1

1.0

1.1

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1.4

1.6

1.8

2.0

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2.5

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3.2

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DEVELOPMENT OF SELECTION CRITERIA
FOR INTERSECTION CONTROL

BY

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A THESIS SUBMITTED
TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE
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August, 1981

The undersigned recommend to the Faculty of Graduate Studies and Research, acceptance of the thesis, "DEVELOPMENT OF SELECTION CRITERIA FOR INTERSECTION CONTROL", submitted by Robert Ridley, P. Eng., B. Eng. in partial fulfillment of the requirements of the degree of Master of Engineering (Civil).

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ABSTRACT

The following study was undertaken to define the deficiencies of current criteria for the selection of intersection control, and to develop appropriate alternate criteria.

The study included the preparation and circulation of questionnaires aimed at both the public and various technical agencies in order to elaborate upon the available literature.

The results of these studies, augmented by selected references, defined a variety of factors of relevance to the selection of intersection control. On this basis the current criteria available for this process were evaluated in order to determine appropriate directions for the development of new criteria for intersection control selection.

Analysis of four potential systems for intersection control selection resulted in the development of systems appropriate as an immediate improvement to currently available criteria and also measures which will be suitable for this task in the medium and long term.

ACKNOWLEDGEMENTS

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A further essential contribution to this study was made by the Transportation Department of the Regional Municipality of Ottawa-Carleton who absorbed the cost of the public questionnaire publication and whose vehicular volume and accident frequency data files provided the basis for much of the following analysis.

Finally, gratitude is expressed to Mrs. D. Gorman who was responsible for the typing of both final and preliminary project reports.

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1.0 INTRODUCTION AND BACKGROUND

The control of vehicular and pedestrian travel is essential in order to provide a transportation system which is safe, efficient and convenient. Traffic must be regulated both to minimize the potential for conflict between opposing traffic streams and to minimize the undesirable impacts of transportation.

This need is particularly evident in urban areas where the intense activity results in increased potential for traffic conflicts and damage. Further, it is evident that this potential for conflicts is greatest where traffic streams must cross each other; that is, at intersection locations. The subject of this thesis is the regulation of traffic at intersection locations.

The control of traffic at intersections is not a widely researched field and it has only been recently that a methodical scientific approach has been used to establish intersection control.

As a result, the selection of intersection control is still done on a generally subjective basis, particularly for types of intersection control other than traffic signals. As a result, current warrant systems for these devices are incomplete and generally non-uniform between jurisdictions.

These drawbacks are recognized amongst traffic engineers as a result of which both the Roads and Transportation Association of Canada and the Institute of Transportation Engineers have established technical committees to deal with the preparation of criteria for intersection control.

The current practices of intersection control selection suffer from two primary inadequacies. Firstly, current systems are technically inadequate due to incompleteness or lack of uniformity and inadequate treatment of certain factors affecting the process of selection of intersection control. Secondly, the available criteria for intersection control selection do not generally reflect current trends of thought in North America, particularly with respect to considerations of energy usage, environmental protection, economics of vehicle usage, and the need for public input to technical decisions. Further, there is increasing evidence, noted in Section 4.1.5, that traffic engineers may be held liable for the results of intersection control selection:

In order to define and rectify the foregoing shortcomings, the following thesis has been undertaken to develop a revised criteria for the selection of intersection control.

1.1 Background

The types of intersection control to be dealt with in this thesis, and their hierarchy in increasing order of restrictiveness follows:

- no intersection control
- yield control
- stop control
- multi-way stop control
- traffic control signals

It should be noted that, in the absence of intersection control, (no intersection control above) traffic is generally obliged to follow the right-of-way rule which states that, upon approaching an intersection, drivers will yield to vehicles approaching on the right.

For the purpose of this work only intersection control for at grade, or level, intersections has been considered and without the addition of other measures such as flashing beacons or police supervision.

Of the devices noted, the application of yield control is comparatively new and this device is still not widely accepted for routine usage. Conversely, the application of stop type control is widely used, often without regard to the need for such control.

Finally, while all of the foregoing types of intersection control can be used at either urban or rural locations, it is the urban locations which are generally more critical and which are stressed in this study.

The general procedure adopted for this study, illustrated in Exhibit 1, consists of three basic stages. The first of these stages was the collection and assessment of various

EXHIBIT 1

STUDY PROCEDURE

factors relevant to the selection of intersection control which included a literature review and the preparation of two questionnaire studies to collect further information from public and technical sources.

It should be noted that this report is based primarily upon data, and experience, from North America since this research was considered to be most relevant. Similar data is also available from European countries but has not been stressed in the following work.

In the second stage the data collected was reviewed and used to define a variety of factors of apparent importance to the selection of intersection control and to evaluate current criteria for the selection of intersection control. In many cases data collected from the Ottawa area, and available from the files at the Regional Municipality of Ottawa-Carleton, have been used to alleviate shortcomings in the available literature.

Finally, several potential systems for the selection of intersection control were defined and evaluated, culminating in a statement of recommended practice for the selection of intersection control.

2.0 PUBLIC QUESTIONNAIRE STUDY

During the review of literature with respect to the selection of intersection control it was noted that very little information has been published with respect to public opinion on this topic. In view of recent evidence in news media reports that considerable public opinion existed it was considered essential that an effort be made to gauge this feeling.

To prepare for this study a comprehensive review of available media material was undertaken in order to define areas where uncertainty existed. The most evident areas of controversy were found to be the application of multi-way stop control and public displeasure with the inflexible attitude of technical agencies concerning the application of intersection control. Similarly, there is evidence that technical agencies tend to doubt public input in many cases, assuming that such input represents only the vocal minority.

The foregoing considerations resulted in a short questionnaire which was placed in all local Ottawa newspapers during October 1978 for two consecutive days, one of which was a Saturday to ensure maximum distribution. The newspapers and their circulations follow:

- Ottawa Citizen, English language daily, 120,000
- Ottawa Journal, English language daily, 75,000
- Le Droit, French language daily, 45,000

The questionnaires were placed in the papers approximately one month before a municipal election which had sparked considerable interest in this subject.

The interest in this topic was augmented by articles in both English daily's immediately preceding the placement of the questionnaires. Unfortunately the articles tended to publicize the study as an engineer versus politician showdown which may have influenced the replies somewhat. This resulted from numerous prior decisions at a political level in which the recommendations of the engineering staff concerning intersection control selection were rejected.

During the period following placement of the questionnaire there was a lengthy postal strike which clearly reduced the number of replies received since the questionnaire had noted a deadline for responses. Despite this, the questionnaire resulted in 355 usable replies ranging from a minimum of four out of ten questions answered to some replies which included numerous pages of general comments on this topic.

Generally, the study was well received with few replies indicating that the study was biased or unnecessary. In order to avoid influencing the replies, each of the questions provided respondents the opportunity to indicate their own feelings; that is, the study format was not a multiple choice type. It should be noted that the format chosen made analysis of the replies fairly tedious and not amenable to statistical analysis. This latter drawback was not considered serious as this type of study does not result in a random sample and therefore statistical conclusions are of questionable value.

These observations were verified by members of the Carleton University Mathematics Department whose views are presented in Annex A.

Reproductions of both the English and French versions of the questionnaire form appear, as published, in Exhibits 2 and 3 respectively. The analysis of this study is detailed in subsequent sections.

2.1 Factors of Importance to the Selection of Intersection Control

The intent of this question was to find out from people what factors they felt should be reviewed before selecting a type of intersection control. Two types of responses were anticipated, and received; some responses were quantitative and described measureable factors, while other responses were more qualitative and are representative of the perceived objectives of intersection control. The question wording specified factors in order to encourage the latter response, as follows:

"What factors do you feel are particularly important in order to determine which type of intersection control to use at a given location?"

A total of 327 replies were received to this question and in most cases more than one factor was specified. The responses were reduced to 39 distinct categories and aggregated as shown in Exhibit 4. Of these 39 categories, 28 represent measurable, or quantifiable, factors. The

EXHIBIT 2ENGLISH PUBLIC QUESTIONNAIRE FORM

THE REGIONAL MUNICIPALITY OF OTTAWA-CARLETON, TRANSPORTATION DEPT.

The Transportation Department of the Regional Municipality of Ottawa-Carleton, in conjunction with research being conducted at Carleton University, is currently reviewing the criteria used to establish intersection traffic control.

A considerable volume of technical input has now been collected from literature searches and a questionnaire study of other North American municipalities.

In order to augment this data with an indication of public opinion within the Regional Municipality, you are invited to COMPLETE AND RETURN THE FOLLOWING QUESTIONNAIRE along with any other comments which you may have, by 16 OCTOBER, 1978, to:

Mr. M.J.E. Sheflin, Transportation Commissioner
Transportation Department, Ottawa, Ontario K1P 5Z3

1. What factors do you feel are important in order to determine which type of intersection control to use at a given location?
2. To you, what are the best attributes of each of the following types of intersection control? Yield _____ 2 Way Stop _____
3 or 4 Way Stop _____ Traffic Control Signals _____
3. What do you feel are the worst drawbacks of each of the following types of intersection control? Yield _____ 2 Way Stop _____
3 or 4 Way Stop _____ Traffic Control Signals _____
4. Do you feel that stop signs should be used to discourage traffic or reduce vehicle speeds in order to improve the environment in an area? Yes _____ No _____
5. When arriving at a stop sign the law requires that motorists must come to a full stop. Do you feel that this law should be rigidly enforced? Yes _____ No _____ Do you feel that the current level of enforcement is adequate?
6. In your opinion, what are the drawbacks which result from the poor application of intersection control such as the provision of inadequate or overly restrictive traffic control or the overuse of a particular type of control?
7. It has been stated that the overuse of any type of intersection control, particularly multi-way stop signs, results in decreased driver respect for the control. Do you feel that this is true?
Yes _____ No _____
8. In your opinion, are any of the following types of intersection control devices overused in the Ottawa area? Yield _____
2 Way Stop _____ 3 or 4 Way Stop _____ Traffic Signals _____
9. Do you feel that there are any types of control which should not be used under any circumstances, and if so why? _____
10. Do you have any other general comments with respect to the provision of intersection control? _____

LE SERVICE DE TRANSPORT DE LA MUNICIPALITE REGIONALE D'OTTAWA-CARLETON, a l'aide de recherche menée par l'Université Carleton, fait presentement la revue des critères pour la mise en oruvre d'une méthode de contrôle de la circulation aux intersections.

Un grand nombre de données technologiques est déjà recueilli provenant de recherches littéraires et d'une étude à base de questions se rapportant aux municipalite de l'Amérique du Nord.

Afin d'ajouter davantage a ces donnees en démontrant l'opinion publique de la Municipalite regionale concernant ce sujet, vous êtes invites a remplir et nous renvoyer le questionnaire suivant, apportant d'autres commentaires, s'il y a lieu, d'ici le 16 octobre, 1978, à:

M. M.J.E. Sheflin, Commissaire des services de transports
Service de transport, 222 Queen Street, Ottawa, Ontario K1P 5Z3

1. D'après vous, quels facteurs s'avèrent importants dans le choix des méthodes de contrôle de la circulation à une intersection?
2. Quels sont, d'après vous, les avantages premiers pour chacune des méthodes de contrôle aux intersections suivantes? Cedez _____
Arrêt en deux sens _____ Arrêt en trois ou quatre sens _____
Les signaux de contrôle de la circulation _____
3. Quels sont, d'après vous, les désavantages néfastes des méthodes de contrôle de la circulation aux intersections suivantes?
Cedez _____ Arrêt en deux sens _____ Arrêt en trois ou quatre sens _____
Les signaux de contrôle de la circulation _____
4. Croyez-vous que les panneaux d'arrêt devraient être employes pour détourner la circulation ou de minuer la vitesse véhiculaire afin d'amellorer le milieu amblant d'un secteur? Oui _____ Non _____
5. La foi exige les automobilistes d'arrêter complètement devant un panneau d'arrêt. Croyez-vous que cette loi devrait se faire observée davantage? Oui _____ Non _____ Croyez-vous que le degré actuel d'observance est suffisant? Oui _____ Non _____
6. D'après vous, quels sont les désavantages provenant du mauvais emploi de méthodes de contrôle aux intersections tel, disposer de méthodes de contrôle aux intersections tel, disposer de méthodes de contrôle insuffisantes ou trop limitées ou l'emploi affected d'une certaine méthode?
7. On remarque que l'emploi affected de toute méthode de contrôle aux intersections, surtout des panneaux d'arrêt a voies multiples, donne suite a réduire le respect chez les automobilistes envers le contrôle. Croyez-vous que ceci est vrai? Oui _____ Non _____
8. D'après vous, parmi les dispositifs de contrôle de la circulation aux intersections suivants est-ce qu'il y en a qui sont employés trop fréquemment dans la région d'Ottawa? Cedez _____ Arrêt en deux sens _____ Arrêt en trois ou quatre sens _____ Les signaux de contrôle de la circulation _____
9. Croyez-vous que certaines méthodes de contrôle aux intersections devraient, en aucun temps, être employées et si oui, expliquez?
10. Avez-vous d'autres remarques à apporter concernant les méthodes d'emploi de contrôle aux intersections?

EXHIBIT 4FACTORS OF IMPORTANCE TO THE SELECTION
OF INTERSECTION CONTROL PUBLIC RESPONSES

<u>Rank</u>	<u>Quantifiable Response</u>	<u>%</u>	<u>Rank</u>	<u>Qualitative Response</u>	<u>%</u>
1	Volume of Traffic	14.6	1	Maintain Traffic Flow	12.9
2	Pedestrian Volume	8.6	2	Safety	12.6
3	Vehicular Volume	5.7	3	Pedestrian Safety	4.0
4	Traffic Density	3.5	4	Fairness/Common Sense	1.5
5	Presence of Children	3.0	5	Public Acceptance	1.3
6	Direction of Traffic	2.7	6	Efficiency	1.0
7	No. of Accidents	2.5	7	Convenience	.7
8	Proximity to Schools	2.4	8	Vehicular Safety	.5
9	Speed	2.4	9	Clarity, Uniformity	.3
10	Visibility	2.2	10	Justification	.3
11	Type of Area	2.2	11	Flexibility	.2
12	Intersection Geometry	1.8			
13	Average/Peak Traffic	1.7			
14	Minimize Delay	1.7			
15	Side Street Access	1.3			
16	Type of Traffic	1.0			
17	Volume of Turning Traffic	1.0			
18	Traffic Pattern	1.0			
19	Type of Street	.8			
20	Presence of Senior Citizens	.8			
21	Amount of Cross Traffic	.7			
22	Cost	.7			
23	Need for Control	.7			
24	Minimize Fuel Usage	.5			
25	Winter Impact	.5			
26	Cyclists	.2			
27	Capacity	.2			
28	Ease of Enforcement	.2			

Note:

Results based on 327 distinct replies in which a total of 595 factors were specified.

perceived importance of traffic volume, both pedestrian and vehicular, as a justification for intersection control is evident. Equally evident is the fact that the most important goals of intersection control are maintenance of traffic flow and safety. The replies indicated maintenance of traffic flow to be closely related to minimization of delay.

The perceived importance of the presence of children, proximity to schools, type of area, presence of senior citizens, cost, fuel usage, winter impact and ease of enforcement are noteworthy, as these factors are not currently considered in the selection of intersection control.

2.2. Attributes of Intersection Control by Type

This question, together with the following one, was considered to be particularly important because the intent was to define the benefits and drawbacks of intersection control devices and thereby further define the public objectives for the application of these devices.

The format was carefully chosen and deliberately general to avoid coaching the replies as this area was a strong issue in the news media.

The wording selected for this question follows:

"What do you feel the best attributes of each of the following types of intersection control are?"

- Yield
- 2-Way Stop
- 3 or 4-way Stop
- Traffic Control Signals

This question resulted in 300 replies which are summarized by intersection control type in the following paragraphs.

Yield type intersection control is used relatively frequently in the Ottawa area to control both intersections and ramp type locations. Thus, the replies reflect Ottawa experience with this device and may not be applicable elsewhere. The five most frequently noted attributes of yield control follow in Table 1.

Table 1 - Attributes of Yield Control

<u>Attributes</u>	<u>% of Total Response</u>
Allow smooth traffic flow	33.9
Minimize delay	12.7
Cautionary	10.2
Maintain flow speed	7.2
Safety	5.5

Total Number of Responses - 236

With the exception of safety, all responses noted are related to the minimization of delay.

In view of the clear differences of opinion regarding stop and multi-way stop control these two types of intersection control were dealt with individually. It should be noted

that conventional two-way stop control is the most frequently used type of intersection control in this area. The five most frequently noted attributes of this device are shown in Table 2.

Table 2 - Attributes of Two-Way Stop Control

<u>Attributes</u>	<u>% of Total Response</u>
Benefit through traffic	21.0
Safety	19.5
Allow/Control access to major street	11.9
Designate right-of-way	10.5
Cautionary	5.2

Total Number of Responses - 210

Three of the responses noted are related to the protection of through traffic, while the remaining two deal with safety.

The increasing use of multi-way stop control in this area over the past few years has resulted in great polarization of opinion and resultant publication of both the attributes and drawbacks of this device. The five most frequently noted attributes follow in Table 3.

Table 3 - Attributes of Multi-Way Stop Control

<u>Attribute</u>	<u>% of Total Response</u>
Safety	21.3
Slows traffic	20.2
Provides equal opportunity	20.2
Benefits side street	9.6
Clarity	5.3

Total Number of Responses - 94

It is noteworthy that the majority of responses to this portion of the question indicated that multi-way stop control had no attributes.

Finally, the following Table 4 depicts the results of this question with respect to traffic control signals.

Table 4 - Attributes of Traffic Control Signals

<u>Attributes</u>	<u>% of Total Response</u>
Safety	15.7
Allow/Control access to major street	13.6
Flexibility	10.5
Positive Control	9.4
Clarity	8.4
Fairness	8.4

Total Number of Responses - 191

The response noting the flexibility of traffic control signals may have been prompted by extensive publicity regarding the installation of a computerized traffic control signal system in the Ottawa area.

To summarize the results of this question all responses by intersection control type were aggregated to develop an overall list of the perceived attributes of intersection control. It is suggested that this list provides valuable insight to public objectives for the selection of intersection control since an attribute is only perceived as such if it satisfies a personal objective.

This aggregate listing follows in Table 5.

Table 5 - Aggregate Attributes of
Intersection Control Devices

<u>Attribute</u>	<u>% of Total Response</u>
Safety	14.2
Allow smooth traffic flow	11.5
Benefit through traffic	7.5
Allow/Control access to major street	7.4
Minimize delay	5.3
Cautionary	5.2
Clarity	4.5
Designate right-of-way	4.2
Flexibility	3.8
Slow traffic	3.7

Total Number of Responses - 731

2.3 Drawbacks of Intersection Control by Type

This question was intended to complement the previous question and was therefore identical except that best attributes was replaced by worst drawbacks. The wording of this question follows:

"What do you feel the worst drawbacks of each of the following types of intersection control are?"

- Yield
- 2-Way Stop
- 3 or 4-Way Stop
- Traffic Control Signals

This question was not generally as well received as the foregoing one, possibly because they are basically similar. In any case, 275 replies were received which are summarized by intersection control type in the following paragraphs.

The results of this question with respect to yield type intersection control follow in Table 6.

Table 6 - Drawbacks of Yield Control

<u>Drawback</u>	<u>% of Total Response</u>
Disrespect by drivers	47.0
Danger	14.6
Indecision, confusion	9.1
Requires judgement, caution	7.6
Provides marginal control	5.6

Total Number of Responses - 198

All of the foregoing comments relate to the fact that motorists are not obliged to stop at locations where yield control is provided. This underlines an apparent desire by drivers to have a positive control to relieve uncertainty.

Judging by the limited number of replies received it appears that 2-way stop type intersection control has few drawbacks. The most frequently noted drawbacks follow in Table 7.

Table 7 - Drawbacks of Two-Way Stop Control

<u>Drawback</u>	<u>% of Total Response</u>
Access difficulties	22.4
Numerous stops, delays	20.6
Disrespect by drivers	13.9
Unfair	5.5
Indecision	4.2
Inflexible	4.2

Total Number of Responses - 165

These drawbacks are generally unrelated; however, all drawbacks noted result from the intended operation of this device, which is to provide drivers on one roadway priority over drivers on intersecting roadways.

In contrast to the foregoing type of intersection control a large number of responses were received which defined drawbacks of multi-way stop control. These responses are detailed in Table 8.

Table 8 - Drawbacks of Multi-Way Stop Control

<u>Drawback</u>	<u>% of Total Response</u>
Numerous stops, delay	19.2
Indecision, confusion	17.6
Frustration	9.3
Disrespect by drivers	9.0
Waste	8.7

Total Number of Responses - 323

The drawbacks of disrespect and waste are frequently noted by technical agencies as drawbacks of this type of intersection control which may have influenced the responses. To elaborate on the foregoing it is noted that results of studies in Ottawa and elsewhere^{1*} indicate serious problems due to driver disrespect of this type of intersection control and the frustration caused by it.

The section of this question dealing with traffic control signals did not result in a large number of replies. The drawbacks noted most frequently follow in Table 9.

* Indicates reference number 1. References are provided at the end of the thesis.

Table 9 - Drawbacks of Traffic Control Signals

<u>Drawback</u>	<u>% of Total Response</u>
Numerous stops, delay	47.1
Over control, overuse	15.9
Disrespect by drivers	6.5
Inflexible	5.1
Poor application	5.1

Total Number of Responses - 138

It is likely that these replies were generated by two distinct factors, namely excessive delay at such devices and poor application of these devices. The use of this device in the Ottawa area has increased dramatically in recent years resulting in many less major intersections being controlled by traffic control signals. Of the 415 current traffic control signals in this area, 160 were installed in the past 5 years.

In order to consolidate the foregoing information, an aggregate list of drawbacks has been prepared and is shown in Table 10.

Table 10 - Aggregate Drawbacks of Intersection Control Devices

<u>Drawbacks</u>	<u>% of Total Response</u>
Numerous stops, delay	19.9
Disrespect by drivers	18.7
Indecision, confusion	10.0
Danger	6.8
Access difficult	5.1
Frustration	4.7
Waste	3.4
Fuel waste	3.4
Over control, overuse	2.9
Inflexible	2.1

Total Number of Responses - 824

It is particularly interesting to note the close similarity between the above table and the table of aggregate attributes presented in Table 5. This is illustrated in the following Table 11.

Table 11 - Comparison of Aggregate Attributes and Drawbacks of Intersection Control Devices

<u>Drawbacks</u>	<u>Attributes</u>
Danger	Safety
Stops, delay	Minimize delay
Inflexible	Flexibility
Indecision, confusion	Clarity
Difficult access	Allow/Control access

As noted earlier, these results provide a clear insight to the objectives of intersection control, as perceived by the respondents to this study. In order to numerically define these objectives various attributes and drawbacks related to the same objective have been aggregated, and arithmetically manipulated to give a weight of 1.00 to the objective which received the greatest aggregate total. These results follow.

Table 12 - Perceived Objectives of Intersection Control

<u>Objectives</u>	<u>Calculated Weight</u>
Minimize stops and delays	1.000
Maximize safety	.788
Maximize driver respect	.758
Ensure smooth traffic flow	.600
Ensure clarity of control	.566
Allow/Control access	.472
Designate right-of-way	.423
Minimize waste	.276

The results of the above table provide initial insight to the objectives of intersection control but require further refinement based upon the remainder of the public questionnaire study results. Further discussion of these objectives will therefore follow later.

2.4 Use of Stop Control to Improve the Environment

Currently, one of the most frequently noted reasons for residents requests to implement stop control is to either reduce traffic speeds on a street or to divert traffic to other roadways.

As detailed in the literature², and verified by studies in this area, the extent to which stop control accomplishes either of these objectives is slight and may be off-set by other drawbacks such as reduced safety and increased cost.

Despite the foregoing, requests for stop control persist as does technical opposition to such requests leading to considerable controversy. In order to further assess this problem area, a question was included in the questionnaire as follows:

"Do you feel that stop signs should be used to discourage traffic or reduce vehicle speeds in order to improve the environment in an area?"

This question was well received with 347 of the questionnaire respondents replying. Of the respondents, 22% indicated their support for such applications of stop control, while 78% indicated opposition. In many cases it

was noted that, if speed reduction was the objective, it could be better accomplished by physical obstacles such as speed bumps or by increased police enforcement of existing speed limits.

