## Planning of an Unconventional Urban Arterial Intersection
## A Context Sensitive Design Approach


### Abstract

Calgary's population has recently exceeded the one million mark. Blessed with an oil-rich economy, the City has been experiencing an unprecedented growth, which has created significant additional demands on the municipality's transportation system.

As a result, many of the City's intersections are now at capacity, and desperately need improvement. Although grade separation solutions for urban arterials are not common because of their higher construction costs and right-of-way (R.O.W.) requirements, the projection of high future traffic volumes on many of Calgary's urban thoroughfares has forced transportation engineers to examine the use of innovative and unconventional alternatives.

Major arterials in built-up urban areas face problems not necessarily present in typical freeway-type interchange design. In such built-up areas, there is usually insufficient room for the construction of expansive loop ramps. Maintaining the existing flow of traffic during implementation is another critical consideration. The proximity of existing commuter transit and/or freight rail lines is often an added constraint.

This paper describes some of the innovative techniques used in the functional design of an interchange at one of the busiest intersections in Calgary, Macleod Trail and 25 Avenue SE. Macleod Trail is an important north-south arterial road, with an average daily traffic (ADT) of 53,000 vehicles trips per day (vpd). 25 Avenue is an east-west through road with an ADT of 17,000 vpd. The paper outlines some of the unconventional options considered, and attempts to rationalize a methodology of alternative selection using a context sensitive design approach.

## 1.0 Background

Calgary's population has recently exceeded the one million mark and the City is currently the heaviest populated municipality in the Province of Alberta. Blessed with an oil-rich, turning now into a more mature and diversifying economy, Calgary has been experiencing unprecedented growth in recent years, which in turn has created, among other social needs, significant new demands on the municipality's existing transportation system.

As a result of this rapid growth, many of the City's local at-grade intersections along major urban corridors are at or beyond capacity. Grade separations as an improvement measure for urban arterials are not normally common or desirable because of their higher construction costs and R.O.W. requirements. However the increase of existing, and the projection of high future traffic volumes on many of Calgary's thoroughfare roadways has forced the City's transportation engineers to examine unconventional, innovative, sometimes more expensive solutions, in order to provide sufficient capacity and to reduce congestion on at-grade roadways otherwise under traffic signal control.

Major arterial roadways in built-up urban areas face problems not necessarily present in typical freeway-type interchange design. These designs are far more sensitive to the land use adjacent to the surrounding network. In such built-up areas, there is generally insufficient room for the construction of expansive loop ramps, such as those present in a parclo (partial cloverleaf) or conventional diamond configuration. Further, properties land with frontage at the intersection of two busy thoroughfares in an urban environment can be particularly valuable to retail, commercial or residential uses, as such parcels are often coveted for their ease of access and high visibility. Driveway access to the thoroughfare roadways is therefore of great importance and the structural elevation and subsequent grade and distance to downstream access points needs to be minimized. Maintaining the existing flow of traffic during implementation is another critical consideration. In some cases, as is the situation in this study, the proximity of an active existing light rail transit (LRT) line, currently running north-south at headways of as short as five (5) minutes in either direction, is an added complication.

Because of the lack of open space, and other considerations such as aesthetics; public acceptance; environmental and geotechnical issues; cost of structures; traffic accommodation; transit integration and road safety design, traditional planning and engineering, approaches to mitigating arterial traffic congestion may no longer be sufficient to achieve a total solution. Unconventional and innovative alternatives will have to be explored.

This paper describes some of the innovative techniques used in arriving at a functional design of an unconventional interchange at one of the busiest intersections in the south part of Calgary, Macleod Trail and 25 Avenue SE. A location map of the project site is shown in **Figure 1**. Macleod Trail is an important north-south primary arterial road, bisecting and dividing the southern part of the City into its southeast and southwest quadrants, with an average daily traffic (ADT) volumes of 53,000 vehicles per day (vpd).

25 Avenue SE is an east-west arterial leading to a major exhibition and sports complex site known as Stampede Park, the residential community of Ramsay, and the industrial areas of Manchester and Highfield to the east, with an ADT of 17,000 vpd.

