NORTH LRT DRAINAGE CONSTRUCTION PROJECTS

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The North LRT tunnel

Introduction

SUPPORTING NEW INFRASTRUCTURE

The installation of a major new infrastructure represents a complex and multidimensional undertaking requiring the interactions of hundreds of people from different disciplines and costing millions of dollars — not only to construct, but to integrate into the existing infrastructural system. The City of Edmonton's North LRT expansion project – now called the Metro Line – epitomized many of these exciting challenges. Stretching from Churchill Station on the east side of downtown Edmonton and continuing north for over 3 kilometers to the Northern Alberta Institute of Technology (NAIT), the North LRT is located at the heart of one of Edmonton's oldest and most congested areas. For this enormous undertaking, several drainage projects were identified as requiring work due to conflicts between the existing and new infrastructure.

CHALLENGES FOR DOWNTOWN TUNNEL CONSTRUCTION

Two of these drainage projects faced significant challenges. Through the downtown core, the LRT will be carried by underground tunnel until it finally passes out of a portal, constructed at 105 Avenue and 103 Street. Since the proposed LRT tunnel alignment would intersect with an existing double barrel tunnel, the City's Drainage Design and Construction branch needed to coordinate with the LRT Design Team responsible for the tunnel in order to develop a strategy for

Project Complexity

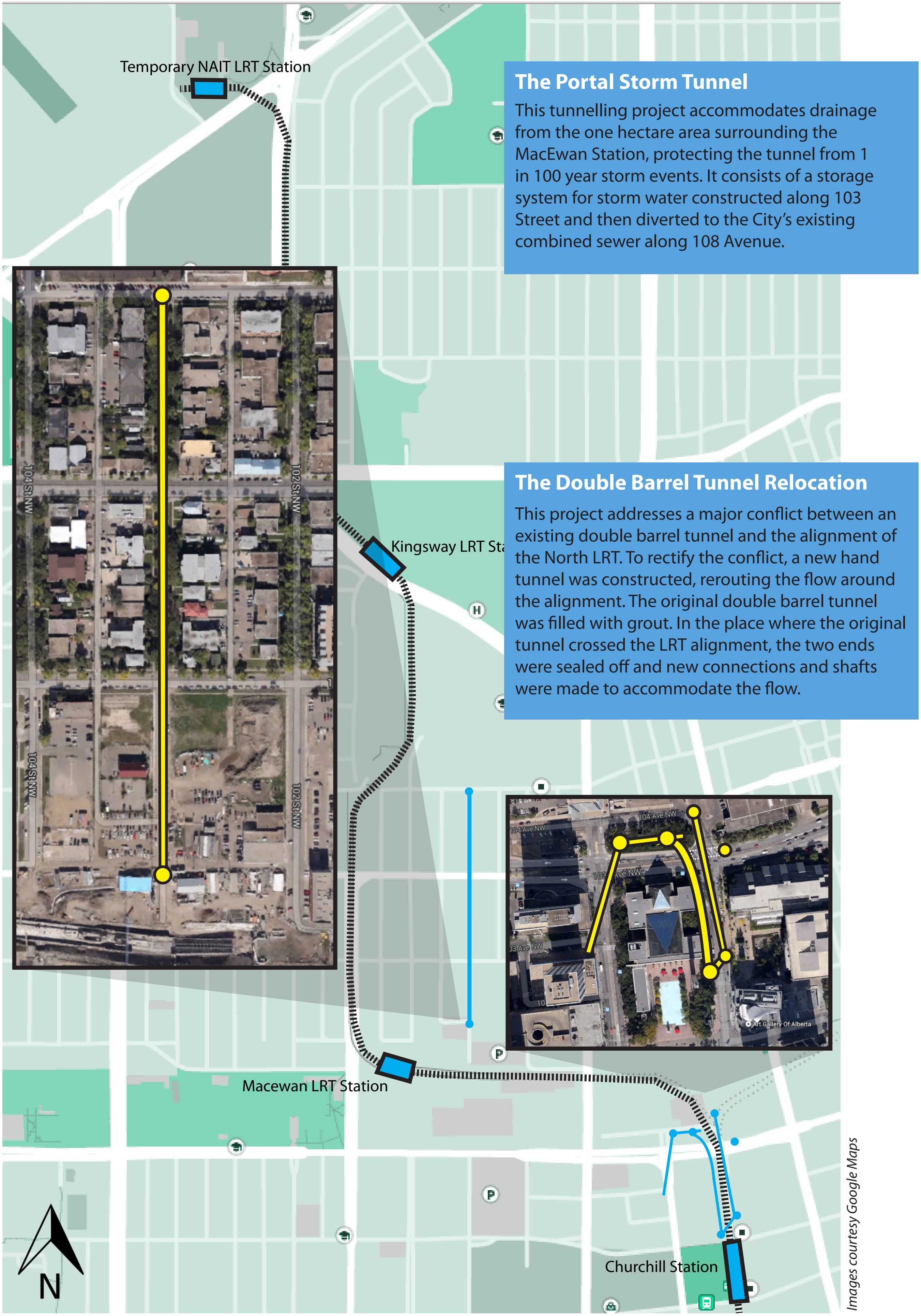
- Schedule adherence was important because of coordination with LRT project and also the impact of delays downtown.
- High ground water and clay soil conditions around MacEwan Station portal.
- The Double Barrel project encountered significant excavation challenges, including rebar, abandoned I-beams, and concrete pilings, all of which had to be overcome using hand-tunnelling.
- Missing or incomplete as-built information about existing drainage connections.
- Traffic management was demanding and vital as the location of the double-barrel work is in an extremely high traffic zone, adjacent to several major downtown landmarks including City Hall.
- Related to the location, the double barrel project also faced tight laydown areas, which rendered construction more challenging.