It is believed that the clear opposition to this use of stop signs indicates that requests for multi-stop signs represent the feelings of a minority of people, even allowing for possible bias of the respondents as a group.

2.5 Violation of Stop Control

Due to the current level of stop control usage within this area, and particularly the increase in multi-way stop control usage, it is felt by many that the level of violation of this control has increased in recent years. As a result, two general viewpoints have been reported, in some cases there is a feeling that stop control should be rigidly enforced to ensure a full stop is completed before proceeding. In other instances amendment of current laws in order to allow rolling or half stop is favoured.

In either case the level of police enforcement plays an important role. To clarify these questions, the following question was included in the study:

"When arriving at a stop sign, the law requires that motorists must come to a full stop. Do you feel that this law should be rigidly enforced?"
Yes or No.

"Do you feel that the current level of enforcement is adequate?" Yes or No.

It was recognized that this question would result in responses which were quite subjective, depending upon the respondent's driving status and habits. Also, it is evident that responses would vary if the respondent was a driver or a homeowner. The first part of this question resulted in 342 responses while 320 replies were reviewed for the second part.

The responses received were clearly in favour of retaining the existing legislation and enforcing it, with 66% of the respondents noting this choice. Further, it was apparent that the current level of enforcement was considered to be adequate (57% of the responses) but the narrow margin between those who felt enforcement to be adequate and those who did not suggests some uncertainty.

2.6 Drawbacks of Poor Application of Intersection Control

As a means of further defining the objectives of respondents with respect to intersection control, and to verify allegations frequently made by technical agencies, it was felt that respondents should be asked what drawbacks would result from the poor application of intersection control. This question was very controversial because some people felt that it was an attempt to justify technical arguments against the use of multi-way stop control. Further, it was felt that the news media coverage and frequent technical comments featuring the comment that the overuse of a type of control would lead to driver disrespect and would unduly influence the responses.

In order to minimize influence on the responses, the following wording was selected:

"In your opinion, what are the drawbacks which result from the poor application of intersection control such as the provision of inadequate or overly restrictive traffic control or the over-use of a particular type of control?"

A total of 306 replies were received, most of which indicated more than one drawback. It should be noted that many of the drawbacks noted in response to this question were identified in response to Question No. 3. The new categories generally relate to system type effects as opposed to drawbacks which would result at individual locations. The most frequently noted drawbacks follow in Table 13.

Table 13 - Drawbacks of Poor Application of Intersection Control

<u>Drawback</u>	<u>% of Total Response</u>
Disrespect, violation	25.9
Accidents, design	12.6
Frustration, anger	12.6
Fuel waste	11.2
Congestion, delay	6.5
Traffic slowed	6.0
Waste time	3.2
Pollution	2.6
Noise	2.1
Confusion	1.9

Total Number of Responses - 617

Based on the similarities between the above table and Table 10 it is apparent that the perceived drawbacks of intersection control application at a particular intersection or in a system are similar, hence strengthening the view that these responses can be used to define the objectives perceived for intersection control by the respondents.

2.7 Overuse and Disrespect of Intersection Control

As noted in the previous section, one of the most disputed statements made respecting intersection control is that overuse of a particular type of control breeds disrespect for the control amongst drivers.

There are many examples which verify this statement. For instance, the experiences of cities such as St. Louis Missouri³ and Troy Michigan⁴ are typical.

To clarify this question and to ensure that it was formally addressed by respondents to the study, the following question was developed:

"It has been stated that the overuse of any type of intersection control, particularly multi-way stop signs, results in decreased driver respect for the control. Do you feel that this is true?" Yes or No

Again, virtually all respondents answered this question (348 replies), with 88% indicating that they felt that the statement was true. In view of this disproportionate response it is felt that there is definitely some merit to the statement..

Further, the results tend to verify results noted elsewhere respecting the drawbacks of intersection control.

2.8 Overuse of Intersection Control by Type

Currently, the application of intersection control within the Ottawa area is based upon a variety of criteria, guidelines and formal warrants. The installation of yield and stop control follows the guidelines of the Ontario M.U.T.C.D. subject to the provision that no four-way intersection will remain without intersection control. Traffic control signals are provided on the basis of the formal warrants of the Ontario M.U.T.C.D. Multi-way stop installations are based upon the I.T.E. guidelines on major roadways (Regional roads) and on a specially developed set of warrants for local intersections.

To generally assess the perceived adequacy of current selection criteria, the following question was developed:

"In your opinion, are any of the following types of intersection control devices over-used in the Ottawa area?"

- Yield
- 2-Way Stop
- 3 or 4-Way Stop
- Traffic Control Signals

The results of this question are detailed in the following Table 14, based on a total of 355 responses for each type of intersection control.

Table 14 - Overuse of Intersection Control by Type

<u>Type of Control</u>	<u>% of Total Response</u>			
	<u>Overused</u>	<u>Not Overused</u>	<u>Moderately Overused</u>	<u>No Comment*</u>
Yield	5.3	93.5	-	1.1
2-Way Stop	21.1	75.2	2.0	1.7
3 or 4-Way Stop	83.4	13.8	0.8	2.0
Traffic Signals	21.7	62.8	7.0	8.5

* Some of the no comment responses are likely "no" responses (not overused).

The responses indicate that yield signs are probably currently underused as 95% of the respondents indicated that this control was not overused. A similar but reduced trend was noted for 2-way stop control since 76% indicated that this device was not overused. The replies concerning multi-way stop control indicate general dis-satisfaction with this device, with 85% of the respondents indicating that it is overused. The existing usage of traffic control signals falls between these extremes, with 31% of the respondents indicating that this device is overused. The foregoing results also indicate the probable acceptability of each device in the view of the respondents.

2.9 Intersection Control Suitability

The questions detailed in this, and the following, sections were intended to offer respondents the opportunity to recap or stress any points noted earlier. Further, the

opportunity was presented to comment on other devices not specifically noted to this point in the study. For these reasons, the following question was developed.

"Do you feel that there are any types of intersection control which should not be used under any circumstances, and if so, why?"

This question resulted in a total of 301 replies of which 33% of the respondents indicated that all types of intersection control had some application, while 51% and 4% respectively indicated that multi-way stop control and yield control should not be used. The reasons noted for the avoidance of multi-way stop control were confusion, danger, energy waste, frustration and delay. Many respondents indicated other devices which should not be used, including street closures, traffic circles and 3 or 5-way stop control.

2.10 General Comments

In order to ensure that adequate opportunity for comment was provided, the final question invited general comments with respect to the provision of intersection control.

The responses resulting were quite diverse and included complaints about overuse of stop signs, requests to use more yield signs, requests to eliminate all unnecessary intersection control and comments that intersection control should be decided by technical staff and not by politicians or resident pressure groups.

2.11 Summary of Results

The primary benefit of this study lies in the insight that it provides to public feelings with respect to intersection control. While suffering from the possible effects of biased response and questionable publicity it represents the first comprehensive effort at collecting this type of information from the public.

The responses indicate a variety of factors which the public feel should be considered in the selection of intersection control including pedestrian and vehicular volumes, presence of children, accidents, speed and visibility.

The replies also define the objectives perceived by the respondents for the selection of intersection control which include such things as safety, reduced delay, increased driver respect, control of access and minimization of waste.

Further, it is evident that the current methods of selecting intersection control in the Ottawa area have resulted in over or underuse of some types of intersection control.

Finally, it is clear that the use of stop signs to reduce speeding or divert traffic is not acceptable and that excessive intersection control does breed driver disrespect.

3.0 TECHNICAL INFORMATION STUDY

In order to elaborate upon the data collected through the literature search, and to get a consensus of intersection control selection from the affected agencies, it was decided to develop and circulate a technical information form. One of the most recent efforts in this direction was work done by DeLeuw, Cather during the late 1960's in conjunction with National Co-Operative Highway Research Program projects No. 11⁵ and 42⁶.

The information form ultimately developed was based on the desire to further define certain intersection control policies, establish objectives for this task and define the various factors involved.

The information form was sent to all North American cities having a population in excess of approximately 100,000 people. This rule was relaxed somewhat for Canadian cities in order to get a larger domestic sample. This resulted in a final list of 181 cities which were circulated. Unfortunately, reliable contacts could only be established in 159 cities. The initial circulation and subsequent follow-up letter resulted in 64 replies, although not all respondents completed the entire information form which was quite lengthy. The information form developed is attached as Annex B.

3.1 Information Form Overview and General Considerations

As noted, the final information form was lengthy due to the large variety of data collected. In order to ease the time demanded of respondents, the form was divided into two parts. The first part included questions of a general

nature, while the second, colour coded portion, dealt with specific information by intersection control type. Respondents with limited time resources were encouraged to complete the first portion only. Despite this, approximately half of the respondents completed the entire information form.

The general questions included were developed to clarify areas of inadequacy in the literature, define noted problems with intersection control, and to cater to the anticipated needs of later phases of the study.

Briefly the questions included for review in this section included:

- What forms of intersection control are used?
- How are intersection control decisions made?
- What are the objectives of intersection control?
- Are urban and rural conditions treated differently?
- Are intersection controls reviewed periodically?
- Are combinations of intersection control used?
- What areas of difficulty are experienced?
- What are the impacts of poor selection of intersection control?
- What factors are important to the selection of intersection control?

The following sections detail the results of responses to these general questions.

3.1.1 Intersection Control Usage

The responses to this question varied widely, due in part to the type of jurisdictions circulated. In some cases the respondents represented Regional jurisdictions where their only responsibility was traffic control signals. Unfortunately, a technical error in the preparation of the questionnaire resulted in the omission of the category for two-way stop control. Fortunately, this oversight was noted by most respondents. The following Table 15 details the approximate frequency of use for each type of intersection control reported by the respondents of 64 jurisdictions.

Table 15 - Intersection Control Usage*

<u>Type of Intersection Control</u>	<u>Percent of Intersections</u>	
No Control	4.25	(15.3)
Yield	2.8	(15.1)
Stop	47.5	(59.1)
Multi-way Stop	1.9	(3.8)
Traffic Signal	5.1	(6.7)

() Bracketed figures indicate usage within the Ottawa area.

Three jurisdictions had traffic signals only, and there was an evident trend by many respondents to avoid the use of yield control. This is evident in the above data. Similar data for the Ottawa area is indicated from which it is noted that yield control is more widely used in this area than elsewhere. In addition, locations with no intersection control occur less frequently in this area. It is likely that this situation has occurred as a result of the decision to provide intersection control at all four-way intersections, currently a consideration for intersection control in this area.

* Due to differing intersection control strategies, and the limited responses considered, this data is for information purposes only and may not be representative of other jurisdictions.

3.1.2 Intersection Control Decision Criteria

In view of the wide variety of criteria available for the selection of intersection control, the following question was included in order to define the most popular warrant systems. The question also provides insight to the adequacy of existing warrants by noting the extent to which decision criteria, other than accepted warrants are used. The results of this question follow in Table 16 which indicates the number of jurisdictions using each criteria for each control type.

Table 16 - Intersection Control Selection Criteria

Percent of Jurisdictions Using Each Decision Criteria

<u>Decision Criteria</u>	<u>No Control</u>	<u>Yield</u>	<u>Stop</u>	<u>Multi-way Stop</u>	<u>Traffic Signal</u>
National Manual	23	37	34	41	58
State/Province Manual	19	27	31	31	47
City Manual	9	11	11	11	11
Department Policy	31	48	47	31	19
State/Province Law	6	9	13	9	14
City Law	6	9	14	9	6
Public	3	9	23	20	16
Rule of Thumb	9	8	8	5	-
ITE Practice	11	13	19	19	13
Other - Political 5					
- Commission 2					
- Precedent Reports 2					

Total Number of Jurisdictions Responding - 64.

From the above data the high degree of acceptance of the National and Provincial manuals is evident, as is the reliance on department policy. The degree of influence exercised by the public is also evident, especially for stop and multi-way stop type control.

3.1.3 Objectives of Intersection Control

Although the questionnaire form provided respondents space to indicate both their department's objectives and their own perceived objectives for intersection control, the replies were similar. Hence, only the personal perceived objectives were analysed. The resultant perception of objectives for the selection of inter-section control follow in Table 17.

Table 17 - Objectives of Intersection Control

<u>Objective</u>	<u>Mean*</u> <u>Rank</u>	<u>Mode**</u> <u>Rank</u>	<u>Weight***</u>
Safety	1.4	1	1.00
Delay	2.4	2	.58
Consistency	4.1	3	.34
Policy	4.2	3	.33
Cost	5.0	7	.28
Uniformity	5.1	5	.27
Public	5.3	6	.26

From approximately 50 replies received it is evident that safety is perceived as the most important objective, followed by the minimization of delay. Interestingly, meeting public demands and cost were the lowest ranked objectives.

* - Mean Rank indicates the average rank given to each objective by the respondents.

** Mode Rank indicates the rank most frequently noted for each objective.

*** Weight indicates the results of an arithmetic manipulation of the mean rank which gives the most important (lowest ranked) objective a weight of 1.00.

3.1.4 Urban Versus Rural Distinction

Review of the literature, and analysis of existing warrant systems, indicates that while the need to differentiate between urban and rural conditions is acknowledged, few systems consider this distinction.

The survey results, based upon 58 replies, indicated that only about half of the jurisdictions currently make this distinction, while 65% of the replies indicated that they felt such a distinction should be made. It is felt that the need to provide this distinction is slight.

3.1.5 Frequency of Review of Intersection Control

In order to develop a comprehensive system for the selection of intersection control it is evident that a clear review procedure is required. Thus, the respondents were requested to indicate the basis on which intersection control adequacy was reviewed. The results generally suggest that most jurisdictions have insufficient resources to undertake systematic reviews and respond instead to public complaints or unusual accident history.

The following Table 18 depicts the percentage of the 58 respondents currently using each review strategy.

Table 18 - Intersection Control Review Strategy

<u>Review Strategy</u>	<u>% of Respondents</u>
Regular review	1.7
Review upon complaint	3.4
Review due to accident history	3.4

Review based on all three considerations	39.7
Review based on complaint or accident history only	51.7

Total Number of Respondents - 58

From the above table it is evident that the regular review of intersection control is not feasible and probably not required. The popularity of accident related data as an indicator of intersection control adequacy should be noted.

3.1.6 Combinations of Intersection Control

Experience within the Ottawa area* indicates that the use of combinations of intersection control devices to control conflicting traffic movements is not generally effective, other than at locations having traffic control signals at which right turning ramps can be effectively controlled by stop or yield signs.

Approximately half of the 60 respondents indicated that such combinations of intersection control were not used.

In jurisdictions using combinations of intersection control, the usual justification was unusual or extreme intersection geometry which made a particular type of intersection control inappropriate on some approaches.

3.1.7 Prevalent Sources of Difficulty

As noted earlier, the selection of intersection control has recently become an area of considerable interest to the public. Additionally, there appears to be an increasing trend towards lack of political acceptance of intersection control decisions. Thus, respondents were

* Where indicated, experience from the Ottawa area is based upon analysis of the data files of the Regional Municipality of Ottawa-Carleton.

asked to indicate current sources of difficulty in selecting intersection control in order to define current weaknesses in the current selection process. A total of 50 replies were received for this question.

Most respondents (69%) indicated that negative public attitude was the greatest problem area, with lack of political acceptance of decisions the next greatest problem.

The observations underline the need to justify intersection control decisions on the basis of criteria which are understood and accepted by the public and to place greater emphasis on their desires.

3.1.8 Impact of Poor Application of Intersection Control

In order to verify the objectives noted earlier and to indicate areas of intersection control ineffectiveness perceived to be important, respondents were asked to rank order a variety of potential detriments of intersection control drawn from the literature, news media and public comments. The results follow in Table 19.

Table 19 - Ranked Impact of Poor Application of Intersection Control

<u>Detriment</u>	<u>Mean*</u> <u>Rank</u>	<u>Mode**</u> <u>Rank</u>
Loss of respect	1.38	1
Accidents	3.42	3
Motorist confusion	3.77	3
Motorist delay	3.13	2
Environmental damage	4.83	6
Inefficient use of funds	4.38	5

- * Mean Rank indicates the average rank given to each detriment by respondents.
- ** Mode Rank indicates the rank noted most frequently for each objective.

Apparently the most important perceived impact of the poor application of intersection control is the loss of driver respect which will result. This result parallels that noted earlier in the analysis of the public questionnaire.

Responses for other detriments were far less definite, as evidenced by the narrow spread in mean rank. The replies do restate the earlier noted lack of concern for costs related to intersection control and also suggest an unfortunate lack of concern for the environment.

3.1.9 Relative Ranking of Intersection Control Selection Factors

The final question included in the general section of the information form was a request of respondents to rank 15 possible factors in order of their perceived importance to the selection of various forms of intersection control. This information was considered essential to define areas of stress for the selection criteria to be developed.

On the basis of the literature reviews completed a list of 15 factors of potential relevance to the selection of intersection control was defined. Since it was anticipated that the priority of these factors would depend to some extent on the type of intersection control being considered the opportunity was provided to indicate differing ranks for each type of intersection control. The resultant ranked listing of intersection control selection factors is depicted in Exhibit 5, which indicates the modal rank (that is, ranked selected most frequently) for each intersection control selection factor by type of intersection control.

EXHIBIT 5MODAL RANK OF INTERSECTION CONTROL SELECTION
FACTORS, TECHNICAL QUESTIONNAIRE RESPONSES

	<u>No Control</u>	<u>Yield</u>	<u>Stop</u>	<u>Multi Way Stop</u>	<u>Traffic Signal</u>
Accident Rate	1	1	1	1	1
Major Street Volume	1	1	1	2	1
Minor Street Volume	3	2	3	2	1
Vehicular Delay	5	4	3	4	2
Visibility Conditions	5	4	4	4	4
Roadway Geometry	5	1	2	8	8
Pedestrian Volume	5	7	7	4	4
Vehicular Speeds	7	8	7	7	6
Other Control On Route	9	9	8	8	7
Street Classification	3	11	10	10	8
Existing Type of Control	13	15	5	11	10
Adjacent Land Use	12	12	13	11	12
Parking Factors	13	13	10	13	13
Public Opinion	14	14	14	14	12
Political Factors	15	15	15	15	15

- The results of this question verify the importance of safety, traffic volumes and delay as selection factors. The importance of roadway geometry when considering either stop or yield control, and street classification when considering no control are also evident.

Surprisingly, the results are somewhat contradictory with factors such as public opinion, political acceptance and roadway geometry ranked quite low despite their noted significance elsewhere. The type of adjacent land use and roadway classification were also ranked lower than had been anticipated.

From the results it is felt that respondents tended to base their replies on the existing warrant systems which are generally based upon traffic volumes and accident rate for restrictive forms of control and upon visibility and physical characteristics for lower forms of intersection control.

3.2 Specific Responses by Intersection Control Type

To assist in the ultimate development of a selection criteria for all types of intersection control, respondents were also asked to answer a variety of questions in an effort to place numerical values on the factors noted in the previous section. A total of 6 questions were asked which were identical for each type of intersection control. The results of these questions, which received approximately 30 replies, follow:

3.2.1 Vehicular Volumes

Respondents were requested to indicate traffic volume ranges for which each type of intersection control was appropriate. The results follow in Table 20.

Table 20 - Average Traffic Volumes Appropriate
for Intersection Control by Type

<u>Type of Control</u>	<u>Major Street Hourly Volume</u>	<u>Minor Street Hourly Volume</u>
No control (26)	160	120
Yield control (19)	500	250
Stop control (24)	600	300
Multi-way stop control (31)	550	320
Traffic control signals (39)	630	200

() Bracketed figure indicates number of respondents.

The results indicate a progression of increasing traffic volumes as the type of intersection control becomes more restrictive. It should be noted that the above data represent averages for the responses received to ease presentation.

Generally, the hourly volume ranges indicated tend to corroborate data noted elsewhere in the literature and from studies within the Ottawa area, with the exception of no control and yield control for which volumes appear to be high.

Further, for no control, yield control and stop control, approximately one-quarter of the replies indicated that traffic volumes were not required.

As noted earlier, it is suspected that the responses tend to be based upon existing intersection control selection practice.

3.2.2 Major Street/Minor Street Vehicular Volume Ratio

There is evidence within the literature that the ratio of traffic volumes may be an appropriate consideration for intersection control selection. Therefore, respondents were asked to indicate volume ratios which could be tolerated for effective operation of each type of intersection control. Responses to this question were few, suggesting that this consideration is of little importance.

Most respondents to this question indicated that they felt this consideration was not required except for multi-way stop control. The most frequently noted ratios by other respondents were 1:1 or 2:1 major/minor street ratio. In this regard, it is noted that the responses of the previous question defined a ratio of about 2:1 as well.

It appears that the major street/minor street vehicular volume ratio is not essential to the selection of intersection control.

3.2.3 Pedestrian Volumes

News media reports and public comments indicate that the consideration of pedestrian volumes is important to the selection of intersection control. Therefore, respondents were asked to indicate pedestrian volumes which might be appropriate for each type of intersection control. Currently, this factor is considered only in warrants for multi-way stop control and traffic control signals.

The responses indicated that most considered this factor unimportant except at traffic control signals, and to a lesser extent, multi-way stop control, in which case

pedestrian volumes crossing the major street were considered important. Respondents who felt that this factor was important indicated pedestrian volumes in the range of 90-150 pedestrians per hour for all types of intersection control. This volume is much lower than that specified in current warrants, and much higher than that found at most non-central business district intersections.

3.2.4 Delays

In view of the perceived importance of intersection delay as an indicator of intersection operation, it was hoped that respondents would assist in the definition of appropriate numerical values for this factor. Of the respondents, approximately 65% indicated that this factor was not required except for the consideration of stop control. The respondents who provided a numerical reply indicated relatively short delays were acceptable in the range of 30-40 seconds per vehicle for all types of intersection control, except traffic signals, for which a shorter delay of 1-20 seconds per vehicle was noted by the majority.

It is likely that the respondents to this and other questions who indicated that a factor was not required may have done so because a numerical reply was not immediately evident.

3.2.5 Accident Rates

Discussion elsewhere in this report has stressed the importance of accident data as an indicator of intersection operation. It is also clearly the most important factor to the selection of intersection control.

To elaborate on this factor, respondents were provided considerable latitude for comment with respect to accidents. From the literature review areas of importance were total yearly accident frequency, angle accident frequency and injury accident frequency.

The responses received to this question are depicted in Exhibit 6. Again, responses appear to reflect the existing warrant values for accidents where available.

Judging from the number of replies indicating that the number of injury accidents was not required, it would appear that this factor is the least necessary type of accident data. Conversely, the number of angle accidents appears to be most important.

All replies fell in the range of 0-10 accidents per year regardless of accident category or intersection control type. The modal range chosen was 4-6 accidents per year except for injury accidents for which the modal range was 2-4 accidents per year.

Except for injury accidents, the number of accidents acceptable is lower at less restrictive forms of intersection control.

From the responses it is apparent that the number of angle accidents is the most important type of accident data for the selection of intersection control.

3.2.6 Visibility Conditions

Current warrant systems for the application of yield control and stop control are primarily based on visibility conditions. In order to verify the importance of this

EXHIBIT 6QUANTIFICATION OF ACCIDENT RELATED
FACTORS BY INTERSECTION CONTROL
TYPE, TECHNICAL RESPONSES

<u>Total Accidents</u>	<u>No Control</u>	<u>Yield</u>	<u>Stop</u>	<u>Multi Way Stop</u>	<u>Traffic Signal</u>
0- 2	28	17	4	0	0
2- 4	24	22	20	0	0
4- 6	12	22	28	46	41
6-10	4	4	0	4	0
8-10	8	8	12	17	24
Not Required	24	26	36	33	37
Total Response	25	23	25	24	17

<u>Total Angle Accidents</u>	<u>No Control</u>	<u>Yield</u>	<u>Stop</u>	<u>Multi Way Stop</u>	<u>Traffic Signal</u>
0- 2	24	20	3	0	0
2- 4	48	53	33	3	3
4- 6	12	20	40	72	81
6- 8	4	0	0	7	3
8-10	0	4	3	7	3
Not Required	12	4	20	10	10
Total Response	25	25	30	29	32

<u>Total Injury Accidents</u>	<u>No Control</u>	<u>Yield</u>	<u>Stop</u>	<u>Multi Way Stop</u>	<u>Traffic Signal</u>
0- 2	22	10	4	0	0
2- 4	26	24	21	14	16
4- 6	4	10	8	14	8
6-10	0	0	0	0	0
8-10	0	0	0	0	0
Not Required	48	57	67	71	76
Total Response	23	21	24	21	25

Note: Numbers indicate the percent of respondents who selected the indicated annual accident frequency for each type of intersection control.

factor and to develop appropriate limits, respondents were asked to indicate appropriate safe approach speeds for each type of intersection control.