## 2.0 Project Genesis

In 1973, a new roadway which included the subject intersection was proposed to improve the connections between Calgary's downtown area and the existing or proposed north-south routes to the southeast of the City **[1]**. This roadway was known as the East Calgary downtown Penetrator. Although tentatively planned, the functional study was never approved by the City Council. In 1980, Council again directed the City Administration to review possible routes for a bypass to accommodate traffic between the south downtown area and the major north south freeway of Deerfoot Trail (Provincial Highway 2) to the east of the subject intersection **[2].** This new route later became known as the South Downtown Bypass. It would provide direct access to the south downtown area from the south and east districts of Calgary, allowing traffic to bypass the south downtown if necessary, and linking it to an expressway on the west side of downtown. However, during the 1990's when the City reviewed its transportation master plan, the planned Bypass was removed from the master plan for various reasons.

Currently, there is still a desire on the part of the City to better connect the south and east areas of Calgary into the downtown area **[3]**. The 25 Avenue SE corridor provides the nearest connection between a north-south arterial (Macleod Trail) and a major road (Blackfoot Trail) that directly leads into the south downtown area. Upgrading this road to the City's major roadway standard and providing better connections to the expressway and to the direct route into the downtown area will help to fulfill this function. It will also improve current and future transit operations, as well as lessen community shortcutting along 25 Avenue SE.

In 2006, the City of Calgary initiated a functional study of what is known as the 25 Avenue SE Connector that included the design of improvements at the intersection of Macleod Trail and 25 Avenue SE.

## 3.0 The Intersection, its Surrounding Area, and the Planning Challenge

The existing layout of the intersection of Macleod Trail and 25 Avenue SE, where improvements are currently planned, is shown in **Figure 2**.

### 3.1 The Intersection

Macleod Trail is major north-south urban arterial, which has a basic six-lane divided cross-section highway. It extends from Riverfront Avenue, just south of the Bow River, to the south City limits where it transitions into Highway 2A as part of the provincial highway infrastructure. Macleod Trail becomes a multi-lane one-way road for northbound traffic north of 22 Avenue SE. The posted speed limit is 60 km/hr.

25 Avenue SE, east of Macleod Trail, is a four-lane undivided east-west major collector joining north-south Dartmouth Road at its eastern terminus. Just east of the Macleod Trail intersection, 25 Avenue SE crosses an existing Light Rail Transit (LRT) line at grade. West of Macleod Trail, 25 Avenue SE narrows down to a two lane residential minor collector to 5 Street SW. The posted speed limit is 50 km/hr.

### 3.2 The Surrounding Area

Land at the four quadrants of the intersection is heavily dotted with existing or planned development, and is severely constrained in terms of available R.O.W. for improvement initiatives. Plans are well in place at the north-west corner for a commercial re-development to convert a 4 acre parcel from its existing low density commercial to a mixed use site including residential towers, multi-family residential units, a potential food store, and various other commercial and office uses. Because of this, further land acquisition is not possible. The northeast corner is occupied by an at-grade LRT station and beyond that, the Calgary Exhibition Grounds and Stampede Park. Stampede Park is an important activity centre, generating heavy traffic during special events held on a regular basis. Further, Stampede Park has plans to expand into the adjacent leased lands north of 25 Avenue in the near future. At the southeast corner is the Union cemetery situated on a small hill, where land appropriation is basically unattainable. The southwest corner of the intersection is lightly developed commercially. However, topography is difficult with steep slopes currently retained by an approximately 12 metre high concrete retaining wall.

### 3.3 The Planning Challenge

Besides land issues, traffic conditions are equally critical. As well as high traffic volumes on both highways, heavy truck percentages in the traffic stream are high, at about 12 to 15% currently, increasing to a projected 20 to 25% during peak hours of travel. Overhead and underground utilities in the vicinity of the intersection are numerous, including a major 530mm (20”) diameter trunk water main, gas and sewer lines, and several transmission power lines and towers.