The Portal Storm Tunnel

This tunnelling project accommodates drainage from the one hectare area surrounding the MacEwan Station, protecting the tunnel from 1 in 100 year storm events. It consists of a storage system for storm water constructed along 103 Street and then diverted to the City's existing combined sewer along 108 Avenue.

The Double Barrel Tunnel Relocation

This project addresses a major conflict between an existing double barrel tunnel and the alignment of the North LRT. To rectify the conflict, a new hand tunnel was constructed, rerouting the flow around the alignment. The original double barrel tunnel was filled with grout. In the place where the original tunnel crossed the LRT alignment, the two ends were sealed off and new connections and shafts were made to accommodate the flow.



Images courtesy Google Maps

rectifying the conflict. The second issue was the need for a storm tunnel to be constructed at the MacEwan Station portal where the train returned to street level, which would address storm water flows entering the tunnel. In addition to ground condition issues, this second project raised questions about how to optimize productivity. The City brought SMA Consulting Ltd. on board to provide planning, management, and control for both projects.

Hand tunnelling in the double barrel tunnel

ADVANCED PLANNING AND PROJECT MANAGEMENT SERVICES

SMA mobilized a wide range of services for each of the projects.

For the double barrel tunnel, SMA oversaw value engineering, risk analysis, and constructability reviews in order to ensure that the construction options were optimized and to identify a design that would be able to work within all constraints. During construction, SMA applied several state-of-the art tools, including lean production (in the form of the Last Planner System) and a monthly system for reporting cost and progress. Finally, and above all, the earned value analysis (EVA) SMA performed was instrumental in ensuring that the project came in under budget and within schedule.

The storm tunnel to be installed at the MacEwan Station portal faced a number of geotechnical and coordination challenges. SMA facilitated a value engineering session for this project to help determine the best option for its design. Productivity analysis on the project was also performed by drawing on SMA's expertise in simulation modelling. As with the other project, it was able to stay on budget and meet its productivity targets through the use of EVA and regular cost-progress reporting.

The projects provided excellent proof of the big impact that advanced tools can have – even on projects using traditional methods of construction and which might otherwise appear "small-scale." The customizable suite of planning and management services that SMA brought to both projects helped to enhance the work done on each project and set the stage for the successful integration of the LRT work with the existing downtown core.