Generally the responses indicated that this factor should be considered, particularly for the lower forms of intersection control, but the wide range of values selected (8-90 kilometers per hour) and the drastic deviation from values normally accepted suggests that this question was mis-understood.

3.2.7 Vehicular Speeds

Vehicular speeds are not generally a consideration in current guidelines for intersection control devices other than traffic control signals. It is intuitively evident, however, that the effectiveness of certain types of intersection control is reduced by excessive speeds.

To quantify this feeling, respondents were requested to indicate vehicular speeds which they felt to be appropriate for each type of intersection control, both on the major street and on the minor street. The results of this question indicated modal responses in the range of 50-65 kilometers per hour for all types of intersection control except traffic signals. Speed appeared to be most important in assessing yield control and least important in assessing stop control. In general, the value of this factor in assessing intersection control appears questionable.

3.2.8 Intersection Geometrics

Clearly, the geometry of an intersection affects the probable effectiveness of the intersection control chosen.

In order to define appropriate conditions of intersection geometry, for each type of intersection control, respondents were asked to comment on skew angle, number of approaches, grade and number of lanes. The results of these comments follow.

Generally, current practice is to avoid constructing intersections with a skew angle of greater than 70 degrees. Excessive skew results in large intersection area and increases the difficulty of the driving task.

Replies to the information form indicated that skew should be considered with the range 60-70 degrees selected as most appropriate. The skew appeared to be less important if multi-way stop control was being considered.

Respondents were also asked to indicate the number of intersection approaches appropriate for each type of intersection control. The results indicated that this factor should be considered and that increasing numbers of approaches were appropriate as the intersection control became more restrictive. A similar trend was also noted with respect to the number of lanes, but the results were not conclusive.

Finally, respondents were asked to indicate the approach grades acceptable for each type of intersection control. The responses varied from 0-15 percent with the range 3-6 percent noted most frequently. Unexpectedly, this factor did not appear to be important to the selection of stop control, multi-way stop control or traffic signals despite the considerable adverse impact of grade at locations having such control during poor weather. Perusal of the

replies clarified this, however, as most respondents would probably not experience this problem due to warm climate.

3.2.9 Intersection Control Usage

During the analysis of the technical replies and the literature sources it was determined that the selection of intersection control could be based upon roadway classification only. In order to elaborate on this observation, respondents were asked to indicate for which type of intersection each type of intersection control would be appropriate.

The resultant replies are depicted in Table 21 which indicates the percentage of responses in each category.

Table 21 - Intersection Control Usage
by Road Classification

<u>Control Type</u>	<u>Intersection Type</u>					
	<u>A/A*</u>	<u>A/C</u>	<u>A/L</u>	<u>C/C</u>	<u>C/L</u>	<u>L/L</u>
No Control	0	0	0	1	3	6
Yield	0	1	1	2	5	5
Stop	3	6	7	4	5	4
Multi-way Stop	5	4	3	4	2	3
Traffic Signals	7	7	5	4	3	1

* A - arterial roadway

C - collector roadway

L - local roadway

The results verify that increasingly restrictive intersection control is appropriate at increasingly complex locations. Further, analysis of the response frequency defines a band in Table 21 indicating the most probable types of intersection control at each type of intersection.

The results are summarized briefly below:

- No control - collector/local, local/local
- Yield control - collector/collector, collector/local, local/local
- Stop control - arterial/local, collector/collector, collector/local
- Multi-way stop control - arterial/collector, arterial/local, collector/collector
- Traffic control signal - arterial/arterial, arterial/collector, arterial/local

Adoption of the foregoing guidelines for the selection of intersection control would tie roadway classification and intersection control together and would ease the intersection control selection task.

3.3 General Summary of Technical Information Form Results

The foregoing study results provides considerable insight to the selection of intersection control in other jurisdictions and also provides technical input to this task.

Respondents indicated that the most frequently used type of intersection control was stop signs, and the least

frequently used type was yield control, which was in fact, avoided in some jurisdictions.

The review of intersection control was typically based upon public complaint or the occurrence of unacceptable accident history. The greatest source of difficulty with respect to the selection of intersection control was the lack of public and political acceptance of such decisions.

It was felt that the worst drawback of poor application of intersection control was the resultant loss of driver respect. The worst quantifiable impacts were delay and accidents.

Finally, the respondents indicated that the factors of accident rate, traffic volume, delay and visibility were most important to the selection of intersection control.

The portions of the information form dealing with the definition of numerical values for the various factors was less successful due to the reduced response rate.

Nevertheless, definite ranges of traffic volume and accident frequency were defined for each type of intersection control. Major street versus minor street volume ratio, visibility, and vehicle speeds were found to be less critical. The data returned was not adequate to quantify pedestrian volume and delay factors.

It was apparent that intersection geometry became less critical with increasingly restrictive intersection control.

Finally, the detailed responses were found to outline the type of intersection control appropriate for different intersections based upon roadway classification.

In addition to the foregoing, a large amount of useful information was received from the respondents with respect to departmental guidelines for the application of intersection control.

4.0 FACTORS RELEVANT TO THE SELECTION OF INTERSECTION CONTROL

The preceding discussion of the results of the public and technical questionnaire studies has defined a variety of factors that are potentially relevant to the selection of intersection control. Analysis of over twenty such factors has made it evident that some factors are of relatively little importance. The following sections of this chapter detail the results of review into all factors; however, as noted, certain factors are stressed. The factors deemed to be most significant were volume of traffic, safety, delay, environmental concerns, energy concerns and cost.

Factors have been aggregated into two categories; those that are intersection related such as volume and safety, and those which address wider concerns such as the environment and energy.

In each case relevant references from the literature review are detailed with elaboration, where required, provided on the basis of studies conducted for this project in the Ottawa area.

On the basis of those factors, the current warrant systems for intersection control devices are evaluated in the following chapter preparatory to the development of a new selection criteria for intersection control.

4.1 Intersection Related Factors

At the outset approximately fifteen factors related to the individual intersection were studied. As noted, traffic volume, safety and delay were judged to be considerably more important than the others. Subsequent sections detail these factors under the headings of physical attributes, traffic volume, safety, delay and legislative conditions.

4.1.1 Physical Attributes

The physical attributes of an intersection reflect a variety of characteristics which are usually fixed and have some bearing on the selection of intersection control, such as approach grades, visibility conditions and intersection configuration.

a. Approach Grades

The grade on the approach to an intersection has an important impact on the selection of intersection control since the presence of excessively steep grades may make certain types of intersection control impractical.

The presence of grades also affects the length of time and distance required to stop or start a vehicle, and therefore affects intersection delays and safety.

In general, grades of up to three percent have no effect on automobile travel and little effect on

trucks and buses unless the length of grade is excessive. The technical responses noted earlier suggested appropriate grade to be in the range of 3 - 6 per cent.

The impact of grades is of particular significance in areas where extensive periods of travel under wet or icy conditions are encountered.

In view of the foregoing, and experience in the Ottawa area, it is apparent that intersection grade should be considered and that a maximum grade of 6 percent is appropriate where stop control or traffic control signals are considered.

b. Visibility Conditions

The visibility conditions at an intersection are a significant factor in the determination of intersection control since the safe operation of vehicles at an intersection depends upon drivers being able to see and, if necessary, take evasive action to avoid each other.

Visibility conditions at an intersection are usually related to safe approach speed, which is the maximum speed at which a driver can approach an intersection and still see a conflicting vehicle in time to avoid a collision.

Research suggests that, at low volume intersections, a lack of intersection control is appropriate where the safe approach speed equals or exceeds the 85th percentile speed of traffic; for safe approach speeds of less than 20 km/h and 15 km/h, yield control and stop

control are considered appropriate respectively.

The calculation of safe approach speed and the underlying principles are dealt with in various literature such as that by Pignataro⁷.

c. Intersection Configuration

The configuration of an intersection is usually described in terms of the angle between intersecting streets, or skew, and the number of intersecting roadways. Also included are the number of lanes on the intersecting roadways.

The configuration of certain intersections reduces the need to consider visibility conditions. For instance, at three-way right-angle intersections the calculation of safe approach speed is redundant because the alignment of the intersection prevents excessive approach speed on the minor street. This affect can be off-set by the skew angle of an intersection however.

The skew angle can also result in a need for better visibility conditions than normally required since the potential conflict area within the intersection is larger. This occurs because minor street vehicles are in a potential position of conflict for a longer period of time. Excessive skew also results in lengthy crossings for pedestrians.

The affect of the number of intersecting roadways is more difficult to ascertain. During the literature

review no evidence was found of studies done to assess the impact of multi-leg intersections on the operation of various types of intersection control at such locations. It is evident that the possibility of traffic conflicting from a number of angles increases the complexity of the driver's task. This factor is evident in a later section wherein it was noted that traffic control signals tend to be most effective in reducing accidents at complex, or multi-leg, intersections.

Finally, the number of lanes on the intersection approaches should be considered, as wide, multi-lane approaches impair the effectiveness of some types of intersection control. Yield signs and stop signs are particularly susceptible to problems on multi-lane approaches, as vehicles in the curb lane can obscure the sign from vehicles in the centre lane. The presence of multiple lanes on the major roadway increases the delay and difficulty of crossing the roadway safely for both minor street vehicles and pedestrians.

The foregoing discussion has dealt briefly with the affects of various physical attributes on the selection of intersection control. The underlying point is that common sense should be exercised and the physical attributes should be considered in each case.

Generally speaking, less ideal conditions can be tolerated with increasingly restrictive intersection control.

4.1.2 Traffic Volumes

The consideration of traffic volume, both vehicular and pedestrian, is essential to any review of criteria for intersection control selection for a variety of reasons. Traffic volume, unlike safety and delay, is a primary determinant of intersection operation and is usually an independent variable in equations describing other factors. Traffic volume also provides a useful basis for quantifying other factors such as accident rate.

Traffic volume was judged the factor most important to the selection of intersection control by respondents to the public questionnaire, and was judged second most important by respondents of the technical questionnaire. This stresses a particularly important aspect of this factor, namely the fact that traffic volume is readily perceived and understood by members of the public and by their elected representatives. Thus, the acceptance of decisions made on the basis of traffic volumes is likely to be high.

Since traffic volume is usually dealt with as an independent variable in analysis of other factors, there is little reference to traffic volume by itself in the literature. Despite this, certain aspects of traffic volume have a direct bearing on the assessment of warrants for intersection control, particularly the temporal variation of traffic volumes.

The volume of traffic observed at a given location exhibits variation due to time of day, day, month and to a lesser extent, year studied. This variance is significant

to the selection of intersection control because appropriate time periods must be sampled in order to choose effective control.

For highway design purposes the 30th highest hour is usually selected with a typical pm peak-hour often used to approximate this value. Currently, no such standard exists for intersection control warrants. The most popular time period used is the peak eight-hours of an average day and this period is specified in most warrants for traffic control signals and in certain warrants for multi-way stop control. In other cases, the traffic volumes of the 8th highest hour are specified. For comparison purposes, the 8th highest hour of a typical day usually occurs during the mid-morning or mid-afternoon periods.

The primary complaint with using the 8th highest hour in all cases is the workload imposed in collecting the necessary data. This is off-set by the desire to have a reliable estimate of daily traffic volume. The foregoing point is becoming increasingly important with recent manpower and budgeting constraints.

Traffic volume is also closely related to flow speed, density and headway of a traffic stream. Therefore, it has been suggested that, rather than surveying traffic volumes, a more meaningful result can be achieved by observing the effect of traffic volumes; for instance, the measurement of gap size and availability. This possibility has not been pursued in view of its limited application and the current lack of acceptance amongst traffic engineers of such techniques.

Another aspect related to traffic volumes is the development of techniques to model traffic flow in order to

develop accident potential and other characteristics of conflicting traffic streams. For traffic volumes in the range of 0 to approximately 500 vph traffic flow is essentially random and can be modelled by a Poisson distribution. Work by DeLeuw, Cather⁸ in this regard indicated that this randomness is not affected by the presence of yield or stop control in the volume range noted. At volume levels in excess of this range, traffic flow becomes increasingly non-random due to the presence of platooning caused by adjacent intersection control devices.

The usefulness of mathematically modelling traffic flow is primarily to predict future delay, accidents or other factors. In the case of assessing intersection control, current data is usually readily available and the need for review has been illustrated historically. Therefore, while the potential for modelling traffic flow will be noted later with respect to accident analysis, it has not been pursued for purposes of this project due to time and data limitations.

In order to place traffic volume in perspective, extensive analysis was undertaken of traffic volume data at approximately 1,100 intersections of varying road classification and intersection control in the Ottawa area. The summary results of this study are depicted in Exhibit 7. From the data presented it is evident that the use of Poisson distribution for analysis of lower forms of intersection control at local or collector type streets is appropriate due to the low observed volumes. Further, the data provides valuable insight into traffic volumes to be expected under various conditions. It should be noted that these data represent conditions in the Ottawa area which have resulted from the intersection control

EXHIBIT 7SUMMARY OF TRAFFIC VOLUME DATA FOR THE
OTTAWA AREA

a. Street Classification	Average Hourly Approach Volume
Arterial	510
Collector	130
Local	30
b. Intersection Control Type	Average Hourly Total Volume
No Control	70
Yield Control	95
Stop Control	740
3 Way Stop Control	270
4 Way Stop Control	315
Traffic Control Signal	1510
c. Study Hour	Percentage of Total 12 Hour Peak Traffic Volume
AM Peak Hour	9.33%
PM Peak Hour	11.39%
Average of Peak 8 Hours	9.18%
Eighth Highest Hour	7.75%

NOTE: The traffic volumes noted above represent average hourly data determined from traffic counts at 1100 locations in the Ottawa area. These traffic counts were done for a variety of durations ranging from two to twelve hours. The data approximate traffic volumes which would be obtained by averaging the peak eight hours of the day.

strategies used to date and therefore similar types of intersection control in other areas may experience differing volumes. The volumes anticipated by roadway classification are likely to be duplicated elsewhere however.

Traffic volume will be further discussed in the context of review of other factors for which traffic volume is an independent variable.

4.1.3 Safety

As noted in the consideration of responses to both the public and technical questionnaires, the primary area of concern with respect to the selection of intersection control is that of safety. In many instances the review or upgrading of intersection control is done on the basis of a perceived need to improve safety.

Review of published data regarding intersection safety indicates that considerable controversy exists concerning the effect of intersection control devices on safety. Further, it is evident that intersection control devices are considered, by the public, to be safety devices, despite the sometimes adverse affect on safety.

Accidents occur because of a failure, or inadequacy, of intersection control, driver input or a combination of these factors. The selection of intersection control is primarily concerned with the elimination of accidents due to inadequate intersection control. Accident occurrence is frequently related solely to traffic volumes, as the likelihood of accidents at a given location is primarily

dependent on the traffic volumes in conflict. The concept of conflicts has been increasingly used to represent accidents, there being many more conflicts than accidents at any location. A conflict is considered to occur whenever two vehicles occupy the intersection at approximately the same time. Various authors have calculated conflict rates for low volume intersections. Hall, Sinha and Michael⁹ did so by modelling arrivals using a Poisson distribution, while Glennon¹⁰ did similar work using average arrival rates. Vehicle arrivals within 3 seconds were considered to be in conflict in the first work, while a period of 2 seconds was used by Glennon. Data on the number of conflicts anticipated is then converted to an expected accident rate usually based on such ratios calculated by Perkins and Harris¹¹, Baker¹² or Cooper¹³. Perkins and Harris developed a ratio of .00033 accidents per conflict, while Baker and Cooper proposed ratios of .00016 and .00040 respectively.

Analysis of the sort noted above is useful for predicting accident rates at low volume locations which can be used to evaluate existing accident experience or to project accident rate.

Much literature exists concerning the effect of varying types of intersection control on the accident rate. The following paragraphs summarize this literature, segregating the results by type of intersection control as appropriate.

Based on analysis of conflict data it has been illustrated that no intersection control is appropriate for low volume intersections, up to the point where the cost of anticipated accidents exceeds the benefits of reduced delay.

The effect of providing yield control at locations previously uncontrolled are widely documented with virtually all evidence favourable. Clark and Ogden¹⁴ noted that the provision of yield control at 20 low volume locations resulted in reductions of 69% and 86% in right-angle and injury accidents respectively. Kell¹⁵ reviewed the installation of yield signs at a variety of uncontrolled low volume urban intersections and reported general accident reductions of 44-52%. Studies by Andreassend¹⁶ were less favourable and indicated conflicting results. In this case, reductions of both right-angle and injury accidents at 33 study locations were insignificant and when reduced to equivalent personal injury accidents, showed slight increases. The most frequently noted analysis of accidents at yield control was that conducted by DeLeuw, Cather¹⁷. Their study of the uncontrolled intersections which were upgraded to yield control indicated overall accident reductions of 23-62%. Generally, they concluded that the provision of yield signs resulted in a temporary decrease in accidents for a novelty period following which the frequency rose slightly to a level below that which had existed before the provision of yield control. DeLeuw, Cather¹⁸ also developed a nomograph to predict the expected annual accident frequency involving vehicles controlled by a yield sign. The nomograph provides for consideration of a variety of factors including average daily traffic volumes, safe approach speed, approach speeds, street classification and geographic area. Unfortunately, a lack of data makes the usefulness of this nomograph questionable.

Analysis of accident statistics in the Ottawa area for one year (1979) are detailed in Exhibit 8. Calculations with

EXHIBIT 8ACCIDENT RATE BY INTERSECTION CONTROL TYPE
FOR THE OTTAWA AREA - 1979

<u>Type of Intersection Control</u>	<u>Accident Rate (Acc. / MEV*)</u>			
	Total Accidents	Right Angle Accidents	Injury & Fatal Accidents	Property Damage Accidents
No Control	.483	.226	.095	.369
Yield Control	.199	.141	.053	.139
Stop Control	.182	.092	.049	.124
3 Way Stop Control	.242	.124	.054	.171
4 Way Stop Control	.251	.131	.092	.150
Traffic Signal	1.149	.287	.324	.756

* Accidents / MEV - Accident frequency per one million entering vehicles. This method is the most frequently used way of relating accident frequency to the conflicting traffic volumes at an intersection.

respect to accident rate are based on the average hourly traffic volume calculated from a study of volumes at 109 yield controlled intersections. On this basis average hourly volume was found to be 95 vph. It will be noted that the exhibits include data for intersections having no control, stop control, multi-way stop control and traffic control signals developed similarly. Average hourly traffic volumes were found to be 69, 740, 271 (3-way), 315 (4-way) and 1,509 vehicles respectively.

Due to the widespread use of conventional two-way stop control there is relatively little documented evidence of the effect of this type of control on accidents. Studies by Andreassend¹⁹ of 41 intersections at which stop signs were installed indicated reductions of both total accidents and right-angle accidents of 25% despite increased traffic volumes. Other studies of two-way stop control generally appear to be oriented to predicting accident rates at two-way stop controlled locations on the basis of intersecting volumes. Work of this type suggests that accident frequency is largely a function of minor street traffic volumes. Analysis of the effect of upgrading intersection control to conventional type stop control was evaluated on the basis of studies in the Ottawa area. In this case, 8 locations were studied at which stop control was provided at previously uncontrolled locations, with the result that aggregate total accidents and angle accidents decreased to nil from frequencies of .088 and .064 accidents per location per year respectively. It is evident from the foregoing that accident frequency was low before upgrading. Similar studies at 8 locations at which yield control was upgraded to stop control indicated a

reduction of total accidents from .130 accidents per location per year to .047. Right-angle accidents also declined from .114 to .047 accidents per location per year.

Finally, the data of Exhibits 9 and 10 should be noted for a complete review of one year accident data in the Ottawa area, particularly the relative frequency of accidents by intersection control type.

Finally, DeLeuw, Cather²⁰ has developed a nomograph to predict the expected annual accident frequency involving vehicles controlled by a stop sign similar to that noted elsewhere for yield control. This nomograph is also subject to reservations noted earlier and is based on similar factors supplemented by cross-street width.

Much more research has been done into the effect on accident frequency of replacing conventional two-way stop control by four-way stop control. Studies by Syrek²¹ of intersections with two-way stop control or four-way stop control under differing traffic volumes indicated a lower accident rate with four-way stop control for low traffic volumes (5,000 ADT major, 3,000 ADT minor) and a higher rate with four-way stop control at high traffic volumes (12,000 ADT major). Other studies by Wenger²², Hammer²³, Heary²⁴, and Crinion²⁵ verify that the upgrading of two-way stop control to multi-way stop control reduces accidents, particularly right-angle accidents, considerably. Wenger²² studied 38 locations in St. Louis and found the reductions of total accidents and angle accidents to be 56% and 75% respectively. Similar studies by Hammer²³ of 6 intersections in California indicated reductions of

EXHIBIT 9ANNUAL ACCIDENT FREQUENCY STATISTICS FOR
THE OTTAWA AREA - 1979

a.	Type of Intersection Control	Range*	Annual Frequency Statistics	
			Modal Frequency**	85 Percentile Frequency
	No Control	0-3	1	0
	Yield Control	0-5	1	0
	Stop Control	0-15	1	1
	3 Way Stop Control	0-5	1	1
	4 Way Stop Control	0-4	1	1
	Traffic Signal	0-71	5	14

* Range in Accidents / Year

** Modal accident frequency excluding 0 Accidents / Year

b.	Type of Intersection Control	Type of Accident			
		Fatal	Injury	Property Damage	Non- Reportable
	No Control	2	32	132	6
	Yield Control	0	26	68	3
	Stop Control	9	729	1849	115
	3 Way Stop Control	0	7	22	2
	4 Way Stop Control	0	24	39	2
	Traffic signal	5	1105	2590	235

EXHIBIT 10ANNUAL ACCIDENT FREQUENCY BY ACCIDENT TYPE
FOR THE OTTAWA AREA - 1979

a. Aggregate Annual Frequency

Type of Intersection Control	Rear End	Right Angle	Accident Turning Movement	Type Approach	Side-Swipe	Single Vehicle
No Control	11	81	18	12	2	40
Yield Control	3	69	5	2	1	12
Stop Control	424	1372	334	45	124	346
3 Way Stop Control	6	16	4	1	0	2
4 Way Stop Control	13	34	2	0	4	12
Traffic Signal	877	980	1225	23	320	462

b. Average Annual Frequency *

Type of Intersection Control	Rear End	Right Angle	Accident Turning Movement	Type Approach	Side-Swipe	Single Vehicle
No Control	.012	.086	.019	.013	.002	.042
Yield Control	.003	.074	.005	.002	.001	.013
Stop Control	.116	.375	.091	.012	.034	.094
3 Way Stop Control	.069	.186	.046	.012	0	.023
4 Way Stop Control	.086	.226	.013	0	.026	.080
Traffic Signal	2.118	2.367	2.958	.055	.773	1.116

* Average annual accident frequency data shown above includes all locations for each type of intersection control. Average annual accident frequency per location based upon only those locations that had at least one accident is considerably higher.

total accidents and angle accidents to be 73% and 75% respectively. Crinion²⁵ studied 2 locations in Australia and found that the total accident rate declined by 37% and 49%. Reductions in the angle accident rate were even more dramatic (84% and 75%). Heany's²⁴ research was less sophisticated but indicated total accident reductions of 87%. The prediction of accident frequencies at locations having multi-way stop control was also dealt with in the aforementioned report by DeLeuw, Cather²⁶, resulting in a nomograph based on factors similar to those used for two-way stop control.

The effect on intersection accident frequency of providing traffic control signals has been widely reported with fairly consistent results. Soloman²⁷ studied 39 intersections and found that total accidents increased by 23% with a decrease in right-angle accidents of 51%. The greatest accident increases were noted at simple intersections. Connor²⁸ studied 65 rural intersections with the result that total accidents were found to increase by 16% but right-angle accidents were reduced by 34%. It was also noted that provision of traffic control signals was ineffective in reducing accidents in the range of ADT volumes 9,500-11,000 vehicles. Clyde²⁹ studied 52 locations and found that total accidents increased by 33%, while right-angle accidents were reduced by 45%. Cribbons and Walton³⁰ studied 19 rural intersections and noted that total accidents increased by only 7%, while right-angle accidents decreased substantially, by 73%. They also noted that injury and fatal accidents declined substantially with the provision of traffic control signals. Schoene³¹ studied the effects of upgrading either conventional stop control or multi-way stop control to traffic signals. His results suggest that a slight increase

results when two-way stop locations are upgraded, while a substantial decrease occurs if multi-way stop control is upgraded.