The proximity of Macleod Trail to the LRT tracks and station poses a particularly tight geometric alignment problem for proposed changes in the roadway configuration. The future increased frequency of train services to 3-minute intervals will substantially reduce intersection capacity, and pedestrian/passenger and cyclist travel desire lines have to be maintained.

Given the above land use and engineering constraints, and the large number of stakeholders each with their own agenda, attempts to find an acceptable solution by consensus have been particularly onerous. The following sections describe the functional design team’s effort, not the least of which was the holding of multiple public information sessions and problem solving charrettes, in an attempt to arrive at a technically sound and time context sensitive design solution that will be accepted by most interested parties.

## 4.0 Framework for the Identification of Alternatives – An Innovative Methodology

The study approach started with the task of identifying families or groups of similar feasible alternatives, which later became the focus of subsequent detailed analysis. In any transportation planning process, very often the alternatives have been previously given, in which case the study objective is simply to conduct an analysis and evaluation. In some cases the alternatives under consideration might have come from previous studies or they have been identified by public officials. In the case of the present study, aside from the injection of a few minor ideas from the City, the planning team had relatively large degrees of freedom, so that the objective was to develop and analyze a wide range of alternatives that had not been identified or considered previously. Taking advantage of this open agenda, the methodology adopted for alternative development took the format of several carefully planned and managed brainstorming sessions. These sessions brought together new ideas from a small group of selected professionals represented by the City's transportation department and consultants in different disciplines transportation and urban planners, traffic and highway engineers, structural and environmental engineers, and transit facility designers to bear on the problem in a freethinking atmosphere that encouraged fresh approaches.

## 5.0 Possible Candidate Solutions and Technical Analysis

Given the high projected volumes along the proposed 25 Avenue corridor in the planning horizon (year 2018), and with a high background growth of traffic along the two major highways, the principal arterial roadway of Macleod Trail at the intersection of 25 Avenue, which is currently operating at capacity, is no longer able to adequately serve increasing travel demand. Trip efficiency is lost, even at off-peak hours, as motorists experience stop-and-go traffic conditions between adjacent intersections along the highly developed north-south arterial.

To solve future congestion problems, and in an attempt to seek alternative total solutions addressing all issues and concerns, an urban arterial interchange design concept was considered. To achieve such an objective, "conventional" and "unconventional" intersection designs, both at-grade and grade-separated alternatives, were examined.

Traditional or "conventional" approaches to mitigate congestion including installing minor surface intersection improvements, adding multiple through lanes and left or right turning bays, building bypasses, or modifying and introducing multi-phase including protected left-turns signal control, were examined but found insufficient or impractical to achieve a total solution.

"Unconventional" intersection design concepts were developed based on three primary principles. First, the design and operation emphasis was on through and high volume left or right turn movements. Second, the design and operations allowed for a reduction in the number of existing signal phases (preferably to two). Finally the ultimate design would have to reduce the number of conflict points at intersections and separate conflict points that remained.

Currently, there are at least two dozen or more unique at-grade and grade-separated intersection designs of the "unconventional" type that are being used or have been tested by computer simulation in North America and elsewhere **[4]**.

## 5.1 At-grade Intersection Options

The better known "unconventional" urban isolated or arterial system at-grade intersection solutions were carefully reviewed, with some quickly ruled out as either not applicable or unsuitable for implementation. Amongst the options initially considered include:

1. Michigan Median U-Crossover
2. Alabama Superstreet Median Design
3. Left-over Design
4. **New Jersey Jug-handle**
5. Quadrant Roadway Intersections
6. Paired Intersections
7. Continuous Flow Intersections (CFI), also known as Displaced Left Turn and Enhanced At-grade Intersections
8. Continuous Green "T"
9. **Multi-Lane Roundabouts**
10. Split Intersections