Project Complexities

DOUBLE BARREL TUNNEL

A double barrel tunnel is a pipe capable of carrying both sanitary and storm water flows separately via an angled wall. The storm water flows along the upper division of the pipe while the sanitary flow uses the lower division. As indicated in the figure on the opposing page, the project entailed a complex rerouting of flows by connecting existing tunnels with new hand tunnels and closing off the original double barrel in places where it conflicted with the LRT alignment. The project encompassed five shafts, four connections, a 112-meter hand tunnel, another 47-meter hand tunnel with a 12-meter connection tunnel, the double barrel abandonment, and a pilot tubing section of 92 meters which was changed to a hand tunnel. Because of this complexity, the double barrel drainage project undertaken for the North LRT faced several significant challenges.

Drainage for the North LRT tunnel built as part of the double barrel relocation

Conflict with the NLRT Tunnel

In the first place, a major design decision needed to be made regarding conflicts with the alignment. The North LRT tunnel would directly conflict with the existing double barrel, which stretched across 99 Street. Initially, it was suggested that the double barrel might be diverted above the LRT tunnel. However, this option was dropped given the high risk it carried. Several new options were explored, with a hand tunnelling approach finally decided upon. The portion of the existing double barrel tunnel cutting across the alignment would be abandoned, and the tunnel itself would be closed off on both sides. The flows that had been using this portion of the tunnel would then be diverted elsewhere.

Removing debris from the portal storm tunnel excavation

Missing Information

Diverting flows, however, poses a number of challenges: connections needed to be made to the existing network, the double barrel itself had to be closed off, and reliable information about the location and nature of the existing underground infrastructure became imperative. As the project progressed, it was discovered that there was missing information about the as-built. The area of downtown in which the project was located has undergone many changes over the years given its place at the heart of the City. Other geotechnical issues were encountered as well. The central location of the project, including its proximity to City Hall, resulted in a number of unforeseen encounters with rebar, abandoned I-beams, and even concrete piles. The unknown service connections between certain manholes also complicated the process for determining how to construct the tunnel. The result was that CCTV had to be ordered for the areas under construction to confirm the as-built.

Likewise, as a hand tunnelling project, the project is physically demanding on the workers and poses other risks, particularly in the downtown core, with its extensive utilities and diverse ground conditions. Finally, at the surface level, the project had the potential to impact traffic in a big way: with over 10,000 vehicles per day using the 103A Avenue block between 99 Street and 100 Street, along the north edge of Edmonton's City Hall, construction would be directly impacting the daily operations of many downtown users. These challenges all in turn elevated the overall pressure to ensure that the project would be completed on time and within budget.

PORTAL STORM TUNNEL

The portal drainage project needed to provide 1 in 100 year storm event protection to the North LRT tunnel, which would meet the design standards for the LRT. Due to the proposed elevations for the NLRT track and landscaping around MacEwan Station, an area of approximately one hectare will drain towards the MacEwan Station portal. The opening of the tunnel is located near 103 Street and 105 Avenue at a high point west of the station at 105 Street. Several options were proposed for design of the drainage tunnel. Determining between these involved gauging the respective benefits of connecting with the 111 Avenue storm system, undertaking storm sewer separation, or using the combined system that continues to operate in the area. Ultimately, the City decided to construct a storage system for the storm water along 103 Street, and then divert it into the existing combined system along 108 Avenue. In addition to horizontal and vertical alignment requirements, the project needed to meet objectives related to sizing and connections. Meeting these aims is essential to ensuring that there is adequate storm water storage. The design of the outlet structure and connection to the 108 Avenue tunnel also poses a challenge as it must permit the maximum allowable outlet rate of 35L/s based on the current service area.

Meeting Client's Needs

- Given that the North LRT is a $750 million project, any impact to its schedule through poor construction interface or interruptions from parallel projects in the area is going to be costly. SMA's careful tracking of cost and schedule meant that trends could be better captured and therefore better managed. The actual cost for both projects were below the initial estimates and both were able to stay on schedule.
- The alignment of the North LRT has been subject to detailed scrutiny and cannot be altered without enormous redesign work. Through intensive value engineering and constructability review, the points at which the alignment conflicts with the existing drainage system have been identified and mitigated.
- The portal tunnel experienced delay due to poor ground conditions and other issues; through the application of leading-edge project management tools, SMA helped the project to recover from the delay and finish on schedule.