Contrasting the foregoing results are those of authors in Australia and California whose studies consistently indicate that the provision of traffic signals reduces both total accident frequency and right-angle accident frequency. Australian studies by Thorpe³², Andreassend³³, and Crinion³⁴ indicated that total accident frequency was reduced by 50%, 32% and 52% respectively following the provisions of traffic signals. Both Thorpe and Andreassend reported near identical decreases in right-angle accident frequency of 80% and 72% respectively. Californian studies undertaken by Smith and Vostrez³⁵, Hammer³⁶ and Wilson similarly indicated that total accident frequency was reduced. Smith and Vostrez, Hammer and Wilson similarly indicated that total accident frequency was reduced. Smith and Vostrez, and Hammer reported reductions of 39% and 27% respectively. Hammer also noted that right-angle accident frequency was reduced by 76%, with the greatest reduction occurring at complex intersections. He further speculated that the accident frequency was unlikely to improve after the provision of traffic signals unless the rate before such action was in excess of .6 accidents per million entering vehicles. Wilson studied 125 intersections where traffic signals were provided and found that total accidents were reduced at 61% of the locations. Finally, studies by Vey³⁸ at 599 intersections noted an average decrease in total accidents of 20%, with the proviso that generally accidents only decreased at locations having volumes in excess of 900 vph. He also noted that accident frequency generally increased if the

frequency before the installation of traffic control signals was 3 per year or less.

Studies from the Ottawa area indicate that accident rates at traffic control signals are higher than all other types of control, both for total accidents rate and the rate of right-angle type accidents. Alternately, for the year studied, 56% of the total accidents occurring did so at locations having traffic signal control; despite the fact that only 7% of the intersections have such control. Details of this work have been provided in Exhibits 13 and 14.

In contrast to all of the foregoing discussion of accident frequencies under differing forms of intersection control is the work by Roer and McLaughlin³⁹ which suggests that the number of collisions between vehicles at an intersection is not affected by the type of intersection control in use.

While all of the preceding discussion of this section has dealt with the effect on accidents at specific intersections, it should be noted that varying intersection control strategies have a system wide effect as well. For instance, intersection control which may result in a low frequency of accidents at one intersection could divert traffic or otherwise alter its flow, resulting in increased accident frequency elsewhere. Clearly it is the minimization of accidents in the entire system which is desirable.

As a final note, some characteristics limiting the value of accident data bear mention. Firstly, the existing intersection control is generally fairly effective in

reducing accidents regardless of its form since the continued existence of high accident locations is unacceptable. Therefore, extreme problems are usually rectified as soon as possible, often not permitting studies.

Also, the whole question of accident rate is very much in question, as no agreed upon method of calculating rate exists. The most accepted method is that of using the sum of entering vehicles but other authors have prepared different rate measures such as the product of entering vehicles or the square root of this product. For this thesis the sum of entering vehicles approach has been taken.

4.1.4 Delay

A review of the available reference material concerning the selection of intersection control suggests that delay measures are an essential part of any warrant system developed. In many instances delay, together with accidents, is identified as a major performance indicator for intersection operation. The aforementioned work of DeLeuw, Cather⁴⁰ culminates in a proposal to relate an index of operation to accident and delay performance.

Further, as noted elsewhere, the current warrants for traffic control signals in both the Ontario and United States M.U.T.C.D. contain specific mention of delays. In both cases it is noted that the installation of traffic control signals should not be considered unless it will result in reduced delay for minor street vehicles.

Delay is the most frequently cited adverse impact of stop type intersection control and respondents to the technical

questionnaire indicated minimization of delay to be the second most important objective, only safety being ranked higher. Delay was also selected as the second ranked adverse impact of poor selection of intersection control by the technical respondents.

In addition to the misuse of time caused by delay, there are a number of other undesirable impacts which bear mention. These include degradation of air quality due to increased vehicle emissions, possible diversion of traffic to other routes in an effort to avoid delay, and encouragement of poor driving habits amongst drivers attempting to compensate for delay.

Delays occur whenever a vehicle is diverted from its steady state speed to negotiate an intersection. Therefore, it is evident that, in general, increasingly restrictive intersection control, or increasingly complex intersections, will result in greater delay.

To provide a basis for undertaking intersection delay the concept of gap/lag acceptance will be briefly considered. Gap or lag acceptance relates to the size of gap in major street traffic which a minor street driver will use. A gap is the space between major street vehicles (usually in seconds), while a lag is the time period between the arrival of a minor street vehicle and the next major street vehicle. Gap/lag acceptance characteristics are extremely complex and are influenced by many factors including the type of movement being attempted, community size, major street speed, intersection control, driver characteristics, visibility, road classification and the presence of queues. Work in this area by various authors suggests the following general results:

- median lag acceptance and gap acceptance times are similar
- drivers do not accept time intervals of less than 2-3 seconds or reject intervals greater than 12 seconds
- median acceptance times of 8 seconds are typical.

While studies into gap and lag acceptance provide an important basis for consideration of intersection delay, the remainder of this section will be devoted to work giving a clearer insight to the effect of delay on intersection operation, specifically in terms of total delay resulting from differing types of intersection control and average delay per vehicle under differing types of intersection control.

At the outset, intersection operation under differing forms of intersection control should be considered:

No Control - in this case the driver approaching an intersection can continue without delay providing no vehicle conflict potential exists. Generally, low volumes and good visibility are required to allow this type of intersection control.

Yield Control - in this case a driver is required only to slow to avoid conflict with another vehicle. No stop is required and delay is due to the extent of speed

reduction which is usually caused by poor visibility of opposing traffic. Studies in the Ottawa area indicate typical delays at yield controlled locations of 2-4 seconds.

Stop Control - in this case a driver is required to stop regardless of the potential for conflict. The time stopped is related to the gap/lag acceptance characteristics noted earlier. Studies in the Ottawa area indicate delay at stop signs to range from 5 seconds upwards.

Traffic Signals - as in the case of stop signs, a driver is required to stop irregardless of the potential for conflict and is further limited by being unable to proceed until permitted, even though gaps may exist which would permit this. Analysis based on Webster's Equation and studies by the author indicate average delays per entering vehicle ranging from approximately 25 seconds upwards.

From the foregoing it is evident that, at low traffic volumes, delay at locations having no control and yield control is similar. Further, it is evident that, as traffic volumes increase, the delay at locations having no control and yield control will approach the delay associated with stop control. These observations are verified by the results of Bandyopodhyay's⁴¹ study at low volume intersections. Briefly he found that:

- Travel time (delay) increased with increase in cross-street volume.

- Travel time through stop controlled intersections was significantly greater than yield controlled locations in all volume ranges.
- Travel times through yield controlled intersections under differing cross-street volumes were not significantly different. This was also noted for stop controlled intersections.

The foregoing observations are corroborated by the work of DeLeuw, Cather⁴² wherein it is noted that delay under yield control for volumes up to 300 vph was 2-3 seconds less per vehicle than under stop control. This difference increased to 5-6 seconds for major street flows approaching 400 vph and declined to nearly zero for major street flows of 100-200 vph. This latter observation suggests that observance of the stop control may have been poor. Additionally, it should be noted that the above delays reflect only stopped delay.

To further elaborate on the foregoing data, analysis was undertaken of field observations undertaken at 25 locations in the Ottawa area for a total of 124 hours. All locations studied currently have two-way stop control and most locations were arterial arterial/collector or arterial/local type intersections. The results, depicted in Exhibit 11 indicate delays in the range of 7-27 seconds duration.

EXHIBIT 11 TWO-WAY STOP DELAY STUDY RESULTS*(Ottawa Area)

Major Street Hourly Volume

	500 - 600	700 - 800	900 - 1000	1100 - 1200	1300 - 1400	1500 - 1600	1700 - 1800	1900 - 2000						
0-50	9.594 (2)	8.712 (1)	7.162 (2)	7.321 (1)	10.455 (6)	10.163 (5)	12.333 (9)	18.831 (9)	20.668 (4)	16.972 (7)	13.416 (2)	18.795 (2)	14.391 (6)	24.008 (2)
50-100	6.480 (2)	8.888 (2)	13.371 (4)	15.833 (1)	9.751 (3)	15.533 (3)	16.952 (6)	17.431 (3)	20.728 (4)	19.894 (2)	25.289 (2)	14.244 (1)	14.595 (2)	-
100-150	8.911 (2)	-	24.979 (1)	7.051 (2)	14.879 (3)	-	12.12 (2)	18.982 (2)	-	-	22.009 (1)	-	26.786 (1)	-
150-200	12.692 (2)	-	-	-	15.206 (2)	21.41 (2)	-	17.895 (3)	-	-	-	26.406 (1)	-	-
200-250	-	-	-	-	16.883 (2)	-	-	-	-	-	-	-	-	-

TABLE ENTRIES INDICATE MINOR STREET DELAY IN SECONDS.

() Bracketed figures indicate number of hours of data considered in that cell.
 * Results are based upon studies at 25 intersections for a total of 124 hours. All locations surveyed were of arterial/collector or arterial/local classification.

This delay only relates to stopped or creeping time and does not reflect decelerating/accelerating time loss. The data indicates increasing delay with both increased major and minor street traffic. Delay increase due to major street volume increase is substantially greater than that due to minor street volume increase however.

Limited data available at intersections having four-way stop control suggests that, while delay to minor street vehicles is similar to that noted in Exhibit 18, the delay experienced by major street vehicles is considerably higher, due to the time lost while queued in traffic. Finally, data collected at a variety of intersections controlled by yield signs indicate typical delays of 2-4 seconds, although it should be noted that virtually all intersections having yield type control have less than approximately 250 vph total volumes.

Another approach to considering delay at intersections was taken by Volk⁴³ who developed a delay hierarchy for an intersection under varying types of intersection control, but having equal traffic volumes as follows:

- 2-way stop	19,000 seconds of delay
- traffic actuated signal	21,400 seconds of delay
- 4-way stop	32,200 seconds of delay
- fixed time signal	33,000 seconds of delay

The above results, while not calibrated, do provide an insight to the relative effects of intersection control on total delay.

Finally, it is instructive to consider the work of Vodrazka, Lee, and Haenel⁴⁴ who considered the feasibility of delay as a warrant for intersection control using studies at two-way stop, four-way stop and traffic-signal controlled intersections. These studies indicated that delay experienced by the stop street at two-way stop locations was closely related to total intersection volume and that delays increased sharply at volumes in excess of 750 vph. At intersections having four-way stop control, the total delay was also related to total intersection volume with an increased volume of delays at total volumes in excess of 900 vph. It was also noted that delay on the stopped approach at intersections having two-way stop control was reduced by the installation of four-way stop control but that the total intersection delay increased. On this basis the authors suggested that the intersection control warrants should be revised to set a limit on average delay and then use this figure to develop an appropriate traffic volume.

A more elaborate proposal for the use of delay as a warrant for intersection control is that presented by DeLeuw, Cather⁴⁵ in their work on intersection control warrants. In this case, extensive field studies and computer analysis were used to develop regression equations for delay which were used to derive nomographs for delay prediction. These nomographs require extensive background data and are based on a limited number of study locations. Factors included in the nomographs for delay include cross-street width, detailed traffic volumes by type of turning movement, approach speed, safe approach speed, area, street classification, presence of nearby traffic signals and the number of moving lanes.

Based on the foregoing, the following observations can be made:

- Delay should be considered on a per vehicle basis as this is easily understood and is amenable to other calculations such as the time cost of delays.
- Assuming that appropriate intersection control is used, delays are less with less restrictive control.
- Delay appears to be related in large part to major street traffic volume, although many other factors are of some impact as well.

As a basis for further analysis in a subsequent chapter it is suggested that the following delay ranges be used: no control - no delay, yield control - 2 to 4 seconds delay per vehicle; stop control - 5 to 27 seconds delay per stopped vehicles; traffic signal - 25 to 50 seconds delay. Further, it is suggested that delay be treated as a linear relation of major street volume for simplicity. It is acknowledged that further refinement and corroboration of this data is necessary but such work is beyond the scope of the current project. In any case, the intent and approximate values are believed accurate.

4.1.5 Legislative Considerations

Of the 5 legislative considerations reviewed, 3 emerge as areas of particular significance; these are, the existing

intersection control, the roadway designation and legal considerations. Further elaboration of the foregoing factors is provided in the following sections.

a. Existing Intersection Control

As noted elsewhere, there is a generally accepted hierarchy of intersection control based on increasing restrictiveness. The hierarchy is no control, yield control, stop control, multi-way stop control and finally, traffic control signals. Since this hierarchy is fairly well accepted, it should not normally be neglected. Therefore, an intersection having no control should be upgraded to yield control and further evaluated, assuming that conditions make the provision of yield control feasible.

Further the presence of any form of intersection control also affects the factors which are reviewed to assess the need for upgrading intersection control such as accident rate and delays.

The only exception to the foregoing occurs at locations which are non-existent at the time of evaluation; for instance, new subdivision planning. In such cases, the proposed roadway designation should be considered.

A factor related to the intersection control at the intersection being studied is the consideration of intersection control elsewhere on the route which the intersection is a part of. The provision of intersection control which is consistent along a route greatly eases the driving task with attendant benefits to

safety. Proper choice of control to designate a through or priority route can also encourage traffic to use the route relieving problems of residential intrusion by traffic.

A statement of the efficiency of such routes was provided by Andreassend⁴⁶ in his evaluation of the STATCON program in Australia. He found that creation of priority routes increased the use of these routes by 10-15%, reduced delays by 10-70% and reduced accident rates by 17-37%.

A final consideration related to the foregoing discussion is the fact that drivers react favourably to intersection control which is anticipated. In the case of stop signs, this is reflected by the poor observation of stop controls, especially multi-way stop controls, which are not anticipated by drivers.

b. Roadway Designation

The designation of a roadway is closely related to both the volume of traffic on the roadway and to the classification of adjacent development. Due to this, the roadway designation also becomes an important consideration in the selection of intersection control. Unfortunately, current warrant systems for the selection of intersection control tend to neglect this factor.

Roadway classification and the application of the land zoning process are complementary functions. Due to the inter-relationship of these processes, it is

essential that neither the roadway classification or zoning be altered independently. While zoning is well protected by local by-laws, the classification of roadways is not generally so protected, as a result of which careless selection of intersection control can alter the function of the roadway to the detriment of the road system. Many of the problems noted in urban areas can be traced to the problem of incompatible development along a roadway.

To ensure that the selection of intersection control reinforces the classification of a roadway rather than detracting from it, it has been suggested that the selection of intersection control be tied solely to the designation of the roadway. There are many merits to this suggestion including the provision of a strong basis for the selection of a particular intersection control, thus reducing the latitude for politically oriented decisions to reduce the effectiveness of the roadway system.

The relation between roadway classification and traffic volume anticipated has been depicted elsewhere in Exhibit 7.

c. Legal Liability

Recent trends with respect to the legal liability surrounding the selection of intersection control make it appropriate to consider this factor carefully.

In the past, government agencies were virtually immune from legal proceedings related to intersection control selection because of the doctrine that a government agency could do no wrong.* Recent decisions in the

* This doctrine stems from English Common Law and the ancient doctrine that the King could do no wrong as his power was divine.

2

United States such as those documented by the Institute of Transportation Engineers in their Technical Notes of July 1978 and July 1979 and by Sheldon Pivnik have drastically altered this situation, and as a result, municipalities are increasingly being held legally liable. Pivnik⁴⁷ in his review defined a number of areas of liability including appropriateness of police action, poor design, improper maintenance or lack of maintenance.

Further, there is evidence that governmental agencies may be liable in instances where inappropriate or ineffective intersection control is used. One such case in Ohio has been detailed by the I.T.E.⁴⁸. In this instance a city was found legally liable for damages resulting from an accident at an intersection where stop control had been implemented to reduce speeding.

The possible liability resulting from the selection of intersection control stresses the need for establishing controls which are effective and well justified.

4.2 System Considerations

While the preceding sections have dealt with the affect of intersection control selection at a specific location or on a particular route, there are a variety of other wider impacts not generally dealt with. At the outset of this project, a variety of deficiencies with the current practice of intersection control selection were noted. All of the following factors are essential considerations not currently dealt with adequately. These include assessment of environmental impact, energy impact, cost and certain other considerations. The following sections detail these factors.

4.2.1 Environmental Considerations

The use of vehicles for transportation has two major impacts on the environment. These are the generation of undesirable noise and the degradation of air quality. There are also a variety of lesser affects including the generation of undesirable vibration, degradation of water quality, visual intrusion, degraded aesthetics and socio-economic impacts. Only the affect of intersection control on noise and air quality, are considered significant at this time.

a. Noise

The noise experienced in a community consists of two elements, noise due to community activities (background noise) and noise due to industrial or commercial concerns of which transport activity is a part. Noise can be both physically and psychologically damaging at extreme levels and, even at moderate levels, noise is a source of aggravation. A useful indication of the effect of noise on communities has been prepared by Klein et al⁴⁹ and Bugliarello⁵⁰ and is illustrated in Exhibit 12.

The noise level resulting from transportation activities depends upon many factors including:

- traffic composition
- traffic speed
- traffic flow characteristics

EXHIBIT 12NOISE IMPACTS RELATED TO
TRANSPORTATION FACILITIES

Source : Klein et al 49
Bugliarello 50

- roadway grade
- roadway surface texture
- distance between observer and noise source
- presence of intervening obstacles

The effect of traffic composition and volume on noise level is illustrated in Exhibit 12.

The presence of intersections increases noise levels due to the deceleration and acceleration of vehicles at these locations.

Finally, it should be noted that the impact of transport related noise varies with socio-economic group, adjacent land use, and time of day, in addition to the source related factors noted above.

b. Air Quality

The most significant form of pollution as far as the automobile and intersection control is concerned, is the emission of pollutants into the air. The magnitude of this problem is amply stressed in the following statement by Edwards⁵¹:

"transportation related pollution has accounted for an average of 60% of the total pollutants in the atmosphere of the major metropolitan areas of the United States; of this total, 90-95% is due to private cars."

The problem is not as severe in Canada at this time; however, effort is required to ensure that further contributions to air pollution are minimized.

Air pollutants resulting from vehicular traffic can take a variety of forms⁵². The primary pollutants include hydrocarbons, oxides of nitrogen, carbon monoxide, lead, and particulate matter including asbestos. The volume and intensity of these pollutants depends upon a number of factors including engine type, vehicle condition, climate, roadway factors such as grade and travel characteristics.

Insofar as the selection of intersection control is concerned, the factor of greatest importance is that of travel characteristics.

From the results of various research^{53, 54}, it is evident that air pollution levels are increased by frequent deceleration, idling, and accelerating cycles such as occurs at stop signs and traffic control signals.

In order to minimize the effects of vehicle travel on air pollution, the selection of intersection control should include the following considerations:

- avoid disruption to vehicle cruising speed
- minimize idling time
- avoid causing congestion
- minimize diversion of traffic to less suitable routes
- assess the probable impact on adjacent land uses

4.2.2. Energy Considerations

The significance of energy considerations in transportation is becoming increasingly evident due to the uncertainty of future fuel availability and the attendant cost increases. These factors have lead to greater public concern for the maintenance of an efficient transportation network including the selection of fuel efficient intersection control. The fact that current warrant systems do not address the use of energy is a serious short-coming in light of this trend.

Vehicular fuel consumption is affected by vehicle design, driving habits and the roadway network. Of these, only the roadway network is within the realm of the current project.

The largest affect on fuel consumption related to the selection of intersection control is the affect of speed change cycles. This affect is quantified by the tables illustrated in Exhibit 13⁵⁵.

In order to place the data of Exhibit 13 in perspective, it is useful to consider the affect of causing vehicles on a typical commuter route to undergo one speed change cycle such as that which would occur due to intersection control. For instance, all vehicles travelling on a route having ADT volumes of 15,000 are required to stop from a running speed of 50 km/h and then regain this speed. In this case, the additional daily total fuel consumption is 526 litres or 192,225 litres per year. Each motorist would require 12.8 additional litres of fuel per year.

EXHIBIT 13FUEL CONSUMPTION LEVELS FOR VARIOUS
OPERATING MODES

A. AUTOMOBILE FUEL CONSUMPTION DUE TO SPEED AND GRADE

Uniform Speed (mph)	Gasoline consumption (gal*/mi.) on plus grades of			
	Level	2%	6%	10%
10	.072	.087	.131	.179
20	.050	.070	.104	.160
30	.044	.060	.096	.154
40	.046	.062	.096	.154
50	.052	.070	.104	.162

B. EXCESS GASOLINE CONSUMED PER STOP OR SLOWDOWN SPEED
CHANGE CYCLE - AUTOMOBILE

Running Speed (mph)	Excess gas consumed by amount of speed reduction before accelerating back to speed (gal*)				
	10	20	30	40	50
10	.0016	-	-	-	-
20	.0032	.0066	-	-	-
30	.0035	.0062	.0097	-	-
40	.0038	.0068	.0093	.0128	-
50	.0042	.0074	.0106	.0140	.0168

* Data presented is based on American gallons.

Note: For conversion to metric values-

gal/mi $\times$ 2.255 = l/km

gal $\times$ 3.632 = l

Source: Transportation and Traffic Engineering Handbook; page 955,956

Studies by others verify the foregoing calculations and provide insight to the affects of other types of intersection control. Analysis by Courage and Parapar⁵⁶ determined that traffic control signal timing could be based on optimizing fuel consumption and illustrated that this goal was not met by current control strategies aimed at minimizing delay. The provision of yield control or the elimination of intersection control reduces fuel consumption by reducing the speed differential at the intersection.

From the foregoing it is evident that the selection of intersection control should minimize delay or idling time, avoid inducing speed change cycles and avoid diverting traffic to less suitable routes in order to minimize fuel consumption. It will be noted that these are virtually identical to the guidelines noted earlier for the minimization of air pollution and noise.

4.2.3 Cost Considerations

As with environmental concern and energy consciousness, cost is becoming an increasingly important aspect in transportation. The selection of intersection control has a wide variety of cost related impacts which can be grouped in 4 categories. These categories are travel cost, vehicle operating cost, accident cost and environmental cost.

Environmental impacts of transportation have been noted elsewhere, and while these impacts pose a cost to society,

this cost is difficult to establish and to place in monetary terms. Therefore, these costs will not be considered in the analysis to follow, but should still be borne in mind in evaluating intersection control costs.

The effect of intersection control selection on travel cost is to either decrease or increase travel time for road users. Therefore, the travel cost component depends upon the traveller's perceived value of his time. Numerous studies show that the perceived value of travel time varies depending upon the income of the traveller and the trip purpose amongst other factors. Analysis by Clark and Ogden⁵⁷ suggested that an appropriate estimate of the cost of travel time would be 50% of the average hourly rate of the community. Thus, in Ottawa, each hour of travel time would have a value equal to \$3.75. By calculating the anticipated delay on the basis of material presented elsewhere in this chapter and applying this hourly cost, an estimate of the travel cost can be attained.

The costs of vehicle operation related to the selection of intersection control include fuel cost, maintenance costs and the cost of vehicle depreciation due to wear and tear. It should be noted that fuel costs is the cost most accurately perceived by motorists and comprises the bulk of total vehicle operation costs in urban areas. Analysis by the C.A.A.⁵⁸ indicates that fuel cost comprises 3.47¢ per kilometer in urban areas. Various researches have documented the cost of vehicle maintenance and tire wear for various operating conditions. One such analysis⁵⁹ indicated typical costs of .71¢ per kilometer for power train components. Tire wear at a steady speed of 50 km/h costs 0.22¢.

per kilometer for asphalt surfaces, while stop and go cycles at this speed add an additional 0.12¢ per stop for maintenance and 0.06¢ per stop for tire wear. To place these costs in perspective and again using the example noted earlier, the cost of one additional stop on a commuter route having ADT volumes of 15,000 vehicles and an operating speed of 50 km/h follow. In this analysis, fuel cost is estimated to be 30¢ per litre.

- additional fuel cost per year	\$71,550
- additional maintenance cost per year	\$ 6,570
- additional tire cost per year	\$ 3,285
TOTAL ADDITIONAL ANNUAL COST	\$81,405

Finally, the cost to society of accidents should be considered, as accidents are closely related to intersection control. Analysis by Lawson⁶⁰ in this regard based on Canadian statistics indicated the following accident related costs based on 1978 dollars.