In most of the above improvement options, pre-existing site conditions are necessary for successful design implementation. For Cases 1, 2 and 3, the presence of a continuous wide median along the mainline is required. Cases 4 and 5 assume available R.O.W. at the jughandle intersection. Case 6 needs available R.O.W. to build and operate parallel collector/backage roads to the mainline arterial. Case 7 must have available R.O.W. at the intersection, and adjacent land parcels must be organized to allow restricted access near the intersection. Case 8 is applicable for T-intersections only. Case 9 is best suited for equal and low to moderate traffic volumes on both roads with high accident rate. Case 10, the split intersection, is only possible in an urban setting where parallel streets with adequate available offset can be converted into one-way traffic. For the above reasons, except for the jughandle and roundabout options, other at grade solutions were rejected as not capable of implementation.

## 5.2 Grade-separated Intersection Options

The common unconventional urban arterial grade-separated intersections that were considered include the following:

1. **Diamond Interchange**
2. **Full Cloverleaf Interchange**
3. **Partial Cloverleaf (Parclo) Interchange**
4. **Echelon Interchange**
5. **Left Flyover**
6. Centre Turn Overpass (CTO)
7. Roundabout Interchanges
8. Michigan Urban Diamond Interchange
9. Contraflow Left Interchange
10. Single Loop Interchange
11. Compressed Diamond Interchange
12. **Single Point Urban Interchange (SPUI)**

As is the case with the list of unconventional at-grade intersection solutions, some of the above innovative ideas have proven impractical because of site constraints. Of the six options (as bolded in the text) considered in detail, the diamond interchange **(1)** is simple and works well with moderate volumes on the cross street (25 Avenue). However, the proximity of the two signals at either ramp termini has resulted in inadequate left turn storage. The full cloverleaf interchange **(2)** provides direct turning movements without stopping from all approaches but requires substantial R.O.W. in all four intersection quadrants, which is lacking in the current situation. The partial cloverleaf interchange **(3)** is one of the most efficient interchange designs. However, it also has high impacts to adjacent properties in at least two intersection quadrants and requires most movements to stop once. The echelon interchange **(4)** is an innovative approach to grade-separated interchange design first introduced in Aventura, Florida. The interchange design elevates three of the four approaches and is modified from the concept of elevating alternating approaches. In this design, all intersection approaches essentially become one-way streets and their intersections can be controlled by simple two-phase signals. The echelon interchange has the greatest overall operations benefits, where the arterial and cross street volumes are similar, and works particularly well where it crosses an active rail line. The left flyover **(5)** addresses issues of left turn traffic only and the practice of merging left to exit is generally not a familiar concept to North American motorists. The single point urban interchange **(12)** is attractive where higher interchange capacities are sought, and where costs are not the primary design selection criteria. The SPUI is particularly efficient compared to other interchanges where left-turn movements are heavy and/or where there are other signalized intersections nearby.

## 5.3 Alternatives Identified

With the above state-of-the-practice knowledge as background, a large number of alternatives resulting from the brainstorming session described above were identified as possible candidate solutions. These were grouped into four generic families, as follows:

- **Family 1 – “Do nothing” Option**
  - 1.1 Minor improvements to the intersection focusing on operational modifications such as signal re-phasing and retiming, lane widening and reconfiguration, etc.
  - 1.2 Lowering of the existing LRT tracks to remove operational conflicts with 25 Avenue

- **Family 2 – At-grade Option**
  - 2.1 Roundabouts
  - 2.2 Jughandles

- **Family 3 – Grade-separated Option**
  - 3.1 Cloverleaf interchange
  - 3.2 Diamond interchange (Macleod Trail passing over 25 Avenue; or 25 Avenue passing over Macleod Trail)
  - 3.3 Single point urban interchange (Macleod Trail passing over 25 Avenue; or 25 Avenue passing over Macleod Trail)
  - 3.4 Echelon interchange
  - 3.5 Grade separate through lanes on Macleod Trail only, with turning movements and 25 Avenue at grade
  - 3.6 Grade separate left turn movements on Macleod Trail and 25 Avenue, with through movements on Macleod Trail at-grade

- **Family 4 – Flyover Options**
  - 4.1 Southbound to eastbound left turn movement flies over intersection
  - 4.2 Southbound to eastbound left turn movements, and westbound to northbound right turn movements fly over Stampede Park

## 6.0 Framework and Criteria for Evaluation

In the development of a methodology for the evaluation and selection of alternatives previously identified, the focus is as much on the process (i.e. the interaction among key participants in the pre-selection process, through extensive discussion, site visits and charrettes) as in the technique (e.g. using a cost benefit analysis) itself.