Optimal Construction Method

Along with the design for the portal drainage, it was necessary to determine the optimal method of construction. Seven different options were explored in a value engineering workshop facilitated by SMA. These ranged from the original concept design, which involved multiple tunnelling techniques, to using a tunnel boring machine (TBM) the entire length of the tunnel, to undercutting an underground storage tank, and others. The evaluation of the options led to the City deciding to use a TBM for the entire tunnel.

Wet and sticky ground conditions encountered during portal construction

Geotechnical Issues

During construction, however, wet and sticky ground conditions slowed up the progress. This caused the project to shift off schedule, which was especially problematic due to the coordinating efforts that needed to be undertaken by the City's Drainage Design and Construction and the LRT's design team. These coordination activities added a further challenge to the project, with multi-disciplinary coordination being required not only for the final integration of the City's drainage work with the LRT's, but also for any boreholes the City needed along the alignment.

Advanced Tools

SMA Consulting brought a comprehensive array of project planning and management services to these projects. From value engineering to simulation modelling, these services used were harmoniously applied in order to provide a customized methodology for meeting the specific needs of each drainage project.

Project Planning and Management Tools Used	Portal Drainage Storm Tunnel	Double Barrel Relocation
Value Engineering	✓	✓
Risk Analysis	✓	✓
Constructability Review	✓	✓
Simulation Modelling	✓	
Earned Value Analysis	✓	✓
Last Planner® lean production technique		✓

PLANNING FOR SUCCESS

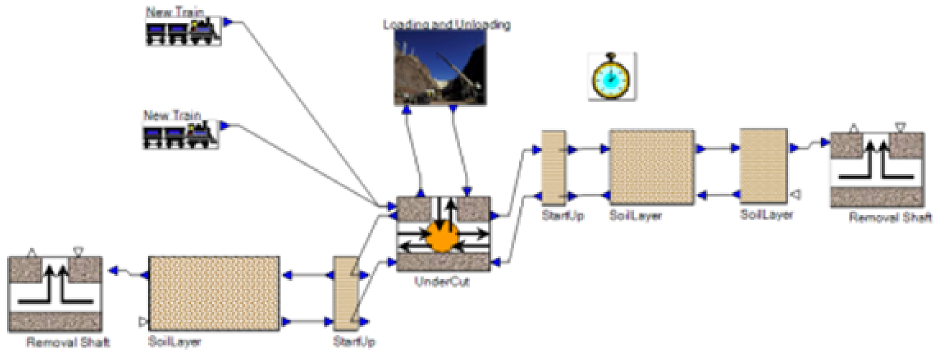
Robust Evaluation with the Analytic Hierarchy Process

On both projects, the City used SMA's unique value engineering approach, which applies a sophisticated consistency validation method called the Analytic Hierarchy Process (AHP) to ensure that the criteria chosen for evaluating options align with the needs of the stakeholders. This process follows and builds upon the process and standards published by the Society of American Value Engineers (SAVE) International. For these projects, options were proposed by the design team and then evaluated in terms of advantages and disadvantages as well as more specific criteria, which participants identified in discussion about the function of the project. These criteria are then defined to ensure that all participants agree upon their respective meanings. Using pairwise comparison, the importance weightings for each of the criteria are then calculated via AHP and checked for consistency. The outcome of this process is a quantified functional value, which is then also evaluated based on total cost. This structured process gives strong justification for decisions and provides a foundation for managing the project.

Value Engineering and Risk Analysis

Value engineering's structured approach, which emphasizes creativity and ensuring that the end-result matches the function identified for the project, helped to define the key issues at stake in each of the drainage projects. It also ensured that the options each project pursued were optimized in terms of cost and schedule. SMA also takes value engineering further by integrating the options evaluation work with risk assessment. For both projects, several risks were identified at the outset. These included standard risks such as approvals and permits, inaccuracies in the estimate, and potential construction site limitations, as well as project-specific risks such as the potential for combined sewer surcharge, condition of the existing double barrel, among others. These factors were quantified in terms of likelihood and impact, and a risk allowance was determined for each project.

The ultimate outcome is a clear picture of how the project could proceed, including an understanding of the benefits and potential challenges associated with each option.