- average accident causing property damage	\$ 1,500
- average accident causing personal injury	\$ 5,500
- average accident causing fatality	\$180,000
- average accident cost	\$ 4,500

In view of the obvious discontinuity of fatality costs and the randomness and low frequency with which such accidents occur, the following analysis was undertaken to develop a more meaningful accident cost based on data from this area. During 1979 there were 7,000 accidents, of which 5,060 caused property damage, 1,925 caused injury, and 15 were fatal.

Using this data the average cost of an accident in the Ottawa area in terms of 1980 dollars is approximately \$3,600.

Finally, with respect to the costs related to intersection control selection it should be noted that all quantifiable costs accrue to the intersection user only and are typically distributed over a large number of drivers. Other costs which are non-quantifiable affect the whole population, but are primarily felt by residents adjacent to transportation facilities. It is evident that the selection of intersection control should consider both costs in order to ensure that cost is both minimized and distributed equally.

4.2.4 Other Considerations Related to Intersection Control

In addition to the numerous factors noted elsewhere in this chapter there are a variety of other considerations not normally dealt with in the selection of intersection control which should be noted.

The selection of intersection control, and the resulting characteristics of its operation such as delay, noise and other factors have a psychological impact on both intersection users and the adjacent residents. Thus, frequent resident complaints can be traced to aggravation resulting from perceived degradation of their immediate environment both physically and mentally. Similar aggravation is experienced by drivers and can lead to altered driving habits. Such changes can ultimately lead to accidents and at the least, reduces the enjoyment of road usage.

Careless or inappropriate selection of intersection control can also cause great social losses. Roadways provide opportunity for social interaction but can also limit social interaction. In the context of intersection control it is desirable to provide the best operation for all concerned which is frequently translated to the satisfaction of majority needs at the expense of the minority. A particularly sensitive point in this regard is the feeling by many that the desire to promote vehicular travel reduces the opportunity of pedestrians to travel comfortably.

Finally, a consideration of importance to the selection of intersection control is that of public opinion. Traffic engineering is, in fact, a service to the public; therefore, the satisfaction of public demands should be an objective. The problem is in the definition of public demands and in treating opposing demands equitably. Failure to consider public opinion will result in loss of credibility since most recommendations respecting intersection control must be approved politically. Further, care must be taken that technical requirements are met.

5.0 ASSESSMENT OF EXISTING WARRANT SYSTEMS

The foregoing chapters have served to detail the factors of relevance to the selection of intersection control. Subsequent sections of this chapter review the systems currently available for this task in order to define advantages and drawbacks of the available systems, and to provide a potential starting point for the development of a new criteria for the selection of intersection control.

At the outset it should be noted that current warrant systems tend to be vague for the least restrictive forms of intersection control, and increasingly defined for more restrictive types of intersection control.

While a variety of criteria exists, the systems detailed in the following three manuals are the best accepted and most relevant to the Ottawa area:

- Ontario Manual of Uniform Traffic Control Devices
- Canadian Manual of Uniform Traffic Control Devices
- United States Manual of Uniform Traffic Control Devices

5.1 Ontario Manual of Uniform Traffic Control Devices

The portions of this manual relevant to the selection of intersection control are attached as Annex C⁶¹.

This manual is essentially an extended version of the Canadian M.U.T.C.D.* expanded or altered where necessary to meet Ontario laws. It should be noted that the warrants for traffic control signals within this manual are currently under review by a Committee of the Ontario

* Henceforth, Manual of Uniform Traffic Control Devices will be indicated in this fashion..

Ministry of Transportation and Communications. Subsequent sub-sections detail the guidelines for each type of intersection control; except no control and multi-way stop control, for which no guidelines are provided.

a. Yield Control

The manual notes that this type of control should be used where the basic right-of-way rule is found to be inadequate. Limited guidelines are provided indicating that traffic volume, speed, visibility conditions and accident occurrence should be considered. Only the visibility conditions and accident rate are quantified with limits of safe approach speed in excess of 15 km/h and occurrence of two or more accidents per year respectively.

b. Stop Signs

This portion of the manual commences by noting that "warrants for stop signs have not yet been scientifically established and therefore no recommended practice is available". General guidelines are provided based on the safe approach speed (less than 15 km/h) with the proviso that this type of control is appropriate where intersection configuration or traffic volumes require a more positive stipulation of right-of-way.

c. Traffic Control Signals

In contrast to the lack of guidelines for the devices noted above, the text in this manual is extremely

specific, the guidelines presented forming the basis for Provincial subsidies paid for the installation of this device.

The warrant requirements are assessed on the basis of extensive data collection including vehicular and pedestrian volumes, accident history and vehicular speeds.

The warrants of this manual for traffic control signals reflect a variety of considerations including the presence of a minimum traffic volume on both the major and minor street approaches, the presence of high enough major street volumes that delay to pedestrians or vehicles on the minor street becomes excessive, the presence of high volumes of pedestrians or a high accident rate or a combination of the foregoing. The need for traffic signals to encourage progressive traffic flow is also considered and the warrants are adjusted to reflect urban or rural conditions and the number of traffic lanes on the major street.

From the foregoing brief description of the warrants of this manual a number of short-comings are evident. These deficiencies include the following:

- lack of definition of traffic volumes for lower forms of intersection control
- lack of complete definition of safety factors for all forms of intersection control
- virtually no consideration of delay due to intersection control
- no guidelines are provided for multi-way stop control or no control

- no consideration is made with respect to the hierarchy of intersection control, roadway designation, energy or cost considerations

Finally, and of most importance, the provisions of this manual are generally only accepted in Ontario and then by only a limited number of the jurisdictions studied. Further, it should be noted that the criteria of this manual for the installation of traffic control signals are conceptually and numerically similar to those of the United States M.U.T.C.D.

5.2 Canadian Manual of Uniform Traffic Control Devices

This manual has been developed to provide a Canadian standard for the installation of traffic control devices including the provision of symbolic signs and bilingualism. Of particular significance is the fact that the section of this manual dealing with warrants for the installation of traffic control signals was totally revised in August 1974.

The following sections detail the pertinent sections of this manual, a copy of which is attached as Annex D⁶². No guidelines are provided in this manual for the installation of multi-way stop control or no control.

a. Yield Control

This portion of the manual is extremely vague, noting only that yield control should be used where no control is not adequate but stop control is considered too restrictive. It is noted that traffic volume,

speed, visibility and accident record should be considered but no numerical guidelines are provided.

b. Stop Control

In this case it is noted that a recommended practice for the installation of stop control has not been established. General guidelines are provided including the application of such control where the safe approach speed is lower than 15 km/h and accident experience indicates the need for intersection control.

c. Traffic Control Signals

As noted, the current warrant system for this device was developed in 1974. Prior to that time, a warrant system virtually identical to that of the United States M.U.T.C.D. was used. The new system is based upon a priority point system, essentially a modified Detroit system.

The traffic control signal warrants of this manual are based upon the assessment of priority points in three basic categories; accidents, progression and traffic volumes. To do this, a variety of factors are considered including accidents, crossing gaps, signal progression, delay, intersection spacing pedestrian volume and roadway designation.

This system is very flexible and allows the assessment of negative priority points for accidents or progression, thus reflecting the adverse impact which the

installation of a traffic control signal could have on these factors.

The actual warrants of this manual for traffic control signals are illustrated in Annex D; however, it should be noted that the system is relatively complicated and requires considerable input data. As a result, this warrant system is not in wide use currently and is, in fact, under review by the Traffic Operations Technical Committee of R.T.A.C. Despite this, the system has a number of good points including the consideration of variables not normally dealt with, the provision of a result which can be easily priority ranked and the flexibility to avoid traffic control signal installations which will increase accident frequency or adversely affect progression.

In many ways it is evident that the provisions of this manual with respect to intersection control are inferior to those of the Ontario M.U.T.C.D. dealt with earlier. Generally, all forms of intersection control except traffic control signals are dealt with inadequately. The section on traffic control signals is quite comprehensive, neglecting only the considerations of energy, cost and delay but due to this comprehensive coverage suffers from extreme complexity.

5.3 United States Manual of Uniform Traffic Control Devices

Based on studies done by the author and others, this manual is the best accepted of the three being studied in the context of this paper. It also coincides with the guidelines of the I.T.E. Transportation and Traffic Engineering Handbook which are widely accepted.

The relevant sections of this manual are provided in Annex E63. The following sections consider the guidelines provided for each type of intersection control in detail, except no control, which is not dealt with in this manual.

a. Yield Control

The criteria presented for this type of intersection control are quite vague with only visibility requirements specified. In this case, a safe approach speed in excess of 10 mph is considered necessary. Further, a variety of special applications such as entrance ramps without acceleration lanes and at the median on divided highways are noted.

The manual also suggests that this type of control be used wherever engineering studies indicate that a problem exists which may be susceptible to correction through such action.

b. Stop Control

The application of stop control is not well covered in this manual with no numerical guidelines presented.

It is noted that this type of control should not be used for speed control or at any location where it would face the heavy direction of traffic flow. The manual suggests that this type of control be used where a combination of high speed, restricted view and serious accident record indicates a need for this type of control. It is, however, stressed that this type of control should not be installed indiscriminately, as such action would breed contempt for both law enforcement and obedience of the signs' command to stop.

c. Multi-Way Stop Control

In contrast to the vagueness with which the application of stop control is dealt, this manual is quite specific concerning the installation of multi-way stop control.

This type of control is considered appropriate at locations having five or more accidents of a type likely to be corrected by the installation of this type of control within 12 months. Alternately, volume requirements are specified; namely, total intersection volumes in excess of 500 vph for at least 8 hours of which 200 vehicles and/or pedestrians per hour are on the minor street. Minor street delays in excess of 30 seconds per vehicle during the peak-hour are also noted.

The foregoing requirements are reduced by 30% at locations having 85 percentile speeds in excess of 40 mph.

Finally it is noted that multi-way stop control is an appropriate interim measure where traffic control signals are warranted but cannot be installed immediately.

d. Traffic Control Signals

The installation of traffic control signals is thoroughly covered in this manual based on a system which is similar to, but more extensive than, that of the Ontario M.U.T.C.D.

In particular, it should be noted that warrants are provided for the installation of traffic signals at school crossing locations, and to encourage the concentration or organization of traffic on a transportation network (the latter being distinct from such installations as a measure to establish progressive flow).

Warrant values are reduced for roadways having 85 percentile speeds in excess of 40 mph and are increased for multiple lane roadways.

As noted in the foregoing sub-sections, the criteria of this manual with respect to intersection control are fairly comprehensive, particularly for multi-way stop control. The major short-comings are evident for lower forms of intersection control such as stop control and yield control.

The greatest benefit of this system, however, is its wide acceptance and use throughout North America. This factor is of considerable importance as it provides a good base for further extension.

The drawbacks of the criteria within this manual are similar to those noted earlier in the consideration of the other manuals. Specifically, the criteria are unacceptably vague for lower forms of intersection control and the considerations of delay, cost, energy and roadway designation are not appropriately dealt with.

5.4 Conclusions of Assessment of Existing Warrant Systems

Based on the foregoing review and associated analysis it is evident that, of the intersection control selection criteria considered, those of the United States M.U.T.C.D. are the best accepted and most extensive. Therefore, further refinement and extension of these criteria is appropriate.

Studies indicate that the criteria of the United States M.U.T.C.D. for traffic control signals are more restrictive than those of either the Ontario or Canadian M.U.T.C.D., although the criteria of the latter manual are not directly comparable and appear to give similar results. Further, it is clear from both the technical and public responses that criteria similar to those of the United States M.U.T.C.D. for traffic signals result in installations which are well accepted and well respected.

The criteria of the United States M.U.T.C.D. for multi-way stop control are clearly oriented towards such installa-

tions on major roadways and studies verify that these criteria are not appropriate at rural intersections or urban intersections of low volume roadways. These conclusions were also reached by Mitchell⁶⁴ who concluded that current warrants, particularly for multi-way stop control, were completely inadequate for intersections of low volume roadways.

Similar findings in the Ottawa area prompted the development by the author of a specialized warrant system for multi-way stops with a reduced warrant prepared for low volume (local or collector) streets and retention of the warrants of the United States M.U.T.C.D. for arterial or major streets. This system has not been published, but is used as a departmental guideline by the Regional Municipality of Ottawa-Carleton.

Finally, criteria of the United States M.U.T.C.D. for no control, yield control and stop control are inadequate, as no means of selecting the most effective of these types of intersection control at a given location is provided. Hence, further review and development of criteria for these types of intersection control are necessary.

6.0 DEVELOPMENT OF INTERSECTION CONTROL SELECTION CRITERIA

Foregoing chapters have provided insight to the factors critical to the selection of intersection control and have determined the suitability of current warrant systems for this task.

It is instructive to recall that this study was initiated to respond to inadequacies of the current intersection control selection criteria in the areas of energy and environmental concerns, consideration of public opinions, cost, and perceived inadequacies in technique. These short-comings have been verified in the previous chapter insofar as current national and provincial manuals are concerned. Accordingly, the current criteria are considered inadequate and should be revised.

In order to be effective, any criteria for intersection control selection must satisfy a variety of considerations aimed to ensure both optimum impact of the device and operational safety. Based on the research of this project one such list of considerations to be satisfied by intersection control selection criteria follows. The criteria must:

- reduce reliance on subjective decisions
- encourage acceptance of results by both the politicians and the public
- minimize data collection requirements
- provide a method of priority ranking expenditure if required

- give results which can be sanctioned by law and enforced reasonably
- give results which fulfill a perceived need

The foregoing list provides the objectives of intersection control selection criteria to be achieved if the goals of operational safety and effectiveness are to be met. Of the potential selection criteria developed and reviewed, the following systems are considered to be the most promising:

- to retain and modify the current criteria of the United States M.U.T.C.D. to satisfy the deficiencies noted elsewhere
- to develop a new set of selection criteria based on the concept of priority points
- to develop a new set of selection criteria based solely on cost factors
- to develop a new set of selection criteria based on the concept of goals achievement

Subsequent sections consider each of the foregoing alternatives in greater detail.

6.1 Modified United States M.U.T.C.D. System

The acceptance of the United States M.U.T.C.D criteria for intersection control as a basis for further work has a number of significant benefits. These include the current wide acceptance of this system, particularly for the application of traffic control signals and the fact that this system is already more extensive than the others studied. The drawbacks of this system have been noted in Sections 5.3 and 5.4.

From the discussions of Section 5.3 it can be seen that the warrants of the United States M.U.T.C.D are based on three factors; safe approach speed, traffic volumes and accident frequency. The following paragraphs will review each of these factors and identify possible extensions.

The volume requirements of this ~~Warrant~~ ^{Warrant} system for traffic signal and multi-way stop installation are illustrated in Exhibit 14. Superimposed upon this exhibit are the average hourly volumes noted elsewhere for local, collector and arterial type streets. From this exhibit it is evident that current warrants for either of these devices are suitable for arterial - arterial, arterial - collector and possibly collector - collector type intersections only. This exhibit also identifies the deficiency of current multi-way stop warrants in dealing with minor intersections as is frequently requested.

In order to extend the above-noted volume warrants to include other devices, it is necessary to define the change-over points for upgrading no control to yield control and yield control to stop control. The methods considered for this task were the evaluation of accident expectancy versus volume for each type of control, consideration of reference material, and review of roadway classification. Finally, to maintain consistency with the existing warrants of this manual, traffic volumes used will be the average hourly volume during the peak 8-hour period.

As intersection control is primarily effective in reducing right-angle accidents, the feasibility of upgrading control on this basis was considered. From data noted for the Ottawa area in Section 4.1.3, the average right-angle accident frequency for each type of intersection control is available. Similarly, the rate or expected frequency of

EXHIBIT 14
GRAPHICAL PRESENTATION OF VOLUME WARRANTS
OF UNITED STATES MUTCD

right-angle accidents has been detailed for each type of intersection control. This data has been extracted from Exhibits 8 and 10 and follows in Table 22.

Table 22 - Average and Expected Accident Frequencies for Right-Angle Collisions

	<u>Average Annual Accident Frequency (Acc/Year)</u>	<u>Accident Rate (Acc/Mev)</u>
No Control	.086	.226
Yield	.074	.141
Stop	.375	.092

By equating the expected accident frequency of the lower form of intersection control and the average accident frequency at the next most restrictive form of intersection control, appropriate changeover traffic volumes were established. The results indicate that no control should be upgraded to yield control for average volumes during the peak 8-hour period, in excess of 60 vehicles per hour and that yield control should be upgraded to stop control for average volumes, during the peak 8-hour period, in excess of 485 vehicles per hour. These are average total intersection volumes.

In order to verify these findings, a comprehensive review of warrant guidelines from other jurisdictions and results of the technical study was made. These data generally indicate changeover volumes of approximately 100 vehicles per hour for no control to yield control and 300 vehicles per hour for yield control to stop control. The difference between these data and the values calculated above tends to expand the usage of no control and stop control slightly while diminishing the application of yield control.

Finally, it is appropriate to consider the affect of roadway classification on intersection control choice. Earlier it was suggested that it may be feasible to use roadway classification to select intersection control in view of the usually close link between roadway classification and traffic volumes. Such a relationship is depicted in Table 23.

Table 23 - Relationship of Roadway Classification and Intersection Control

No Control	collector/local, local/local
Yield Control	collector/collector, collector/local, local/local
Stop Control	arterial/local, collector/collector, collector/local
Four-Way Stop Control	arterial/collector, arterial/local, collector/collector
Traffic Signals	arterial/arterial, arterial/collector, arterial/local

Based on the average hourly approach volumes for various roadway classifications in the Ottawa area it is possible to establish appropriate changeover volumes from the foregoing Table 23. In this case no control would be upgraded to yield control for average total volumes in excess of approximately 200 vph and yield control would be upgraded to stop control for volumes in excess of about 350 vph.

Consideration of all the foregoing data indicates that appropriate changeover volumes are 100 average vehicles per hour for upgrading no control and 350 vehicles per hour for upgrading yield control. This will result in an expected

angle accident rate at no control locations slightly greater than anticipated under yield control but a slightly lower accident rate under yield control at changeover to stop control. Since the accident data is based upon only one year it is felt that this change is not substantial.

The proposed new volume warrant for all types of intersection control is illustrated in Exhibit 15. Superimposed on this Exhibit are the volume ranges anticipated for each roadway classification. It will be seen that the results are generally similar to those of Table 23.

The remaining factor of prime importance to the warrants of the United States M.U.T.C.D. is that of accidents. An accident guideline is provided for both traffic signal and multi-way stop installation; however, in both cases the same value is specified. The suggested criteria is the occurrence of five or more preventable accidents in a twelve month period.

Studies from the Ottawa area indicate that, while this value may be appropriate for traffic control signals, it is excessive for multi-way stop control. Of the 6,187 intersections within the Ottawa area, only 335 experienced total accident frequencies in excess of five per year. The modal accident frequency for locations having an accident was one per year except at traffic control signals where the modal frequency was five per year.

In view of the results of the technical study, and since the existing United States M.U.T.C.D. is well accepted, it is appropriate to retain the current accident warrant for

EXHIBIT 15 PROPOSED VEHICULAR VOLUME CRITERIA
FOR INTERSECTION CONTROL

Average Major Street Hourly Volume (8 Hours)

Average Minor Street Hourly Volume (8 Hours)

traffic control signals. It is then necessary to extend this warrant to other intersection control devices.

One promising method of accomplishing this is to introduce the concept of 85th percentile experience. In other words an annual accident frequency in excess of the 85th percentile annual frequency for that type of control represents a problem. The 85th percentile frequency is the frequency at or below which 85% of the intersection frequencies are found. The following Table 24 depicts the 85th percentile yearly total accident frequency for each type of intersection control studied.

Table 24 - 85th Percentile Annual Accident
Frequency by Type of Intersection Control

No Control	0
Yield Control	0
Stop Control	1
Multi-Way Stop Control	1
Traffic Signals	14

Annual total accident frequencies in excess of those noted above would constitute unusual or excessive experience. It should be noted that, since accidents are random, and as the numbers are extremely low, an experience in excess of the frequency noted would be expected to occur for a long period of time before action was taken. Accident experience over a period of three years is usually used.

A further consideration is the frequency of occurrence of angle type accidents (so called preventable accidents). Based on the Ottawa data, angle accidents represented 36%

of the total accident frequency. If this percentage is applied to the above-noted 85th percentile criteria for traffic signals, a yearly angle accident frequency of 5 or more accidents per year results, precisely the current warrant of the United States M.U.T.C.D.

Therefore, it is proposed that the existing accident warrant of the United States M.U.T.C.D. be modified and extended as follows:

- No Control - total frequency less than 1 per year for 3 years
- Yield Control - total frequency in excess of 1 per year for 3 years
- Stop Control - total frequency in excess of 2 per year for 3 years
- Multi-Way Stop Control - total frequency in excess of 2 per year for 3 years
- Traffic Signal - total frequency in excess of 15 per year for 3 years, or angle accident frequency in excess of 5 per year for 3 years.

Finally, to ensure that an intersection can be negotiated safely, and to avoid liability if this is not the case, it is essential to ensure that drivers have adequate sight distance to avoid an accident if necessary. Calculations, and available reference material suggests the following sight distance criteria:

- No Control - safe approach speed in excess of 20 miles per hour (30 km/h)
- Yield Control - safe approach speed in excess of 10 miles per hour (15 km/h)
- Stop control - safe approach speed less than 10 miles per hour (15 km/h)

A further consideration is the ability of a driver who has stopped to re-start safely. The sight guidelines of the I.T.E. Traffic and Transportation Engineering Handbook⁶⁵ are suggested to reflect this condition; namely, visibility of major street vehicles for a distance of 200 to 300 feet in urban areas and 500 feet in rural areas. This corresponds to safe approach speeds of less than approximately 5 miles per hour. If this case occurs, careful review of the available sight distance is required and if no improvement is possible, then multi-way stop control should be considered to ensure adequate safety.

The foregoing analysis has resulted in the extension of the existing warrants of the United States M.U.T.C.D. to cover all types of intersection control on the basis of traffic volumes, accidents, visibility and roadway classification. It is likely that the resultant criteria would be well accepted as they merely extend a currently well accepted system. Further, experience with these criteria would serve to verify or possibly refine these criteria but such has not been possible in the context of this study. The resultant criteria proposed for the selection of intersection control are illustrated in Exhibit 16.

6.2 Priority Point Based Intersection Control Selection Criteria.

During analysis of the technical returns, and from discussions with others in this field, it became evident that a system of intersection control selection based upon priority points may be desirable. Such a system has the advantages of providing a method of ranking the results for presentation purposes or for budgeting. In addition, it

EXHIBIT 16 SUMMARY OF PROPOSED EXTENDED UNITED STATES
MUTCD SELECTION CRITERIA FOR INTERSECTION
CONTROL

Factor Considered	Type of Intersection Control				
	No Control	Yield	Stop	Multiway Stop	Traffic Signal (1)* (2)*
Major Street Volume**	-	-	-	>300	>590 >890
Minor Street Volume**	-	-	-	>200	>175 >90
Total Intersection Volume**	<100	<350	<350	>500	>765 >980
Total Acc./Year	<1	>1	>2	>2	>15 >15
Total Angle Acc./Year	-	-	-	-	>5 >5
Safe Approach Speed(km/h)	>30	>15	<15	<8	N/A***N/A
Roadway Classification****	L-L	L-L	A-L	A-A	A-A
	C-L	C-C	C-L	A-C	A-C
		C-L	C-C	C-C	A-L

* Traffic volumes depicted are based on the USMUTCD traffic signal warrants number 1 and 2 assuming one lane approaches on both the major and minor street and a speed of less than 60 km/h. Manual volumes have also been adjusted to reflect the use of average hourly traffic volumes, not eighth highest hour traffic volumes as are currently indicated in the USMUTCD.

** All traffic volumes indicated are average hourly traffic volumes for the peak eight hours of the day.

*** This factor is not applicable to this type of intersection control.

**** The letters represent the following road classifications:

Arterial A
Collector C
Local L

can be relatively easily expanded to include as many factors as desired. Possible drawbacks include the need to develop relative rankings for each factor and possible criticism of the selected weightings.

A variety of systems of this type are in current use including the Detroit system, the New York Signal Formula, the traffic signal warrants of the Canadian M.U.T.C.D. and various modifications or extensions of the foregoing developed by various jurisdictions on an individual basis.