### 6.1 Evaluation Framework

Traditionally, there are two evaluation methods commonly used in transportation project planning: the economic evaluation approach (or cost effectiveness approach) and the rating scheme approach (use of scoring techniques or weighing schemes to produce a scalar measure of project attractiveness) **[5]**. The difficulty with the former approach is that it does not provide information on the relative value of the different alternatives. As well, benefits are often difficult to quantify, as non monetary effectiveness and equity implications can at times be much more important than an efficient expenditure of funds.

For these reasons, the economic approach method was not adopted in the present analysis. With the latter approach, the question frequently raised is whose values are being applied in the assessment. This was somewhat overcome on this project by including in the evaluation panel a team of diversified experts and professionals impartial to the planning outcome. Community, technical, economic and other objectives were then weighed to reflect the preference of decision makers, and impacts need not be expressed in monetary terms. The weights assigned to the objectives or evaluation criteria were thoroughly discussed and predetermined by City officials familiar with the goals and objectives of the overall planning scheme. A quantitative score of each alternative was obtained by summing and then averaging the separate scores by each evaluator for each objective-impact category. Statistical tests were carried out to avert errors due to skewing. To convert results to an easily understandable term, scores were "normalized" to some figure out of a total of 100.

## 6.2 Evaluation Criteria

Fourteen (14) criteria were selected in the evaluation process. The 14 evaluation criteria used with their relative ratings (in parenthesis, out of a total of 10) are listed below. From these 14 primary criteria or objectives, measures of effectiveness (MOE) were identified which formed the basis of the final evaluation process.

- Constructability (10)
  - Ease of construction of temporary works
  - Ease of construction of permanent works
- City roadway network compatibility (10)
  - Achieves principles of City network
  - Supports City's strategic policies
  - Incorporates alternative modes
- Cost (9.5)
  - Overall cost
  - Length and time of construction
- Safety (9)
  - Human factor (driver expectancy)
  - Conflict reduction
  - Collision reduction
- Traffic engineering (8.5)
  - Minimal detour impacts
  - Good traffic engineering attributes (LOS, v/c, delays)
  - Provides for all movements
- Stormwater management (7)
  - Requires minimal additional drainage works
  - Does not create a "big" hole in the ground

- Environmental (6.5)
  - Minimum impact during construction
  - Minimum impact post construction
  - Ease of fixing impact
  - Aesthetics
- Geotechnical engineering (6.5)
  - Least amount of deep foundation required
  - Low embankments
  - Minimum number of retaining structures
- Utility conflicts (6.5)
  - Minimum displacement of existing utility services
- Transit integration (6)
  - Ease of pedestrian access
  - Convenience of bus routes and stops
  - Integration with LRT
- Land use constraints (5.5)
  - Best effect on adjacent residential development
  - Best effect on adjacent commercial and industrial development
  - Minimum impacted footprint
- Sociological factors (5)
  - Improves neighbourhood image
  - Fosters community adhesion
  - Will not create a homeless shelter
- Structural components (5)
  - Blend in with environment
  - Cost of structure
  - Least amount of technical problem
- Intelligent Transportation System (ITS) deployment (5)
  - Affords opportunity for future ITS initiatives
  - Ease of ITS implementation
  - Effectiveness of implementation

## 7.0 Public Outreach and Context Sensitive Design

Throughout the planning process, and before arriving at a final preferred design alternative, a vigorous and structured stakeholder and citizen outreach program was designed and implemented to obtain widespread public and interest group involvements. Numerous face-to-face meetings with community associations, business leaders, and private developers were held. Public information sessions were arranged to gather opinions and feedback from interested parties. In all cases, conveniently located meeting venues were chosen, and adequate advance notice given to the public and elected officials to encourage attendance and participation. For ease of understanding during presentations, a "story telling" approach with graphical displays was used to explain the project and the solution to the public to solicit their comments and support. The final preferred solution was conveyed to the public with computer traffic simulation in an open house meeting.