Tunneling simulation model

ENHANCING PRODUCTIVITY

Advanced Simulation Modelling

For the portal drainage project, simulation modelling was employed to enhance productivity during the project. Using *Simphony*, modelling software developed at the University of Alberta and specially designed for construction work and with extensive application to tunnelling projects, SMA modelled the optimal process for the tunnel's construction. By representing the various components of a project, including site layout, resource interactions, on-site processes, and external interferences, the simulation model can give project managers a realistic understanding of the issues facing a project's productivity. Because the project involved a shorter tunnelling effort than other projects, a key question was whether it would be more productive to use a full setup or not, meaning the use of a full train for removing excavation material. SMA simulated multiple scenarios and determined that, if the tunnel is longer than 500 meters, productivity will benefit from the addition of trains. Since this project only involved a tunnel of 500 meters or less, however, it was determined that the additional effort of building a longer undercut would actually make using more than a half train less productive overall. This discovery ensured that the project maximized its deployment of resources to the greatest possible benefit.

Earned Value Analysis

Productivity was a central concern prompting the use of earned value analysis on both projects. Earned value analysis involves regularly comparing the planned value of a project in terms of its accumulating costs over the course of the entire schedule with the actual costs that have been accumulated to date as a result of the work accomplished. The EVA that SMA undertook on both projects gave the City invaluable insight into the actual progress gained. As indicated in the table below, the reports that SMA provided include an extensive amount of detail.

Table 1. EVA Reporting Details

Metric	Description	Status	Description
Progress (%)	*The percentage of the project complete*	Schedule variance	*The difference between work actually performed and work that has been scheduled only*
Budget spent	*The amount of the budget spent as of the report date*	Cost performance index (period and cumulative)	*A ratio of the work performed to the cost so far*
Budget at completion	*The total of all budgets allocated at the end of the project*	Schedule performance index (period and cumulative)	*A ratio of the earned value to the planned value*
Planned value	*The value of the work as it has been planned*	Forecasted cost at completion	*The anticipated cost at the end of the project*
Total actual cost	*The cost of the project as a whole*	Cost variance at completion	*The difference between the initial cost budgeted and the final cost*
Period actual cost	*The cost of the project during a given period*	Forecast duration at completion	*The anticipated duration of the schedule at the end of the project*
Cost variance	*The difference between the planned and the actual costs of work performed*	Duration variance at completion	*The difference between the planned duration and the actual duration*