In most cases the priority point system is oriented to the selection of traffic control signals only and is based on the warrants of the United States M.U.T.C.D., adjusted where appropriate on a subjective basis. Generally the development of all systems proceeds by the definition of factors to be considered in the selection of intersection control. For each of the factors chosen, a threshold value is selected which represents satisfaction of the requirements, and finally the factor is given an appropriate weighting. All that remains then is to subjectively assess the point ratings at which differing forms of intersection control are appropriate.

Based on the data collected and returns of the technical and public questionnaire respondents, it is possible to identify various factors of relevance to the selection of intersection control. Further, as the technical respondents ranked these factors, it is possible to develop appropriate weightings for each factor. It should be noted that, if such a system were to be used within a jurisdiction, appropriate local rankings could be easily established by public and political studies. The factors deter-

mined to be of significance and their relative rankings and weightings follow in Table 25.*

Table 25 - Ranking and Weighting of Selection Factors

	<u>Rank</u>	<u>Weight</u>
Accidents	1	.28.9
Major Volume	1.2	24.1
Minor Volume	2.2	13.1
Delay	3.6	8.0
Visibility	4.2	6.8
Geometry	4.8	6.0
Pedestrian Volume	5.0	5.8
Speed	7.0	4.1
Location Factors**	10.0	2.9
Total Weight		100

** Arbitrary composite representing a variety of factors, assigned rank of 10.0.

For comparison to the foregoing the New York Signal formula considers total vehicular volume (product of major and minor street approach volumes), pedestrian volumes, accidents, through-street designation, progression, one-way streets and certain additional factors. As this system is based on the traffic signal warrant of the United States M.U.T.C.D. formulas are developed for vehicular volume, pedestrian volume and accidents which achieve 100 priority points when the conditions meet the corresponding warrant values of the United States M.U.T.C.D.

* The ranks presented in Table 25 have been developed based on the average modal ranks for each factor independent of intersection control type. Modal rank for each factor by type of intersection control was previously presented in Exhibit 5. Weights have been developed from these ranks based on a total weight of 100.

Priority point totals in excess of 300 are considered to warrant the installation of traffic signals.

Using similar logic, the proposed extended warrants developed from the United States M.U.T.C.D. in the previous section were evaluated in order to define appropriate threshold values for each of the factors of Table 25. In each case, conditions warranting the most restrictive relevant form of intersection control were used. At this point it should be noted that priority point totals cannot exceed 100 with the present system.

The chart presented in Exhibit 17 identifies the threshold values for each of the factors considered and the weighting equation to be used. It will be noted that in some cases, subjective assessment is necessary.

Application of the proposed selection system to a variety of locations suggests that the following priority point ranges are appropriate for the type of intersection control indicated.

No Control	0 - 20 priority points
Yield Control	20 - 35 priority points
Stop Control	35 - 45 priority points
Multi-Way Stop Control	45 - 75 priority points
Traffic Signals	75 - 100 priority points

Several drawbacks of this proposed system were noted. Most significantly care must be taken to ensure that legal obligations are met; for instance, irregardless of point total, the safe approach speed should be adequate for the type of control considered. Secondly, it has been noted that the application of multi-way stop control is quite controversial and the examples reviewed suggest that this system may not reflect demands in this area. Therefore, it is sug-

EXHIBIT 17

PRIORITY POINT SYSTEM FACTOR WEIGHTINGS AND
EVALUATION EQUATIONS

FACTOR	WEIGHT	THRESHOLD	EVALUATION EQUATION
ACCIDENTS	28.9	14 Total/Year	(Average yearly total / 15) 28.9
		5 Angle/Year	(Average yearly angle / 5) 28.9
MAJOR VOLUME	24.1	500 Veh./Hour	(Average hourly major volume / 500) 24.1
MINOR VOLUME	13.1	150 Veh./Hour	(Average hourly minor volume / 150) 13.1
DELAY	8.0	30 Second/Veh.	(Average delay per vehicle / 30) 8.0
VISIBILITY	6.8	20 Mile/Hour SAS	(Safe approach speed - 20) 6.8 20
GEOMETRY	6.0	-	Subjectively assigned
PEDESTRIAN VOLUME	5.8	150 Ped./Hour	(Average hourly pedestrian volume / 150) 5.8
SPEED	4.1	20 Miles/Hour	(Average speed - 20) 4.1 20
LOCATION FACTORS	2.9	-	Subjectively assigned

V

gested that priority point totals in the range 35 -75 be closely evaluated to assess whether two-way or four-way stop control is most appropriate.

Finally, it is essential that such a system be monitored closely for an initial period to allow revision of the weightings, threshold values and priority point ranges as appropriate.

Priority points systems provide a valuable tool for the assessment of relative merit of various intersections. This is becoming increasingly important as the demands for effective use of intersection control funds increase. It is believed that these factors, together with more extensive application of such a system would result in an extremely well accepted and comprehensive warrant system for intersection control.

6.3 Cost Based Warrant System

A consideration frequently dealt with in the context of transportation projects is the concept of economic analysis. A variety of methods are available for such analysis which normally reflects the project costs and benefits over a period of time. The most popular method is the calculation of benefit-cost ratio with positive ratios indicating worthwhile projects.

This type of analysis has not been used in the selection of intersection control for a variety of reasons, primarily the low perceived costs of such actions by political decision makers. The current economic situation has placed increasing stress on the monetary effect of intersection

control and therefore it is appropriate to consider a warrant system based on cost. It should be noted at the outset, however, that cost factors were not considered to be important by either the public or technical study respondents.

In an earlier section on the costs of intersection control it was noted that only the following factors could be readily costed: fuel, vehicle maintenance, tire wear, accidents, delay and installation costs. Installation costs for all types of intersection control are very low; approximately \$500 being typical. Traffic control signal installation costs are far higher, averaging about \$25,000. Annual maintenance and operating costs of \$200 for sign controls and \$2,000 for traffic control signals are typical.

Delay costs were earlier noted to be about \$3.75 per hour of time wasted, in this area. Further, the following ranges of delay were found for different types of intersection control.

- no control - negligible delay if conditions allow unrestricted approach speeds and geometry is appropriate
- yield control - 2 - 4 seconds of delay per vehicle depending upon conditions and traffic volumes
- stop control - 5 - 27 seconds depending upon traffic volumes and stop sign observance
- traffic signals - variable delay depending upon cycle length proportion of green time, flow and degree of saturation. At traffic volumes warranting such control average delays of 24 seconds are typical.

It has been noted elsewhere that intersection delays depend on many factors with the major factor being traffic volume. As a simplification to allow the calculation of delay cost at various types of intersection control, the above data have been plotted versus the approximate traffic volume range for each type of intersection control. This plot is illustrated in Exhibit 18. While the drawbacks of this simplification are evident, the resources available did not allow clear definition of this relationship and the results are adequate to illustrate the relative levels of delay and their associated costs.

The cost of accidents at intersections can be dealt with in a variety of ways. Earlier it was determined that the average cost of an accident was \$3,600 in this area. Also, the average accident frequency, and accident rates were determined for each type of control within this area. Clearly, the installation of some types of intersection control can improve, or possibly worsen, the accident experience, (hence the assessment of negative priority points in the traffic control signal warrants of the Canadian M.U.T.C.D.).

Therefore, it is proposed that the existing accident history at a study location be compared to the anticipated accident history for other forms of intersection control based on the average accident cost noted above. Further, the existence of an accident frequency in excess of the 85th percentile frequency for that type of intersection control is considered to indicate an accident problem at that location. The average accident frequency, 85th percentile accident frequency, and average accident rate have all been developed elsewhere.

EXHIBIT 18ESTIMATED RELATIONSHIP BETWEEN INTERSECTION
DELAY AND TRAFFIC VOLUMES

NOTE : The above-noted graph was established on the basis of limited field data from the Ottawa area, augmented by selected reference material. In addition to this shortcoming the relationship depicted has been simplified by assuming delay to be a factor of traffic volume only, and assuming that a linear relationship exists. Despite these failings the data is considered adequate for the purposes of this study, namely to illustrate the approximate delay cost component of intersection control decisions.

Consideration of the foregoing and the analysis presented earlier in section 4.2.3 allow the relative costs of various forms of intersection control to be assessed. Such assessment would be followed by the selection of the intersection control resulting in the lowest annual cost.

This type of intersection control selection criteria has a variety of drawbacks, not the least of which is the lack of concern for the cost related to intersection control which has been shown to date. Further, it is not possible to calculate costs for many of the benefits and drawbacks of intersection control such as environmental impact, public attitude and social affects. Finally, further work is necessary to ensure that relationships between cost factors such as delay, accidents and energy usage and observed conditions of traffic volume, geometry, etc. are clearly and adequately defined.

Due to the foregoing drawbacks, cost related criteria for intersection control are best dealt with at this time as one component of a more comprehensive intersection control selection system.

6.4 Goals Achievement Considerations

Following analysis of the public and technical questionnaire returns, a final potential method of intersection control selection became evident. The data of these studies provide definition of the goals of intersection control perceived by the respondents. Therefore, a logical extension of this perception is the selection of intersection control to maximize the achievement of these goals. This concept is not new and is basically identical to that

proposed by Schimpeler and Grecco⁶⁶ for the evaluation of alternative transportation system concepts.

Basically the system to be applied in this case defines a variety of community goals each of which is given a point value based on its apparent rank. For each goal considered an effectiveness measure is developed to allow the assessment of each intersection control type insofar as satisfaction of that goal is concerned. As multiple goals, effectiveness measures and intersection control strategies are involved, these calculations take the form of matrices. Multiplication of the latter, so called effectiveness, matrix and the former matrix of point values for each plan results in a matrix of utility values for each plan, again in matrix form. The general form of these matrices and the appropriate definitions are illustrated in Exhibit 19.

As noted earlier, the public respondents' replies concerning the attributes and drawbacks of various intersection control devices can be used to develop a list of objectives of intersection control with rank based upon the relative frequency of mention.

The determination of intersection control objectives from the technical responses is more straight forward as the respondents were asked to rank order seven potential objectives. The resultant lists of public and technical objectives of intersection control are shown in Exhibit 20. It should be noted that the data of Exhibit 20 respecting public and technical objections are repeated from Tables 12 and 17 respectively. Public objectives were developed implicitly from public responses concerning the attributes and drawbacks of intersection control, while the technical objectives were the subject of a specific question to technical respondents.

EXHIBIT 19GENERALIZED GOALS ACHIEVEMENT MATRIX CONCEPT

EFFECTIVENESS MATRIX

OBJECTIVE
WEIGHTING
MATRIXUTILITY
MATRIX

$$\begin{bmatrix} e_{11} & e_{12} & e_{13} & \dots & e_{1j} \\ e_{21} & e_{22} & \dots & \dots & e_{2j} \\ e_{31} & \dots & \dots & \dots & e_{3j} \\ e_{41} & \dots & \dots & \dots & e_{4j} \\ e_{51} & \dots & \dots & \dots & e_{5j} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \end{bmatrix} = \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \end{bmatrix}$$

- Where :
- effectiveness matrix rows correspond to each type of intersection control being reviewed
 - effectiveness matrix columns correspond to effectiveness measures for each objective considered. In this case the percentage of the result achieved with the optimum type of intersection control for the particular objective being considered was used.
 - the objective weighting matrix is a column consisting of the weights assigned to each objective being considered. In this case the objective weights were determined from the public and technical questionnaire responses.
 - the utility matrix represents the aggregate utility or point score for each type of intersection control. The type of control having the highest utility best satisfies the objectives considered.

EXHIBIT 20PUBLIC AND TECHNICAL OBJECTIVES
OF INTERSECTION CONTROL

<u>Public Objectives</u>		<u>Technical Objectives</u>	
Minimize delay	1.00	Maximize safety	1.00
Maximize safety	.79	Minimize delay	.58
* Maximize driver respect	.76	* Consistency	.34
* Ensure smooth flow	.60	* Follow policy	.33
* Ensure clarity of control	.56	Minimize cost	.28
* Allow/Control access	.47	* Uniformity	.27
* Designate right of way	.42	* Meet public demands	.26
Minimum waste	.27		

* Factors marked are those for which quantification is difficult analytically and are therefore better dealt with in the context of committee evaluation.

From Exhibit 20 it is evident that many of the objectives cannot be evaluated numerically to assess the effectiveness of differing types of intersection control. This problem can be overcome by the establishment of a panel of interested/knowledgeable people to determine the effectiveness of each type of intersection control in satisfying each objective. Alternately, only the quantifiable objectives of minimizing delay, accidents and cost could be considered. For simplicity, the latter approach will be taken. The objectives to be considered and their related weights in this case follow:

	<u>Public Weight</u>	<u>Technical Weight</u>
Minimize Accidents	.79	1.00
Minimize Delay	1.00	.58
Minimize Cost	.27	.28

In order to construct the effectiveness matrix it is necessary to calculate the extent to which each type of intersection control achieves these objectives at the intersection being reviewed. One such effectiveness matrix follows, based on a normal intersection with average hourly volumes of 350 vehicles per hour and current annual accident frequency of two accidents per year. The development of this effectiveness matrix is detailed in Annex F.

<u>Type of Control/Objective</u>	<u>Accident</u>	<u>Delay</u>	<u>Cost</u>
No Control	0.65	1.00	1.00
Yield Control	0.98	0.85	0.88
Stop Control	1.00	0.81	0.70
Multi-Way Stop Control	0.92	0.35	0.00
Traffic Control Signal	0.00	0.00	0.62

Based on the foregoing data it is now possible to calculate the type of intersection control having the greatest utility based on the aforementioned technical objectives, as follows:

$$\begin{bmatrix} .65 & 1.00 & 1.00 \\ .98 & .85 & .88 \\ 1.00 & .81 & .70 \\ .92 & .35 & 0 \\ 0 & 0 & .62 \end{bmatrix} \begin{bmatrix} 1.00 \\ .58 \\ .28 \end{bmatrix} = \begin{bmatrix} 1.51 \\ 1.72 \\ 1.67 \\ 1.12 \\ .17 \end{bmatrix}$$

From the above calculations it is apparent that yield control would best achieve the noted technical goals, with two-way stop control the next best choice. As expected, traffic control signals would not be an effective form of intersection control for the location noted. Similar calculations based upon the public objectives achieve similar results, that is, yield control is the best choice.

This system of intersection control selection is promising for a variety of reasons. It provides the means for elected officials, or the public, to participate in the process and it can be extended to consider any number of objectives easily. The major drawback is the need of extensive data and human resources to establish the effectiveness matrix. Based on the limited number of examples evaluated in this way it is not clear that this method of intersection control would result in effective intersection control on a system wide basis, even though the system optimizes objective achievement at specific locations. Further, basic requirements such as the provision of adequate sight distance are not specifically addressed. A final drawback is the likely resistance which such a system would meet due to its complexity and reliance on subjective assessment.

6.5 Proposed Selection Criteria

Foregoing sections have briefly described a variety of possible systems for the selection of intersection control. All suggested systems account for the application of the entire range of intersection control and some can be expanded easily to account for as many observable factors as considered necessary. Earlier it was noted that warrant systems, if they are to be successful, must be acceptable to all parties involved and must give justifiable results. Clearly, this consideration is best dealt with by simply extending the existing warrant criteria of the United States M.U.T.C.D. as this manual is the best accepted, and in view of the apparent tendency of elected and public officials to accept such nationally sanctioned warrant systems.

Following the widespread application of the extended warrant proposal it would be possible to clearly define the appropriate volume and accident warrant values for each type of intersection control, a task which is beyond the scope of this report. Once the new warrants of the United States M.U.T.C.D. are defined it is an easy extension to develop a priority point system based on these warrants, as has been done in the past to develop the Detroit and New York priority point systems for traffic signals. It is believed that the increased need for effective budgeting and priority ranked justification for decisions will inevitably lead to such diversification.

Finally, future considerations of intersection control should recognize the objectives of both technical and public groups and select the optimum type of intersection control on this basis. It is certain that further

development and experience with this type of system would improve its acceptance; however, it is unlikely that either traffic engineers or the public would accept such a system now due to the apparent contradiction of objectives for intersection control.

The use of relative costs as a basis for intersection control is not considered to be feasible for further work. It is evident that cost considerations are not primary in the minds of either traffic engineers or the public insofar as the selection of intersection control is concerned. Further, the bulk of the costs accrue in minute increments to intersection users and so do not affect either local residents or traffic agencies greatly. Consideration of the costs involved does underline the need for effective intersection control however. In this regard, it is calculated that approximately 25% of the intersection travel in the Ottawa area occurs at collector or local intersections for which there are currently no adequate intersection control selection guidelines.

In conclusion, the following intersection control selection guidelines are proposed.

- Short Term - adopt modified and extended United States M.U.T.C.D. criteria
- Middle Term - develop priority point based warrant system
- Long Term - develop appropriate goals achievement based warrant system.

7.0 SUMMARY CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

In view of the evident high degree of interest in the selection of intersection control and more particularly due to the shortcomings of current methods available for this task, the foregoing study has been undertaken.

This study commenced with a review of relevant literature in this area in an effort to define existing shortcomings and evaluate current procedures. From this work it was clear that little public input was currently considered in the selection of intersection control and that this was a shortcoming of current procedures. Likewise, there was little evidence of comprehensive studies of technical opinion in this regard since the late 60's. To rectify these shortcomings, questionnaires were prepared and circulated to both public and technical sources.

The results of these studies, augmented by a further detailed literature review allowed the definition of a variety of factors relevant to the selection of intersection control. Analysis of these factors and consideration of other data collected from the Ottawa area provided a basis for the evaluation of existing criteria for the selection of intersection control. In this regard, the procedures of the Ontario, Canadian and United States Manuals of Uniform Traffic Control Devices were evaluated.

On the basis of the foregoing work it was concluded that, of the existing procedures available, those of the United States Manual of Uniform Traffic Control Devices were the

most comprehensive and best accepted; however, a number of shortcomings were noted despite this.

In order to rectify these shortcomings, new criteria for the selection of intersection control were developed by extending those of the United States manual. These criteria were developed as an immediate solution to current problems surrounding the selection of intersection control.

During the foregoing work, three other proposals for the selection of intersection control were developed and evaluated. These included a priority point based system, a cost based system, and a goals achievement based system. Of the three, the cost based system was judged to be least useful, while the goals achievement based system was noted to have great promise. It was, however, noted that more development of this latter system was required.

As a result, it was determined that the modified United States manual procedure was appropriate as an immediate procedure for the selection of intersection control, while the priority point based and goals achievement based systems were appropriate as medium and long term solutions respectively.

7.2 Conclusion

The analysis undertaken at various stages of this project allow a number of conclusions to be made concerning the selection of intersection control. For the-sake of brevity, these are outlined in point form below:

- The subject of intersection control selection is currently one of considerable controversy and is therefore of great interest to both the public and technical agencies.
- The lack of well accepted, and comprehensive, criteria for the selection of intersection control has resulted in frequent misuse of intersection control and resultant inefficiencies.
- Members of the public perceive the major attributes of intersection control to be safety, smooth traffic flow and benefits to through traffic and delay. Conversely the major drawbacks perceived are confusion, disrespect for the control, delays and danger.
- Most public respondents opposed the use of stop signs to control traffic speed, or divert traffic, and supported the enforcement of current stop regulations.
- It was noted by the public respondents that the poor application, or misuse of intersection control would cause driver disrespect, accidents and frustration.
- The public responses indicated that multi-way stop control is currently overused, while yield control is underused.
- The apparent goals of the public respondents concerning intersection control were safety, minimum delay, optimum traffic flow and maximum respect. The minimization of fuel usage and environmental damage did not appear to be important.

- The technical respondents indicated the most frequently used type of intersection control to be stop signs, while yield control was used least frequently.
- The technical respondents indicated that available criteria for intersection control were used for the selection of traffic signals, and to a much lesser extent multi-way stop, only.
- The majority of the technical agencies responding indicated acceptance of the United States Manual of Uniform Traffic Control Devices.
- The respondents to the technical questionnaire indicated the objectives of intersection control to be safety, reduction of delay, and consistent application of intersection control.
- The technical respondents noted that the major source of difficulties with the selection of intersection control were public attitudes and lack of political acceptance.
- The technical respondents noted that accident frequency, vehicular volumes, vehicular delay, visibility and intersection geometry were the factors of most importance to the selection of intersection control.
- Based on the foregoing it was concluded that any new criteria for intersection control selection should be based upon traffic volumes, accident frequency and visibility conditions. It was also noted that roadway

Classification provided a convenient means of assessing a variety of other factors and should therefore be considered.

- It was determined that traffic volume data for the average of the peak eight hours of a day should be used for the selection of intersection control.
- Due to the generally low accident frequencies at most forms of intersection control, the only accident measure considered to be appropriate was total annual frequency except for traffic control signals for which the total annual frequency of angle type collisions was relevant.
- Based on the apparent importance of traffic volume, accident frequency, visibility and intersection geometry, the criteria of the United States Manual of Uniform Traffic Control Devices were considered to be most appropriate for extension and modification.
- Generally, delay data available from the literature and local studies was incomplete or inappropriate for use in this project. The most readily accepted and useful measure of delay appears to be total intersection delay, in seconds, under differing types of intersection control during an appropriate study period.
- In view of current cost restraints facing many agencies, a method of ranking the need for intersection control, particularly traffic signals, is required. Therefore, a priority point based system should have future application.

- The use of cost based considerations for the selection of intersection control appears unnecessary due to lack of public or technical concern for costs, and difficulties in assessing many of the costs related to intersection control selection.
- In order to provide for the future need to consider public opinion and to allow consideration of a wide variety of factors for the selection of intersection control, a goals achievement based system appears to be promising.

Overall, it is felt that this study has been successful in providing background concerning the selection of intersection control and in defining deficiencies with the current methods used for this process. The proposed amendments to the United States M.U.T.C.D. provide an immediate solution to these problems and also provide a base for the future development of more sophisticated systems.

7.3 Recommendations

Based on the foregoing work, a number of recommendations concerning the future selection of intersection control are evident. Briefly, these recommendations follow:

- a. The selection of all types of intersection control should be based upon a comprehensive system such as that proposed which extends the current warrants of the United States M.U.T.C.D. Application of this system will result in decisions which are both consistent and justifiable.

- b. The proposed extension and modification of the United States M.U.T.C.D. selection criteria should be evaluated and revised, if necessary, after a suitable trial period.
- c. The revised criteria noted in the foregoing paragraph should be used to provide a basis for the development of a priority point based system to allow efficient use of funds.
- d. Further, extensive effort should be made to involve the public in the intersection control selection process to ensure that their demands are recognized.
- e. Further, studies of delay at intersections under differing traffic conditions and types of intersection control should be made to allow reliable consideration of this factor in the selection process.
- f. Ultimately, a system of intersection control based on the concept of goals achievement should be developed to improve the efficiency and effectiveness of this process.

R. Ridley

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ANNEX AComments on the Statistical Analysis of the Public
and Technical Questionnaire Returns

In what follows we have identified a variety of problems which make statistical analysis of the questionnaire studies exceedingly complex.

As noted elsewhere in this report, returns to the surveys were made on a voluntary basis and therefore sample size was not controlled. In the case of the public questionnaire, open advertisements were placed in all local newspapers requesting replies from interested people; this study resulted in 355 returns. The technical questionnaire was circulated to 181 municipal jurisdictions resulting in a total of 64 responses.

a. Public Questionnaire Responses

Due to the high level of public feeling concerning this topic at the time it was determined that the public questionnaire should be general in nature and simple to complete. Thus replies were of two basic types; one actually being a subset of the more general type. Specifically, the questions elicited multiple responses in each case, some questions having as many as 40 specific responses noted. The responses were then aggregated for each category and a "proportion" of the total response calculated for each category. Unfortunately, the statistical analysis of this type of response is extremely complicated due for the following reasons:

- While up to 40 specific response categories are defined, it is evident that categories are not independent.
- No measure of correlation between categories is available.
- The sample was not a valid random sample of the target population as only "interested" people would have replied, and a priori, their characteristics could differ from those of the population as a whole.

In view of the foregoing, the problem becomes one of multivariate analysis as opposed to the application of simple univariate methods. The simplest case of this type of problem, noted earlier, is that of "Yes" or "No" responses to a question. Again, the sample limitations noted apply and analysis is difficult.

b. Technical Questionnaire

The technical questionnaire responses to be analysed are of a related, but more complex form, since respondents in this case were requested to assign a rank to each of a variety of response categories. Aggregation of these replies generates a matrix of values indicating the proportion of respondents assigning or giving rank to a particular response category. As noted, the categories are not necessarily independent and the validity of sample statistics as unbiased estimators of population parameters is questionable.

