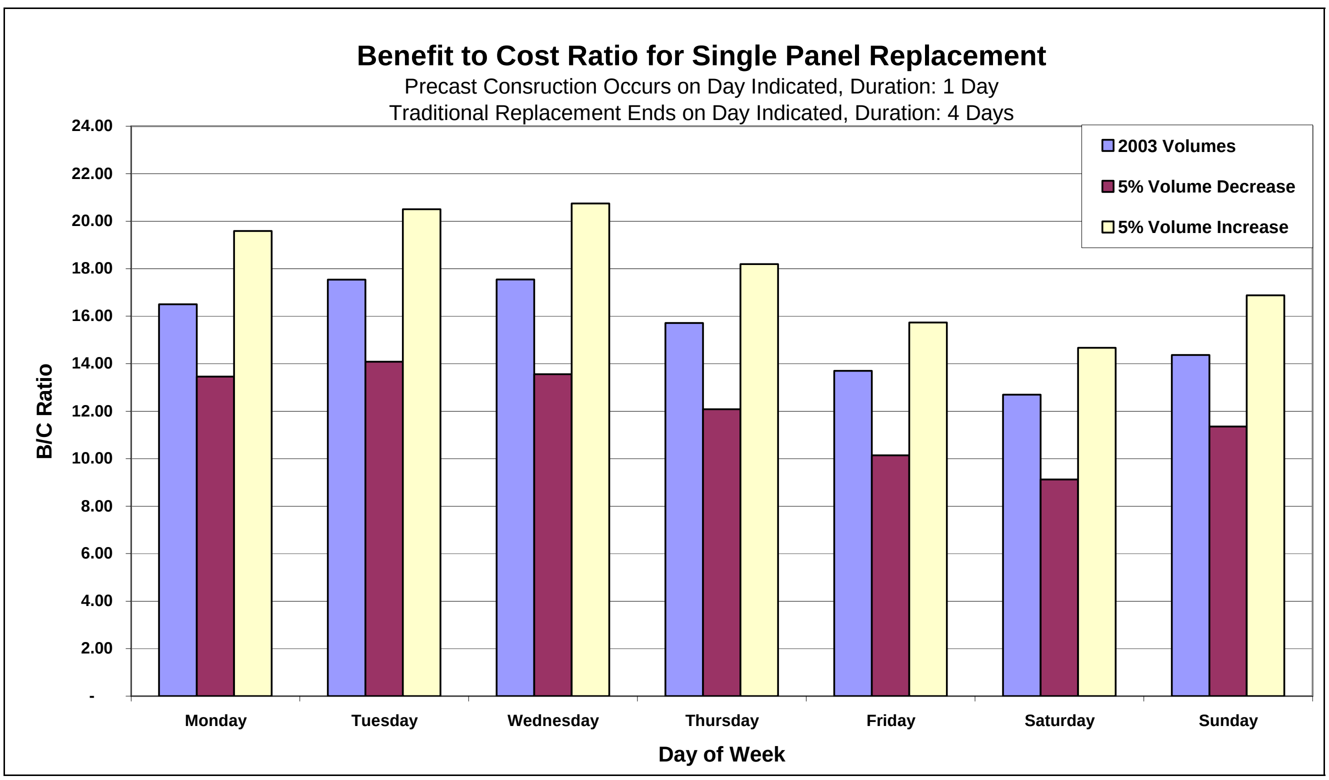

Figure 8. Single panel replacement, projects completed on same day

The B/C ratios range from around 9 up to 21, which all show a definite benefit when compared to traditional methods. The two figures show that as traffic volumes increase, the B/C ratio increases as well. Therefore, the greatest benefits are obtained for precast concrete panels on high-volume roads. Similarly, the B/C ratios are highest on days with continuously high traffic volumes. If a panel needs replacement during the week, the B/C ratio is greatest if work is started at the beginning of the week. Because of high traffic volumes and the fact that a traditional, four-day continuous closure occurs through the week, precast is a technique that will reduce total construction and road user costs. If a traditional measure can utilize a closure on the weekend, the B/C ratio is lower, but the benefits are still much higher than the costs.