To support the public engagement effort, a context sensitive design approach was adopted in the planning process. As well as satisfying appropriate design codes and technical standards, the design team's focus was to work around design parameters that would best suit to the environment and that would receive endorsements from most entities. All potential impacts to neighbouring communities were identified and analyzed. Innovative techniques of solution including statistical analysis of scoring results, expert consultation in specialized areas, peer review of technical analysis, holding of brainstorming sessions, use of Delphi techniques, were employed.

## 8.0 The Preferred Alternative

The final preferred alternative selected for future detail design and implementation at the junction of Macleod Trail and 25 Avenue was an "underpass" type of the Single Point Urban Interchange **(SPUI)** shown in **Figure 3**. In this alternative, the side street 25 Avenue would go over the major arterial Macleod Trail (or Macleod Trail would go under 25 Avenue, hence underpass). The crossing of the LRT tracks from the side street of 25 Avenue was also grade separated, creating safer and more efficient passage by motor vehicles. The alternative separated the through traffic of Macleod Trail from the rest of the traffic at this junction. The signals for the ramps were on 25 Avenue. Considerable structures were required to support the grade-separation and to keep the project footprint small. Pedestrians and cyclists movements were separately planned

The design has the advantage that it can be constructed in limited R.O.W. It reduces signal phases from four to three. Turning paths are flatter and can be made at higher speeds, thus increasing saturation flow rates and intersection capacities. The SPUI solution however suffers from certain disadvantages including higher bridge cost for longer bridge spans, and more difficult pedestrian crossing movements.

Given difficult pre-existing site conditions, traffic and other engineering considerations, and concerns of stakeholders, the chosen alternative is deemed the most favourable to the City.

## 9.0 Summary and Lessons Learnt

This paper outlines the planning process used in the functional design of an unconventional urban intersection. Using a context sensitive design approach; by recruiting the service of a large group of professionals with different but relevant skills and background; and by encouraging and involving the participation of all major stakeholder, the general public, elected officials, community leaders and business and land owners; a large number of innovative alternatives were identified which ultimately led to the development of a preferred option that successfully addressed the multiple constrained parameters on-site which included R.O.W. limitations, LRT crossing issues, topographical problems, traffic engineering concerns and impact to the community and business activities.

Innovations promote advance of the science and should be encouraged. It must be remembered however, that major changes such as solutions to an existing transportation facility are often politically controversial, and proposing unconventional designs can draw additional objections from business owners, stakeholders, and the motorist public, as well as create added anxiety on cautious agency officials.

Highway agencies generally prefer to adhere to conventional proven concepts, as design innovations involves risks. From the public acceptance perspective, it is important that highway users understand the benefits associated with the proposed improvements which must result in reduced travel time and improve safety for their trip overall. Unconventional arterial intersections by definition re-route certain turn movements. Successful designs are those that will not cause driver confusion, or at the very minimum, errant manoeuvres made will not create an unsafe situation. Developers, business and land owners are generally and rightly so concerned that the final design chosen will not restrict their driveway access along an arterial or near the intersection, as they generally rely on direct access to attract customers. Intersection designs using an unconventional method can also bring significant political and institutional issues to the surface, as voters will object to perceived inconvenience and risk. Pedestrian and bike safety, access and convenience is an important design criterion not to be overlooked in an urban intersection environment.

Finally, as an essential part in the planning stages, informing the public and interacting with stakeholders is vital for successful project implementation. To achieve that a comprehensive public outreach program needs to be planned. Context sensitive methods of design are highly encouraged. Educating the public with information sessions, press releases, and brochures and sometimes a driver education program will help to smooth the planning process.

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