Discussions concerning the statistical analysis of these surveys with Dr. Graham and Dr. Rao of the Carleton University Mathematics and Statistics Department verified the problems noted and they indicated that meaningful statistical analyses would be extremely difficult and certainly beyond the scope and resources of the current project. Further, it was determined that, for the purposes of the project, it should be adequate to draw inferences from the data collected based upon the proportions calculated for each response category.

ANNEX BTECHNICAL INFORMATION STUDY FORM

2 Parkfield Crescent
Ottawa, Ontario
K2G 0R8

23 June 1978

Dear Sir

Re: Intersection Traffic Control Study

As noted in my earlier correspondence of 6 April 1978, I am currently attempting to consolidate data on various forms of interest on control in order to prepare a "State of the Art" report on this topic. In this regard, you were mailed an information form, the results of which will provide valuable input to my study.

The results received to date have noted the need for a more concise warrant system, particularly for yield, stop and multi-way stop control, and have provided a valuable data base for further analysis in this direction.

Since I have not yet received your completed form, I would greatly appreciate your co-operation in this matter. If, due to manpower limitations, you cannot complete the entire form, please complete only pages 1 to 5 of the form (white pages). In either case, I would appreciate a reply by 31 July 1978.

I would be pleased to provide you with a copy of both the questionnaire results and the "State of the Art" report, both of which will be of significant interest to you, I believe.

Should you require another copy of the information form, please call me at 1-613-563-2637, or write to the above-noted address.

Thank you again for your co-operation in this matter and I look forward to your reply.

Yours truly

RR/dg

R. Ridley

6 April 1978

Dear Sir:

Re: Attached Intersection Control Study -
Information Form

I am currently employed by the Regional Municipality of Ottawa-Carleton as Operational Studies Engineer. My experiences in this position have made it evident that there are deficiencies in the existing warrant systems for intersection control devices, which have been accentuated in recent years by the public concern over the application of these devices, particularly multi-way stop control.

Therefore, I have prepared the attached information form in an effort to consolidate data which may be available on this subject so that a more concise warrant system may be developed to determine the suitability of various forms of intersection control.

As I am also registered in graduate studies at Carleton University in Ottawa, it is my intent to prepare a Master's Thesis based in part, on the results of this study.

The results of this survey, which has been sent to 200 cities in North America, will be used to augment data which has already been collected through comprehensive literature searches and from case studies selected from the Ottawa area.

Since the thoroughness and ultimately the usefulness of the warrant system developed depends upon the information received in response to this survey, I would earnestly request your co-operation in this regard. I would be pleased to provide you with a copy of this study when available and I am available for any further queries or comments which you may have at (613) 563-2637. When complete, please return this information form to the undersigned at 2 Parkfield Crescent, Ottawa, Ontario, K2G 0R8.

Yours truly

R. C. Ridley

RCR/js

Attach.

INTERSECTION CONTROL STUDY

INFORMATION FORM

Please complete the following questions in as much detail as is practical. In cases where guidelines, or policies, other than those of the national or state/province manual are available, please provide a copy of the appropriate document.

I BIOGRAPHICAL INFORMATION

- i) Who is the person completing this questionnaire?

Name _____

Position _____

Organization _____

Postal Address _____

- ii) Who should be contacted for further information or clarification?

a) the above noted person; or ☐

b) the following:

Name _____

Organization _____

Postal Address _____

Telephone No: _____

- iii) Would you like to receive a copy of the questionnaire summary?

Yes ☐

No ☐

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II GENERAL INFORMATION.

- i) Please indicate the approximate number of intersections under various forms of traffic control within your jurisdiction. (where an accurate number is unavailable, an estimate will suffice).

No control *

Yield sign control *

Multi-way stop signs

Traffic signal control

Other (please specify) _____

* Exclude traffic control used at merge locations.

- ii) On what basis are decisions concerning the application of forms of traffic control made within your jurisdiction? Please indicate each category which is applicable.

	No Control	Yield	Stop	Multi-way Stop	Traffic Signal
National Manual	☐	☐	☐	☐	☐
State/Province Manual	☐	☐	☐	☐	☐
City Manual	☐	☐	☐	☐	☐
Department Policy	☐	☐	☐	☐	☐
State/Province Law	☐	☐	☐	☐	☐
City Law	☐	☐	☐	☐	☐
Public Participation	☐	☐	☐	☐	☐
Rule of Thumb	☐	☐	☐	☐	☐
ITE Practice	☐	☐	☐	☐	☐
Other (Specify)	_____				

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- iii) What, in order of priority, are the objectives of intersection control measures within your jurisdiction and in your own opinion? (Number highest priority 1).

	Your Jurisdiction	Your Opinion
Minimize Vehicular Delay	_____	_____
Minimize Cost	_____	_____
Maximize Safety	_____	_____
Maintain Consistency In Area	_____	_____
Uniformity With Other Areas	_____	_____
Meet Public Demands	_____	_____
Follow Accepted Policies	_____	_____
Other (Specify) _____	_____	_____

- iv) Do the policies, warrants or guidelines used by your jurisdiction to establish intersection control differentiate between urban, suburban, or rural conditions?

Yes ☐ No ☐

Do you feel that this distinction is necessary?

Yes ☐ No ☐

- v) Are the intersection control measures within your jurisdiction reviewed periodically to ensure their adequacy? If so, please indicate all sources which are appropriate and the frequency of review.

Regular Review _____

Review After Complaint _____

Review Accident Rates _____

Other (Specify) _____

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- vi) Are combinations of traffic control measures used at locations within your jurisdiction (e.g. - stop and yield signs at some locations)?

Yes ☐ No ☐

If combinations are used, please indicate the combination and why it was used.

- vii) What are the most prevalent sources of difficulty with the criteria which you currently apply to establish intersection control? (Please indicate relative priorities; worst 1).

Negative Public Attitude _____

Uncertainty, Non-uniformity _____

Lack of Political Acceptance _____

Other (Specify) _____

- viii) What, in your opinion, are the impacts of poor application of intersection control (such as over-proliferation of control). Please indicate priority with the most detrimental effect (numbered 1).

Inefficient Use of Public Funds _____

Environmental Pollution _____

Motorist Delay _____

Motorist Confusion _____

Accidents _____

Loss of Driver Respect for Control _____

Other (Specify) _____

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- ix) Indicate what, in your opinion, is the relative importance of each of the following factors with respect to the selection of intersection control. Number most important factor 1):

	No Control	Yield	Stop	Multi-way Stop	Traffic Signal
Minor Street Volume	_____	_____	_____	_____	_____
Major Street Volume	_____	_____	_____	_____	_____
Pedestrian Volume	_____	_____	_____	_____	_____
Vehicular Delay	_____	_____	_____	_____	_____
Accident Rate	_____	_____	_____	_____	_____
Other Control on Route	_____	_____	_____	_____	_____
Visibility Conditions	_____	_____	_____	_____	_____
Vehicular Speeds	_____	_____	_____	_____	_____
Roadway Geometry	_____	_____	_____	_____	_____
Parking Factors	_____	_____	_____	_____	_____
Street Classification	_____	_____	_____	_____	_____
Adjacent Land Use	_____	_____	_____	_____	_____
Public Opinion	_____	_____	_____	_____	_____
Political Factors	_____	_____	_____	_____	_____
Existing Type of Control	_____	_____	_____	_____	_____
Other (Specify)	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____

In the following sections of this questionnaire, your opinion is requested concerning the acceptable operating range of various parameters for each type of intersection control. The questions are the same for each form of intersection control.

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III NO INTERSECTION CONTROL

- i) Please indicate numerical values which, in your opinion, define the upper and lower limits of acceptable operation for this type of intersection control for each of the following variables. Please ensure that the relevant units of measurement are indicated. Indicate NR if variable is irrelevant.

	Maximum	Minimum
Major Street Vehicle Volume	_____	_____
Minor Street Vehicle Volume	_____	_____
and/or Major/Minor Ratio	_____	_____
Pedestrians Crossing Major Street	_____	_____
Pedestrians Crossing Minor Street	_____	_____
Minor Street Delay	_____	_____
Total Accidents Per Year	_____	_____
Total Angle Accidents Per Year	_____	_____
Total Personal Injuries Per Year	_____	_____
Minor Street Safe Approach Speed	_____	_____
Major Street Vehicle Speed	_____	_____
Minor Street Vehicle Speed	_____	_____

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- ii) Please indicate the maximum allowable for the following geometric conditions, which in your opinion, would allow acceptable operation of this type of intersection control.

Intersection Skew Angle _____

Number of Intersection Approaches _____

Number of Lanes on Minor Street _____

Number of Lanes on Major Street _____

Grade on Any Approach _____

- iii) In general, at what types of intersections would this type of control be appropriate (e.g. - major/major, major/minor or arterial/arterial, collector/local, etc.)?

- iv) Would this type of traffic control be considered for applications other than at an intersection to control vehicle and pedestrian traffic, and if so, in what instances? Yes ☐ No ☐

- v) What, in your opinion, are situations where the application of this form of traffic control should be avoided?

- vi) In your opinion, do the existing warrant systems provide adequately for the application of this form of traffic control? Yes ☐ No ☐
 If you feel that they do, please indicate which system you feel is best; if not, please indicate what you feel the deficiencies are.

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IV YIELD TYPE INTERSECTION CONTROL

- i) Please indicate numerical values which, in your opinion, define the upper and lower limits of acceptable operation for this type of intersection control for each of the following variables. Please ensure that the relevant units of measurement are indicated. Indicate NR if variable is irrelevant.

	Maximum	Minimum
Major Street Vehicle Volume	_____	_____
Minor Street Vehicle Volume	_____	_____
and/or Major/Minor Ratio	_____	_____
Pedestrians Crossing Major Street	_____	_____
Pedestrians Crossing Minor Street	_____	_____
Minor Street Delay	_____	_____
Total Accidents Per Year	_____	_____
Total Angle Accidents Per Year	_____	_____
Total Personal Injuries Per Year	_____	_____
Minor Street Safe Approach Speed	_____	_____
Major Street Vehicle Speed	_____	_____
Minor Street Vehicle Speed	_____	_____

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- ii) Please indicate the maximum allowable for the following geometric conditions, which in your opinion, would allow acceptable operation of this type of intersection control,

Intersection Skew Angle _____

Number of Intersection Approaches _____

Number of Lanes on Minor Street _____

Number of Lanes on Major Street _____

Grade on Any Approach _____

- iii) In general, at what types of intersections would this type of control be appropriate (e.g. - major/major, major/minor or arterial/arterial, collector/local; etc.)?
- _____
- _____
- _____

- iv) Would this type of traffic control be considered for applications other than at an intersection to control vehicle and pedestrian traffic, and if so, in what instances? Yes ☐ No ☐
- _____
- _____
- _____

- v) What, in your opinion, are situations where the application of this form of traffic control should be avoided?
- _____
- _____
- _____

- vi) In your opinion, do the existing warrant systems provide adequately for the application of this form of traffic control? Yes ☐ No ☐
- If you feel that they do, please indicate which system you feel is best; if not, please indicate what you feel the deficiencies are.
- _____
- _____
- _____

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V STOP TYPE INTERSECTION CONTROL

- i) Please indicate numerical values which, in your opinion, define the upper and lower limits of acceptable operation for this type of intersection control for each of the following variables. Please ensure that the relevant units of measurement are indicated. Indicate NR if variable is irrelevant.

	Maximum	Minimum
Major Street Vehicle Volume	_____	_____
Minor Street Vehicle Volume	_____	_____
and/or Major/Minor Ratio	_____	_____
Pedestrians Crossing Minor Street	_____	_____
Pedestrians Crossing Major Street	_____	_____
Minor Street Delay	_____	_____
Total Accidents Per Year	_____	_____
Total Angle Accidents Per Year	_____	_____
Total Personal Injuries Per Year	_____	_____
Minor Street Safe Approach Speed	_____	_____
Major Street Vehicle Speed	_____	_____
Minor Street Vehicle Speed	_____	_____

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- ii) Please indicate the maximum allowable for the following geometric conditions, which in your opinion, would allow acceptable operation of this type of intersection control.

Intersection Skew Angle	_____
Number of Intersection Approaches	_____
Number of Lanes on Minor Street	_____
Number of Lanes on Major Street	_____
Grade on Any Approach	_____

- iii) In general, at what types of intersections would this type of control be appropriate (e.g. - major/major, major/minor or arterial/arterial, collector/local, etc.)?

- iv) Would this type of traffic control be considered for applications other than at an intersection to control vehicle and pedestrian traffic, and if so, in what instances? Yes ☐ No ☐

- v) What, in your opinion, are situations where the application of this form of traffic control should be avoided?

- vi) In your opinion, do the existing warrant systems provide adequately for the application of this form of traffic control? Yes ☐ No ☐
If you feel that they do, please indicate which system you feel is best; if not, please indicate what you feel the deficiencies are.

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VI MULTI-WAY STOP TYPE INTERSECTION CONTROL

- i) Please indicate numerical values which, in your opinion, define the upper and lower limits of acceptable operation for this type of intersection control for each of the following variables. Please ensure that the relevant units of measurement are indicated. Indicate NR if variable is irrelevant.

	Maximum	Minimum
Major Street Vehicle Volume	_____	_____
Minor Street Vehicle Volume	_____	_____
and/or Major/Minor Ratio	_____	_____
Pedestrians Crossing Minor Street	_____	_____
Pedestrians Crossing Major Street	_____	_____
Minor Street Delay	_____	_____
Total Accidents Per Year	_____	_____
Total Angle Accidents Per Year	_____	_____
Total Personal Injuries Per Year	_____	_____
Minor Street Safe Approach Speed	_____	_____
Major Street Vehicle Speed	_____	_____
Minor Street Vehicle Speed	_____	_____

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- ii) Please indicate the maximum allowable for the following geometric conditions, which in your opinion, would allow acceptable operation of this type of intersection control.

Intersection Skew Angle _____

Number of Intersection Approaches _____

Number of Lanes on Minor Street _____

Number of Lanes on Major Street _____

Grade on Any Approach _____

- iii) In general, at what types of intersections would this type of control be appropriate (e.g. - major/major, major/minor or arterial/arterial, collector/local, etc.)?
- _____
- _____
- _____

- iv) Would this type of traffic control be considered for applications other than at an intersection to control vehicle and pedestrian traffic, and if so, in what instances? Yes ☐ No ☐
- _____
- _____
- _____

- v) What, in your opinion, are situations where the application of this form of traffic control should be avoided?
- _____
- _____
- _____

- vi) In your opinion, do the existing warrant systems provide adequately for the application of this form of traffic control? Yes ☐ No ☐
- If you feel that they do, please indicate which system you feel is best; if not, please indicate what you feel the deficiencies are.
- _____
- _____
- _____

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VII TRAFFIC CONTROL SIGNALS

- i) Please indicate the numerical values which, in your opinion, define the upper and lower limits of acceptable operation for this type of intersection control for each of the following variables. Please ensure that the relevant units of measurement are indicated. Indicate NR if variable is irrelevant.

	Maximum	Minimum
Major Street Vehicle Volume	_____	_____
Minor Street Vehicle Volume	_____	_____
and/or Major/Minor Ratio	_____	_____
Pedestrians Crossing Minor Street	_____	_____
Pedestrians Crossing Major Street	_____	_____
Minor Street Delay	_____	_____
Total Accidents Per Year	_____	_____
Total Angle Accidents Per Year	_____	_____
Total Personal Injuries Per Year	_____	_____
Minor Street Safe Approach Speed	_____	_____
Major Street Vehicle Speed	_____	_____
Minor Street Vehicle Speed	_____	_____

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- ii) Please indicate the maximum allowable for the following geometric conditions, which in your opinion, would allow acceptable operation of this type of intersection control.

Intersection Skew Angle _____

Number of Intersection Approaches _____

Number of Lanes on Minor Street _____

Number of Lanes on Major Street _____

Grade on Any Approach _____

- iii) In general, at what types of intersections would this type of control be appropriate (e.g. - major/major, major/minor or arterial/arterial, collector/local, etc.)?
- _____
- _____
- _____

- iv) Would this type of traffic control be considered for applications other than at an intersection to control vehicle and pedestrian traffic, and if so, in what instances? Yes ☐ No ☐
- _____
- _____
- _____

- v) What, in your opinion, are situations where the application of this form of traffic control should be avoided?
- _____
- _____
- _____

- vi) In your opinion, do the existing warrant systems provide adequately for the application of this form of traffic control? Yes ☐ No ☐
If you feel that they do, please indicate which system you feel is best; if not, please indicate what you feel the deficiencies are.
- _____
- _____
- _____

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VIII TRAFFIC STUDIES

- i) Please indicate which of the following studies are currently used in your jurisdiction to review requests for intersection control. Include, where appropriate, comments concerning the study such as time or duration. The type of intersection control for which you feel each type of study is appropriate should also be circled.

Type of Study	Usage		Type of Control						Comments
No Studies	Yes	No	NC	Y	S	MS	TS		
Vehicle Volume Count	Yes	No	NC	Y	S	MS	TS		
Pedestrian Volume Count	Yes	No	NC	Y	S	MS	TS		
Observance Study	Yes	No	NC	Y	S	MS	TS		
Visibility Study	Yes	No	NC	Y	S	MS	TS		
Accident Analysis	Yes	No	NC	Y	S	MS	TS		
Pedestrian Delay Study	Yes	No	NC	Y	S	MS	TS		
Vehicle Delay Study	Yes	No	NC	Y	S	MS	TS		
Other (Specify)	Yes	No	NC	Y	S	MS	TS		

- ii) What, in your opinion, is the minimum, or most appropriate, type of study for each type of intersection control?

No Control _____

Yield Control _____

Stop Control _____

Multi-way Stop _____

Traffic Control Signal _____

ANNEX C

RELEVANT EXCERPTS OF THE ONTARIO MANUAL OF UNIFORM TRAFFIC CONTROL DEVICES

A 2.12 "YIELD" SIGN (Ra-2)

At intersections where it is found that the normal right-of-way rule does not provide safe, convenient and efficient traffic movement and that a stop regulation at one or more of the approaches is too restrictive, a YIELD sign can be an effective control device.

Vehicles approaching the sign must yield right-of-way at the intersection to oncoming vehicles on the priority road and stop if necessary.

Before using a YIELD sign as a substitute for the normal right-of-way rule or for a STOP sign, consideration must be given to its suitability in relation to traffic volume, speed, visibility, sight distance and collision record of the intersection.

The YIELD sign can be considered for use in "assigning" the right-of-way at an intersection where at least the following warrants exist:

- (1) The view at the intersection permits a "safe approach speed", on the approach having the minor volume, of 15 km/hr or more.
- (2) The occurrence of an average of at least two collisions per year resulting from conflict between intersecting traffic streams not found preventable by less restrictive means.

- (3) At a channelized intersection where a separate one way right turn leg enters the through highway on a steep grade or without an adequate lane to allow for acceleration up to the speed of through traffic.

The YIELD Sign shall be used only on the recommendation and approval of responsible traffic officials. Municipalities must secure legal approval of the yield sign by municipal by-law. For further information, pertinent to the legal requirements for the erection of a yield sign, refer to statutes of ONTARIO REGULATION 668/78.

The minimum size YIELD sign (Ra-2) shall be used at qualifying intersections between minor municipal streets or low volume rural road intersections.

The oversize YIELD sign (Ra-102) shall be used at qualifying intersections of Provincial Highways, County Roads, Major Township Roads or other major roads with or without channelized right turn legs.

The educational tab signs (Ra-2t, Ra-102t) shall be used until such time that the meaning of the symbol has become sufficiently familiar to the driving public.

All YIELD signs shall be reflectorized to show the same colour and shape by night and by day.

A 2.11 "STOP" SIGN (Ra-1)

Warrants for STOP signs have not yet been scientifically established and, therefore, no recommended practice is available. In general, however, STOP signs are warranted in the following circumstances.

- (a) on a street intersecting a through highway or through street;
- (b) at a minor intersection where, due to restricted view, the "safe approach speed" is less than 15 km/h and the collision experience indicates the need for STOP sign control;
- (c) where the configuration of the intersection or traffic volumes require a more positive stipulation of right-of-way rather than the basic right-of-way rule.

When two major streets or highways intersect, and there is no priority to determine which direction should be stopped, a thorough study should be made.

Where the one road intersects another road at an acute angle, the STOP sign on the intersecting road should be turned or shielded so that it cannot be read by motorists travelling on the priority road.

A STOP sign shall always be erected at the point where the vehicle is to stop, or as near thereto as possible. It may be supplemented with a Stop Line if it controls traffic, approaching a major intersection. In no case shall a STOP sign be placed further than 15 m from the near edge of the intersecting roadway. Reference should be made to Ontario Regulation 668/78 or amendments thereto for the legal requirements concerning the erection of STOP signs.

The minimum size STOP sign (Ra-1) shall be erected on municipal streets and/or minor low speed gravel roads intersecting designated Local through roads in urban or rural areas.

The oversize STOP sign (Ra-101) shall be erected on all public roads in rural areas, intersecting a Provincial Highway. It shall also be used at the junction of two Major County Roads or Regional Roads, freeway ramps and at the junction of two Provincial Highways in rural areas.

The special oversize STOP sign (Ra-1101) shall be erected at the junction of two major Provincial Highways in rural areas.

Restricted visibility of the STOP sign at any location as well as other traffic or physical conditions, specified in Section A 3.51 of this Manual shall determine the need for STOP AHEAD signs.

STOP signs shall not be erected at intersections where traffic control signals are present. The conflicting commands of two types of control devices are confusing. If traffic is required to stop when the operation of STOP and GO signals is not warranted the signals should be put on flashing operation with the red indication facing the traffic that must stop.

Typical Locations of STOP signs are illustrated in Figure A-3. (see Section A 1.15).

ALL STOP signs shall be reflectorized to show the same colour and shape by night as by day.

PART B

DIVISION 2 — INSTALLATION WARRANTS FOR
TRAFFIC CONTROL SIGNALS**B 2.Q1 TYPES OF TRAFFIC CONTROL
SIGNALS****B 2.01.01 Fixed Time Traffic Signal**

A Fixed Time signal is a traffic control signal which directs traffic to stop and permits it to proceed in accordance with a single predetermined time schedule or a series of such schedules.

Operational features of fixed time signals, such as cycle length, split, sequence, offset, etc., can be changed according to a predetermined program.

B 2.01.02 Traffic-Actuated Traffic Signals

A Traffic-actuated signal is a traffic control signal which operates in accordance with the varying demands of traffic as determined by means of detectors or pushbuttons.

(a) Semi-Traffic-Actuated Control

Semi-traffic-actuated control is applicable to an intersection of a heavy-volume, high speed traffic artery with a relatively lightly travelled minor road or street. Detectors are located only on the minor approaches. The signal is normally green on the major street, changing to the minor street only as a result of vehicle or pedestrian actuation thereon. In some types of controls, the minor-street green interval is of fixed duration, which is undesirable. In the more flexible types, the duration of the minor-street green interval is proportioned to the traffic demand thereon, with provision for a maximum limit beyond which the green light cannot be retained on the minor street even when traffic demand thereon is heavy. Upon the expiration of the required or maximum minor-street phase, the green indication reverts to the major street, where it must remain for at least a predetermined minimum interval. At the expiration of this minimum interval, the control is again free to respond to minor-street actuation. The semi-traffic-actuated control mechanism receives no actuation from traffic on the major street, and therefore may frequently assign the right-of-way to the minor street at the most inopportune time for major street traffic. Hence, the effective use of semi-traffic actuated control

travelled minor streets and to intersections in co-ordinated systems where major-street progression can be assured by means of a background cycle in a co-ordinated traffic signal system.

(b) Full Traffic-Actuated Control

Semi-traffic actuated control does not detect and measure the demands of all traffic streams, and full traffic actuated control therefore should be selected for intersections where failure to take all demands into account will materially impair the efficiency of traffic movement. In full traffic-actuated control, detectors are installed on all approaches to the intersection. Right-of-way is assigned to a street only as a result of one or more actuations on that street. When there is no traffic on any street, the green indication will ordinarily remain upon the street to which it was last assigned, but when one street carries substantially more traffic, it may be more efficient to return the right-of-way to that street. In the event of continued actuation on one street, transfer of right-of-way will be made to waiting cross traffic upon the expiration of a predetermined maximum period, and then automatically return to the first street at the earliest opportunity. This opportunity cannot arise until a predetermined minimum green period on the cross street has expired.