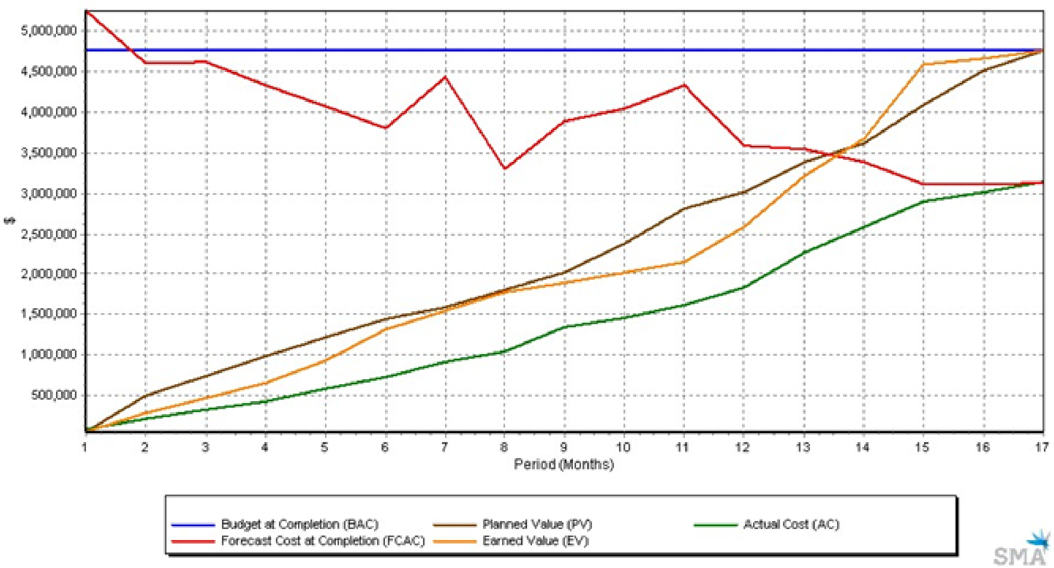
Project: NLRT-DB Relocation

Period: 01/08/2011 ~ 31/08/2011

Task Name	Progress	Budget Spend	BAC	PV	Total Actual Cost	Period Actual Cost	CV	SV	CPI Per.	CPI Cumu.	SPI Per.	SPI Cumu.	FCAC	CVAC	FDAC	DVAC	Cost Status	Sched. Status
210 Indirect Cost	100.0%	121.0%	$976,799	$976,799	$1,181,885	$84,369	-$205,201	-$115	0.68	0.83	0.95	1.00	$1,182,024	-$205,225	370	0		
220 Shafts And Manholes	100.0%	37.0%	$1,101,851	$1,101,851	$408,097	$0	$693,754	$0	0.00	2.70	0.00	1.00	$408,097	$693,754	343	0		
230 Tunnel Excavation	100.0%	63.2%	$923,938	$923,938	$583,537	$0	$340,401	$0	0.00	1.58	0.00	1.00	$583,537	$340,401	207	0		
240 Tunnel Lining	100.5%	67.6%	$660,549	$660,548	$446,530	$0	$217,321	$3,304	0.00	1.49	0.00	1.00	$444,320	$216,229	245	1		
250 Connection	100.0%	70.0%	$188,998	$188,998	$132,386	$0	$56,613	$0	0.00	1.43	0.00	1.00	$132,386	$56,613	191	0		
260 Abandment	100.0%	116.4%	$67,866	$67,866	$79,000	$40,037	-$11,134	$0	1.36	0.88	0.80	1.00	$79,000	-$11,134	23	0		
270 Tunnel between X2 and X6	100.0%	35.8%	$840,000	$840,000	$300,594	$0	$539,406	$0	0.00	2.79	0.00	1.00	$300,594	$539,406	163	0		
NLRT-DB	100.1%	65.8%	$4,760,001	$4,760,000	$3,132,029	$124,407	$1,631,305	$3,333	0.90	1.52	0.47	1.00	$3,129,958	$1,630,044	370	0		

GREEN = On track	YELLOW = Slightly behind schedule or over budget	RED = Needs immediate attention	BLACK = Critical/Needs review of item and plan

The EVA report also represents the cost and schedule statuses on the dashboard using an easy-to-understand colour code system. This provides project stakeholders with an at-a-glance indication of the most urgent issues that need to be dealt with (as in image below).



Combined with a specialized monthly reporting system, which accounted for cost and progress in detail along with risks encountered and issues requiring response, EVA helped both projects complete under budget and on time, despite the setbacks encountered due to geotechnical and other issues.

Last Planner System® Lean Production Technique

The double barrel tunnel project took productivity management even further by implementing an advanced lean production technique, the Last Planner System®, which SMA oversaw for the City. This system places an emphasis on look-ahead planning, eliminating delays due to suppliers and other so-called "incidental" influences upon a project schedule. The benefits of this approach are improved project predictability, profit, productivity, and other key performance indicators. SMA provided both weekly look-ahead and six-week look ahead reports. These enabled the project team to check on changes occurring throughout and were integrated with SMA's cost/progress control reports. Throughout the project, this methodology assessed the extent to which these plans came to fruition, so that alternative strategies can be implemented if necessary. The use of this system in the double barrel tunnel project had a direct impact on its ability to stay on schedule despite delays early on due to the major geotechnical issues the project faced.

Environmental Benefits

- The decision to relocate the double barrel by connecting existing tunnels to a new hand tunnel was in part due to the environmental risk posed by the original plan, which would have allowed the LRT alignment to pass over the existing double barrel. The alternative solution represents a much safer way to meet the project's objectives.
- In addition to preventing the flooding of the LRT tunnel, which could have grave repercussions in terms of safety, the portal drainage project helps to reduce damaging infiltration of storm water into other parts of the drainage system.
- The simulation model developed for the portal construction showed that a less than full setup for tunnelling was more productive, indicating an agreement between a more sustainable approach and the best fit for the needs of the project.