7.3 Break Even Point on Distance

As previously shown, there is a large difference in the B/C ratio of a single-panel project and a longer, multiple-panel project. Therefore, it is desired to find a break even point where the B/C ratio equals about one, based on the length of the project. Table 10 shows the break even point of the weekday and weekend precast pavement panel schedules for three traffic volumes.

Table 10. Break even point for number of precast panels

	B/C ratio	Number of panels	Precast user + construction costs
2003 volumes			
Weekday	0.95	10	$134,398
Weekend	1.03	8	$110,202
5% volume increase			
Weekday	0.98	11	$154,433
Weekend	0.95	10	$133,864
5% volume decrease			
Weekday	0.98	8	$105,142
Weekend	0.97	7	$85,268

Depending on the volume and when the project is scheduled (weekend or weekday), the use of precast panels is no longer cost-beneficial when 7–10 panels are used. Of course, the maximum length of precast panels where the benefits exceed the costs is, in this case, dependent on the availability of diversion routes and the other assumptions made in the analysis. For each case, the maximum length of precast panels will depend on the conditions.

8. SUMMARY OF LOCATION-SPECIFIC ANALYSIS COMPONENTS

With the B/C ratio, many of the inputs used are unique to a specific location, which hinders the ability of an analysis at one location to form the basis for determining whether prefabricated panel construction should be used for a separate location. Traffic and network configurations are unique to each location and are the basis for calculating potential road user cost-reduction benefits. Because prefabricated panels provide for a shorter lane closure time, the benefits are greater if the facility is already congested and traffic is not easily diverted to parallel facilities. In the analysis, the particular STA's threshold values of work zone lane capacity and allowable queue lengths factor into the analysis. A lower work zone lane capacity value will cause more vehicles to be stored in the queue and a longer allowed queue will create greater motorist delay and greater road user costs. Other facility- and network-related impacts not accounted for in this analysis include impacts of diverted traffic on other facilities throughout the network (including incurred delays) and higher safety costs associated with creating a queue on a high-volume highway.

The construction costs of prefabricated concrete panels are considerably more expensive than traditional concrete placement methods. However, this is also a location-specific input. The cost of labor can vary by location and by contractor. If a contractor is selected with a crew that is experienced in prefabricated pavement panel installation, the cost might be greater than that of an inexperienced crew. However, there is potential of a cost savings from shorter work duration by the experienced crew. Transportation costs can play a role in total construction cost as can material costs at the time of purchase. Fluctuation in fuel and material prices can impact total cost of the project, thus impacting the cost portion of the B/C analysis.

Contractor and worker familiarity could significantly impact the schedules and actual work output during panel installation. Utilizing workers that have performed precast panel installation before will allow a more compact project schedule, thus reducing the impact on motorists. However, if the contractor and workers are unfamiliar with the precast panel installation process, a longer schedule might be desired. As a precast panel installation schedule increases in duration, it becomes similar to that of a traditional concrete placement schedule and the benefits of shorter lane closure durations are diminished.

9. CONCLUSIONS

This case study was intended to provide an example of an analysis of the trade-offs between the use of more expensive prefabricated elements and road user costs. Prefabricated elements can reduce the length of lane closures for reconstruction, but they may cost more than conventional constructed-in-place elements. Because the traffic and network configuration will be unique in each potential application of prefabricated elements, an analysis must be conducted for each individual case. Similarly, material costs for prefabricated elements and traditional methods, as well as construction schedules, can affect the analysis results and can vary by location.

The results of this analysis show that on Trunk Highway 62 in the Twin Cities (a grade-separated roadway), the use of prefabricated panels for short sections was cost-effective because prefabricated panels could be placed more quickly and required a shorter lane closure than traditional methods. In this case, when reconstruction involved seven or fewer panels, prefabricated panels were found to be cost-effective. This result was obtained using a weekend construction schedule and a five percent volume decrease from the 2003 traffic volumes. Because of the high cost of prefabricated panels, when reconstruction involved more than seven panels, the use of prefabricated panels was not found to be cost-effective. The greatest benefit is realized when a facility has high traffic volumes. The combination of a reduction in schedule and the opportunity to open the closed travel lane(s) during the end of the construction process reduces the total road user costs when compared to traditional methods.

10. REFERENCES

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