Location of the double barrel relocation work

MacEwan Station under construction near the location of the portal storm drainage tunnel

Client-Focused Value

DOUBLE BARREL TUNNEL

SMA also performed risk analysis and reviews of the project's constructability as well. After the discovery that the double barrel would not be able to cross the alignment at all, this process enabled the project planners to quickly identify an effective alternative design. While all of the options involved hand tunnelling, the discussion helped to identify obstructions that certain alternatives would encounter, such as an existing LRT pedway, and also the areas of uncertainty related to the condition and location of service connections.

The project also experienced significant benefits from the combined productivity management services that SMA performed over the course of the project's construction. Using advanced tools such as EVA and the Last Planner System® rather than more traditional methods of project controls meant that delays and cost overruns were identified soon after they appeared. It also meant that cost and schedule forecasting could be updated more regularly, with the effect of better capturing trends in order to manage them. Thus, the original budget for the project was $4.7 million. The initial estimated cost at completion was forecast to be $5.2 million. Four months into the project, the schedule had to be put on hold due to conflicts with other projects; however, the cost at this time was already somewhat under budget, at $3.9 million. Partly through the application of the techniques described above, the actual cost of the project upon completion was $3.3 million, representing a mere 71% of the budget spent. The project also came in on schedule through the application of these productivity controls.

Innovation

- Applied advanced techniques to low-tech approach
- Simulation for enhancing productivity
- Lean production (Last Planner system)
- Cost/progress monthly reporting integrated with EVA
- Value engineering integrated with risk and the Analytical Hierarchy Process
- Value engineering discovered a new option for the double barrel.
- Orchestrated services controlled budget and helped the projects to finish early.

PORTAL STORM TUNNEL

The value engineering and risk analysis undertaken on this project surveyed seven different options for construction. With total costs ranging from $4.6 million to $9.2 million, the urgency of identifying a cost-effective option was high. Furthermore, the value engineering session determined that stakeholder acceptance was the criterion with the greatest weight, followed by constructability and operability. Applying AHP and SMA's structured risk-based approach, the workshop determined that using the TBM for the entire length of the project represented the best option.

Removing TBM from portal tunnel

As noted, the simulation modelling of productivity during the planning phase of the project helped the project to further refine this option and avoid major cost overruns due to unnecessarily increasing the number of trains used. This finding regarding the optimum length of the tunnel will prove useful in future work as well.

The earned value analysis performed for the project resulted in a strong outcome for the project in terms of cost and schedule. The initial budget for the project was $4.9 million. By the end of the project, the actual cost was $4.3 Million, despite the schedule having been significantly delayed due to the geotechnical issues encountered by the working shaft.

Conclusion

The North LRT drainage projects offered an exciting opportunity to demonstrate the major benefits that can be accrued even on so-called "small scale" projects through the application of advanced project planning and management tools. Drawing upon SMA's expertise in value engineering, risk analysis, and constructability review, as well as its simulation capabilities, the City was able to ensure that these projects could be well coordinated with the North LRT expansion project as a whole. Furthermore, by building the project management approach for these drainage projects upon the solid project planning these tools made possible.

The issues that both projects faced in terms of geotechnical and design complexity are difficult to overcome regardless of the project management methods employed; nevertheless, the success with which the City was able to bring in both projects under budget and on schedule is a testament to the sheer effectiveness of the suite of tools SMA provided.

The ultimate significance of the projects' success is the seamless support of the City's expanded Light Rail Transit system. Whether by providing additional flood protection, as in the case of the portal drainage storm tunnel, or by accommodating the LRT alignment and maintaining the existing capacity, as in the case of the double barrel tunnel relocation, the North LRT drainage construction projects played an essential role in the development of Edmonton's place as a world-class city.

Social and Economic Benefits

- Approach resulted in cost savings and better schedule adherence on this publicly funded project, which is moreover located in a high-traffic area.
- Major cost savings resulted when the simulation model of the portal tunnel construction showed that only ½ spoil train was required for the length of the tunnel (~500 m). The simulation thus showed that more trains would not equal greater productivity.
- The careful value and risk analyses of the projects kept the key stakeholders of the projects – people living and working in downtown Edmonton and those using the LRT system – at the forefront of all decision-making.
- The added capacity that the projects will build for the drainage system fortifies the area against flooding and protects the LRT infrastructure.