The duration of the green indication for each street under normal traffic will fluctuate between the prescribed minimum and maximum values, depending upon the length of time between actuations on the street having the right-of-way. Under the more common type of full traffic-actuated control, the right-of-way will, upon actuations, be immediately transferred to the cross street if the length of time between actuations on the street having the green exceeds a predetermined value, and the minimum period for that street has expired. Hence, the right-of-way is switched from street to street depending upon the frequency of gaps in traffic which exceed in length the predetermined time values for each street. With heavy traffic, such gaps are relatively infrequent and the green periods are extended to their maximums. Under this condition, traffic actuated signal operation

The traffic-density type of full traffic-actuated control provides that the predetermined gap interval described above will diminish during each phase depending upon a number of traffic factors. Thus, the probability that the green period will be terminated and the right-of-way transferred to the other street is increased by a thinning out of traffic moving on the green signal, by the passage of time during which traffic has been waiting on the red signal, and by the number of cars waiting on the red signal. These and other factors make the traffic-density full traffic-actuated control highly sensitive to traffic requirements under wide ranges of traffic volumes.

Full traffic-actuated control of either type can be applied to more than two-phase operations. Equipment is available for three and four-phase intersections. Operation of controllers at such intersections is similar in principle to operation at two-phase intersections. Opportunity for the right-of-way is accorded to the several phases in rotation and phases for which there is no traffic demand are skipped. In three or four phase controls, provision can be made for allowing additional non-interfering traffic flows to move during more than one phase. Thus, a three-phase control may handle four or five flows, provided only three of them are commonly interfering. Pedestrian actuation should be provided where necessary to assure a minimum green period of sufficient length for pedestrians or to establish pedestrian intervals (Section B 4 03).

B 2.02 TRAFFIC STUDIES

In order to ensure that any proposed traffic signal installation is necessary and advisable and to furnish necessary data for the proper design and operation of a signal that is found to be warranted, the following comprehensive information, at least, should be available concerning the location in question

- (a) The number of vehicles entering the intersection in each hour from each approach during any eight hours of a representative day. The eight hours selected should contain the greatest percentage of the 24-hour traffic.
- (b) Vehicular volumes for each traffic movement from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, and public-transit vehicles), during each fifteen minute period of the two hours in the morning and of the two hours in the afternoon during which traffic entering the intersection is greatest.

- (c) Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in paragraph (b) above and also during hours of highest pedestrian volume. Where young or elderly persons need special consideration, the pedestrians may be classified by general observation and recorded by age groups as follows:

- (i) Under 13 years
- (ii) 13 to 60 years
- (iii) Over 60 years

- (d) The 85-percentile speed of all vehicles on the uncontrolled approaches to the intersection.
- (e) A condition diagram showing details of the physical layout, including such features as intersection geometrics, channelization, grades, sight-distance restrictions, bus stops and routings, parking conditions, pavement markings, street lighting, driveways, location of nearby railway crossings, distance to the nearest signals, utility poles and fixtures and adjacent land use.
- (f) A collision diagram showing accident experience by type, location, direction of movement, severity, time of day, date, and day of week for at least three years.

When these data have been collected and evaluated, the results should be compared with the warrants set out below. Unless one or more of these warrants are met to the required extent, the installation should not be proceeded with since it will probably serve no useful purpose and may even hinder traffic movement with consequent congestion and possibility of accidents.

When applying the warrants, the main street should be taken as the street carrying the greatest hourly volume, or, where the intersecting volumes are approximately equal, the street having the least restrictive form of existing control. All studies should be conducted on a normal day; i.e., one on which no special event takes place which might produce unusual traffic conditions.

At locations with heavy seasonal variations, considerations may be given to the aspect of fulfillment of warrants based on seasonal peaks and studies should be conducted during these peaks.

B 2.03 INSTALLATION WARRANTS FOR TRAFFIC CONTROL SIGNALS

The warrants for traffic signals have been developed for two types of conditions: Restricted Flow Conditions and Free Flow Conditions. This division

is necessary due to the different operating characteristics which exist under each condition

Restricted Flow Conditions are those which are normally encountered in urban areas and some suburban areas where the traffic volumes approach or exceed the practical working capacity of the roadway. Restricted Flow Conditions apply only if the 85th percentile speed of the artery traffic is 60 km/h or less.

Free Flow Conditions are those which are normally encountered in rural areas. The basic limitation on vehicle operation lies with the driver himself. Free Flow Conditions apply at any intersection where the 85th percentile speed of the artery traffic exceeds 60 km/h. However, the Ministry also recognizes that the driving characteristics in small communities are different than those in larger urban areas. Therefore, free flow conditions will be used for an intersection within the built-up area of a community having a population of less than 10 000 and outside the commuting influence of a large urban centre, even if the operating speed is less than 60 km/h.

The installation of traffic control signals at any location will be justified and will probably prove beneficial when any one of the following warrants, vehicular, delay, pedestrian or accident, is completely satisfied. These warrants are summarized on the traffic signal warrant sheet - Section 2.03.07. In the application of these warrants the following principles must be observed

- (a) Only vehicles entering the intersection - whether they turn right, go straight through or turn left - should be considered. If the right turns are channelized by means of physical islands, they are not considered to enter the intersection and therefore should not be included in any warrant calculations.
- (b) Right turns are not considered as traffic crossing the artery, therefore they should be deleted from the combined pedestrian and vehicle volume in the Delay to Cross Traffic Warrant. In one-way street systems left turns from a one-way street into another one-way street should be treated similar to right turns and should also be deleted from this warrant.
- (c) The minimum warrant values for the volume on the artery are for two-lane, two-way roadways. Vehicle volume warrants for intersections of multi-lane roadways having two or more moving lanes in one direction on the artery should be 25% higher. Two-lane, two-way roadways with exclusive left turn lanes are not classified as multi-lane roadways.

B 2.03.01 Minimum Vehicular Volume Warrant

Restricted Flow

Total vehicular volume entering the intersection from

all approaches must average at least 720 vehicles per hour for any eight hours of an average day, and;

Total vehicular volume entering the intersection from the minor street or streets must average at least 170 vehicles per hour for the same eight hours.

Free Flow

Total vehicular volume entering the intersection from all approaches must average at least 480 vehicles per hour for any 8 hours of an average day

Total vehicular volume entering the intersection from the minor road or roads must average at least 120 vehicles for the same eight hours

B 2.03.02 Delay to Cross Traffic Warrant

Restricted Flow

At an intersection operating under restricted flow conditions, the vehicle volume along the major road must average at least 720 vehicles per hour for any eight hours of an average day, and;

The combined vehicle and pedestrian volume crossing the major road must average at least 75 units per hour for the same eight hours.

Free Flow

At an intersection operating under free flow conditions, the vehicle volume along the major road must average at least 480 vehicles per hour for any eight hours of an average day, and;

The combined vehicle and pedestrian volume crossing the major road must average at least 50 units per hour for the same eight hours.

B 2.03.03 Minimum Pedestrian Volume Warrant

Restricted Flow

The pedestrian volume crossing the major road must average at least 240 persons per hour for any eight hours of an average day, and;

Vehicular traffic entering from the major road must average at least 575 vehicles per hour for the same eight hours.

Free Flow

The pedestrian volume crossing the major road must average at least 120 persons per hour for any eight hours of an average day, and;

Vehicle traffic entering from the major road must average at least 290 vehicles per hour for the same eight hours.

B 2.03.04 Accident Hazard

While an accident situation alone seldom justifies signal control, the installation of traffic control signals may be warranted when every one of the following conditions is satisfied

- (a) Five or more reported accidents of types preventable by traffic control signals have occurred within a 12 month period, each accident involving personal injury or property damage to an apparent extent of \$400 or more.
- (b) Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce accident frequency
- (c) There exists a volume of vehicular and pedestrian traffic not less than 80% of the requirements specified in the minimum vehicular volume warrant, the delay to cross traffic warrant, or the minimum pedestrian volume warrant

In determining the accidents occurring within a twelve month period the average experience for three years is to be used, i.e., total accidents for three years divided by three.

Preventable accidents are those involving traffic which under signalized conditions would move on completely different phases. Less restrictive measures which should be tried before signals are installed include the improvement of control or warning signs, installation of flashing beacons, the provision of safety or channelizing islands, the improvement of street lighting, and the prohibition of parking and/or turns.

The installation of traffic signals will seldom be justified on the accident warrant alone and it should be remembered that their operation may even increase the intersection accident rate due to rear-end collisions, etc., caused directly or indirectly by the signal operation.

B 2.03.05 Combination Warrant

Signals may occasionally be justified where no one warrant is satisfied, but two or more are satisfied to the extent of 80% or more of the stated values, particularly if there are present other important factors, such as

- (a) A sudden change from rural conditions, to those of an urban business district;
- (b) Extreme width of roadway which pedestrians must cross.
- (c) Predominance of handicapped pedestrians, such as small children, or blind, aged, or crippled adults who need to cross the roadway.
- (d) An intersection on, or at the bottom of, a long steep grade.

B 2.03.06 Progressive Signal System Warrant

The installation of traffic control signals may be warranted to encourage or improve progressive movement of traffic along a major street when the signalization will tend to establish or maintain the platooning of vehicles proceeding at a predetermined desirable rate of speed.

Traffic control signals installed for this purpose should operate on a fixed time basis, since one of their most important functions will be to provide sufficient gaps in the main street flow to allow safe crossing at non-signalized locations in the controlled area. The system should be interconnected in order to ensure the maintenance of the progression and thus to minimize any vehicular delay.

B 2.03.07 Minimum Warrants for Installation of Traffic Signals for Two-Lane Roadways

WARRANT	DESCRIPTION	Minimum Requirement for 2-Lane Highways		Compliance	
		Free Flow	Restricted Flow	Sectional Numerical %	Entire %
1 MINIMUM VEHICULAR VOLUME	A Vehicle volume, all approaches per hour for 8 hours, and	480	720		
	B Vehicle volume, along minor streets, per hour for same 8 hours	120	170		
2 DELAY TO CROSS TRAFFIC	A Vehicle volume, along artery, per hour for 8 hours, and	480	720		
	B Combined vehicle and pedestrian volume crossing artery from minor streets, per hour for same 8 hours	50	75		
3 MINIMUM PEDESTRIAN VOLUME	A Pedestrian volume crossing artery, per hour for 8 hours, and	120	240		
	B Vehicle volume, along artery per hour for 8 hours	290	575		
4 ACCIDENT HAZARD	A Total reported accidents of types susceptible to correction by a traffic signal within a 12 month period, and	5			
	B Adequate trial of less restrictive remedies, where satisfactory observance and enforcement have failed to reduce the number of accidents, and	Yes	or No		
	C Fulfillment of any of the above warrants (Numbers 1, 2, or 3) to the extent of 80% or more	Yes	or No		
5 COMBINATION WARRANT	Two or more of above warrants (Number 1, 2, 3, or 4) satisfied to the extent of 80% or more	Yes	or No		

Note (a) Warrant values are based on the Annual Average Daily Traffic (A.A.D.T.) which approximates May and October traffic. Counts taken other

(b) The lowest sectional percentage governs the first four (4) warrants and should be shown in the Entire % column for that particular

**B 2.04 PROBABLE PERCENTAGE OF
VEHICLES DELAYED AT A
SIGNALIZED INTERSECTION**

- The number of vehicles per hour able to approach and enter the intersection without stopping or with only a short stop made for reasons of safety rather than necessity should be counted. This number expressed as a percentage of the total hourly volume entering from the approach and subtracted from 100 will then be the percentage delay. A vehicle stopped behind another should be counted as delayed even though on reaching the intersection it is able to proceed without further delay. If desired, separate counts may be taken to show the delay experienced by vehicles making right turns, left turns, and through movements. Where right turn lanes and/or cut-offs are provided, the delay study should normally include left and through movements only and the result should be expressed as a percentage of the left and through volume. In certain cases where it is obvious that a back-up of vehicles waiting to make these left and through movements is causing delay to the right turns, all movements should be included in the study.

A vehicular delay study carried out in this way will be self-compensating for such variable conditions as poor visibility, excessive speeds, bad road surface leading to slow starts, driver characteristics and presence of nearby signals creating artificial crossing opportunities.

Delay due to signal operation can be determined from Table B 1. The suitability of the intersection for signalization can usually be determined from the intersection plan and profile. Special note should be taken of any physical feature, such as grades and restricted visibility or complexity, which might render the installation inefficient or even dangerous. Other special conditions such as high approach speeds must also be considered. In all cases where the use of more than two phases would appear necessary, an attempt should be made to simplify the intersection either by channelization or by turn prohibitions and/or the creation of one way streets.

TABLE B-1

**PROBABLE PERCENTAGE OF VEHICLES DELAYED
AT A SIGNALIZED INTERSECTION**

Sum of the Equivalent Hourly Volume in the Heavy Direction on All Other Signal Phases	Percentage of Vehicles Delayed on any Approach when the Equivalent Hourly Volume entering the intersection from that Approach is											
	50	100	150	200	250	300	350	400	450	500	550	600
200	54	55	55	55	—	—	—	—	—	—	—	—
250	59	57	57	57	58	—	—	—	—	—	—	—
300	61	59	59	58	60	59	—	—	—	—	—	—
350	63	61	61	60	62	61	60	—	—	—	—	—
400	64	63	62	62	64	63	62	62	—	—	—	—
450	66	64	64	64	66	65	65	64	65	—	—	—
500	68	66	66	66	68	67	67	66	67	66	—	—
550	70	68	68	68	70	69	69	68	69	68	69	—
600	72	70	70	70	72	71	71	70	71	71	71	71
650	73	72	72	72	74	73	73	73	74	73	74	73
700	75	73	74	74	76	75	75	75	76	75	76	75
750	77	75	75	76	78	77	77	77	78	78	79	78
800	79	77	77	77	80	79	79	79	80	80	81	80
850	81	79	79	79	82	81	81	81	83	82	83	83
900	82	81	81	81	84	84	83	83	85	85	86	85
950	84	82	83	83	86	86	86	85	87	87	88	88
1000	86	84	85	85	88	88	88	88	89	89	91	90

NOTE — (a) This table is based on the relationship

$$D_s = \frac{69.43 (1440 + V_{et} - V_{ex})}{(2000 - V_{ex})}$$

Where

D_s is the percentage of vehicles delayed on Phase X
 V_{et} is the sum of the equivalent hourly volume in the heavy direction on all other phases
 V_{ex} is the equivalent hourly volume in the heavy direction on Phase X

(b) Equivalent hourly volume is given by

$$V_c = \frac{(V + 0.5H + 0.6L + 0.2R)}{N}$$

Where

V is the total approach volume in the heavy direction
 H is the number of heavy trucks and transit vehicles
 L is the number of left-turning vehicles
 R is the number of right-turning vehicles
 N is the number of usable traffic lanes

ANNEX D

RELEVANT EXCERPTS OF THE CANADIAN MANUAL OF
UNIFORM TRAFFIC CONTROL DEVICES

REGULATORY SIGNS

A2.01**APPLICATION OF REGULATORY SIGNS**

Regulatory Signs shall indicate a traffic regulation which applies at a specific time or place upon a street or highway, disregard of which regulation constitutes a violation.

They are essential to indicate the applicability of legal requirements that may not otherwise be apparent. Due care must be exercised to ensure that they are erected whenever needed to fulfill this purpose but unnecessary mandates should be avoided.

Regulatory signs shall be erected at those locations where the regulations apply and shall be easily visible to the motorist. The message on the sign shall clearly indicate the requirements imposed by the regulation. Signs that have been erected but are no longer applicable shall be removed. All regulations indicated by the signs should be zealously enforced. Otherwise, no matter how effectively the signs may be designed and placed, the results desired will not be obtained.

Although applicable regulations differ widely from one location to another, depending on traffic requirements, highway conditions and local legislation, it is possible to establish uniform standards of application, location, size, shape, colour and dimension for different types of regulatory signs in order that the motorist can always recognize them quickly and be governed accordingly.

A2.02**CLASSIFICATION OF REGULATORY SIGNS**

Regulatory signs are classified in this manual into the following sub-classes (See Section A1.03).

Sub Class RA — Right-Of-Way Control

This sub class includes those signs which indicate the right-of-way of vehicle drivers on the approach to an intersection, or of pedestrians at a crosswalk.

Sub Class RB — Road Use Control

This sub class includes those signs which indicate the permitted or prohibited use of a street or highway. Included are signs which relate to,

With few exceptions, regulatory signs shall be designed in accordance with the general specifications set forth in Sections A1 05, A1 06, A1 07, A1 08, A1 09, A1 10, A1 11 and A1 14. With the exception of a few special signs such as the Stop sign, the Yield sign, and the One-Way sign, all regulatory signs are rectangular in shape with the longer dimension vertical and they are comprised of either red, green or black message content on a white background.

In certain cases a reverse screening process is specified (white legend on black background) in order to increase effectiveness. Such cases include the Night speed limit sign and the Overhead lane designation signs.

Minimum dimensions are presented in the following sections for each sign. Where conditions require increased visibility or where the required message cannot be adequately accommodated on a smaller area, larger signs may be used. All dimensions shall be increased proportionately.

LOCATION OF REGULATORY SIGNS

Regulatory signs shall be located in accordance with Section A1 15, Section A1 16, and A1 17. Additional location requirements for certain regulatory signs are set forth in the section dealing with the particular sign where applicable.

RIGHT-OF-WAY CONTROL

Right-Of-Way Control signs as contained in this section shall indicate the right-of-way of vehicle drivers and/or pedestrians as appropriate.

They shall be erected in accordance with the general specifications for regulatory signs (Sections A1 15, A1 16, and A1 17).

Stop Sign (RA-1)

The Stop sign shall indicate that vehicle drivers facing the sign shall stop their vehicles completely before entering the intersection area and shall not proceed until it is clearly safe to enter the intersection.

Although the Council has not as yet established a recommended practice of application, nonetheless the following general rules apply:

RA-1
60 x 60 cm

1. The Stop sign may be used facing traffic on a minor street or highway, intersecting a through street or highway.
2. The Stop sign may be used at a minor intersection, where due to limited sight visibility, the safe vehicular approach speed is less than 15 km/h and the accident experience indicates the need for Stop sign control.
3. At intersections where no priority exists to determine which direction should be stopped a thorough study should be undertaken.
4. Stop signs shall not be erected at intersections controlled by Traffic control signals since the conflicting meanings of the two devices would cause confusion.

Over-size stop signs may be used only in special circumstances where more than average attention value is required from the sign, eg. where a Stop sign is erected among a group of large signs at a channelized intersection, or on the approaches to the junction of numbered routes where a stop is required.

A Stop sign shall always be erected at the point where the vehicle is to stop, or as near thereto as possible. It may be supplemented with a stop line if located at a major intersection. In no case shall a Stop sign be placed further than 15 m from the near edge of the intersecting roadway.

Where an intersection involves an acute angle, the Stop sign shall be so placed to avoid confusion to drivers on the major road. If visibility of the sign is limited, an advance sign shall be located as specified in Section A3.51. A stop line (pavement marking) may be used to augment the sign at major intersections. In no case shall the sign be placed more than 15 m from the intersecting roadway. (See Figure A-3)

The Stop sign shall be octagonal in shape with a minimum dimension of 60 cm. It shall be comprised of white letters (minimum height of 20 cm) and border on a red background and shall be reflectorized or illuminated to show the same colour and shape by night as by day.

A2.12

Yield Sign (RA-2)

The Yield sign shall indicate to vehicle drivers facing the sign that they must yield the right-of-way, stopping if necessary before entering the intersection area, to on-coming traffic on the intersecting roadway.

At intersections where it is found that the normal right-of-way rule does not provide safe, convenient and efficient traffic movement and that a stop regulation at one or more of the approaches is too restrictive, a Yield sign can be an effective control device.

Before using a Yield sign as a substitute for the normal right-of-way rule or for a Stop sign, consideration must be given to its suitability in relation to traffic volume, speed, visibility, sight distance and accident record of the intersection.

The Yield sign shall be an inverted triangle with sides 75 cm long. A tab sign RA-2T shall be used for an education period (See bilingual and French signs for additional tab messages). The sign shall be reflectorized or illuminated to show the same colour and shape by night as by day.

RA-2

75 x 75 cm

RA-2T

45 x 22.5 cm

INSTALLATION WARRANTS FOR TRAFFIC CONTROL SIGNALS

B2.01

NEED FOR A WARRANT AND PRIORITY RATING SYSTEM

The effects of traffic signal operation are the most complex of any traffic control device. Traffic signals exert a major influence on motorists and pedestrians with respect to such factors as safety, delay, and transportation costs. A traffic signal may also affect the movements of motorists and pedestrians at points in excess of 800 m from the traffic signal location. When traffic signals are operated within close proximity to each other, such that their areas of influence overlap, the effects become much more complex.

The installation of a traffic signal is warranted when the net effect will be an improvement in the safe, convenient and economical movement of persons and goods. Experience has indicated that a traffic signal may decrease accidents, but at the same time increase delay and user costs. Sometimes, the reverse may be true. Therefore, if a net effect is to be determined, all factors of signal operation must be rated by some common denominator. It is desirable also to establish a priority for a list of possible locations in order to predict at what point in time conditions at a given location will satisfy the warrant and to determine the best allocation of the funds available for traffic signal installations.

Most important of all, the vigorous application of a comprehensive warrant rating system will foster the development of a geometrically efficient traffic signal system and thus of efficient traffic patterns. The benefits to be gained from this approach rather than the uncontrolled and incoherent traffic signal system which results when random and arbitrary traffic flows dictate the location of traffic signals, in other words, the development of a signal system by default instead of by design, are obvious.

B2.10

ESSENTIAL BASIC DATA AND DEFINITIONS

In order to determine, with the aid of the warrant rating system, whether or not a traffic signal is the appropriate control device for the study intersection, the following minimum amount of information is required:

B2.11

Physical Suitability of Intersection

The physical characteristics of the intersection and its approaches must be evaluated to determine whether a traffic signal can be operated safely and effectively. Examples of factors which might rule out signal control include the following:

- a) Steep grades on one approach leg could make the stopping or starting of motor vehicles difficult or impracticable, especially during adverse road and weather conditions.
- b) A severe skewed angle of intersection could result in excessively long vehicle and pedestrian clearance phases, and very inefficient signal operation.

- c) Offset intersection legs could result in excessively long vehicle and pedestrian clearance phases and undue conflict between vehicles and pedestrians, unless an inefficient multi-phase signal operation is used

B2.12

Accident Priority Points

P_a (determined from GRAPH A) is an index assigned to express the relative effect which the operation of a traffic signal would have on the accident rate at the study intersection

The datum required to use GRAPH A is a representative figure for the current number of total reportable accidents per year before signal installation at the study intersection. This figure can usually be most accurately determined by projecting the trend of the past 4 or 5 year period

B2.13

Crossing Gap, Signal Progression, Delay and Vehicular Stop Priority Points

ONE WAY STREET P_1 (determined from GRAPH B-1) is a qualitative index which expresses individually, for each one-way leg of an intersection, the net effect which the operation of a traffic signal would have upon

- a) the availability of crossing gaps at the intersection and at points remote from the study intersection
- b) the progression of vehicles along the street to or from other existing or proposed traffic signals
- c) the delay to vehicles on the street
- d) the number of stops to which vehicles are subjected by signal operation

TWO WAY STREETS P_2 (determined from GRAPH B-2) is a qualitative index which expresses individually, for each two-way leg of an intersection, the net effect which the operation of a traffic signal would have upon

- a) the availability of crossing gaps at the study intersection and at points remote from the intersection
- b) the progression of vehicles along the street, to and from other existing or proposed traffic signals
- c) the delay to vehicles on the street
- d) the number of stops to which vehicles are subjected by signal operation.

The following data are required for each leg of the intersection, for use in GRAPH B-1 or GRAPH B-2, in order to determine indices P_1 and P_2

- a) Distance to the nearest existing or proposed future traffic signal
- b) Likelihood that good progression between the nearest existing or proposed future traffic signal and the study intersection is attainable (for one-way streets only). In order to determine this factor, it is necessary to evaluate whether the offset of a traffic signal at the study location would result in the stopping of vehicles which otherwise would flow unhindered through the intersection. In the case of a variable system offset operation throughout the day, the offset operation which would accommodate the majority of daily vehicle movements should be used.
- c) Length of the system background cycle (for two-way streets only). The background cycle length which would be in operation for the period of the day during which the greatest total volume of vehicle movements would be accommodated should be used for this purpose. This is usually the "normal hour" cycle length. In cases where an isolated actuated traffic signal operation is proposed for the indefinite fu-

3 3
OF / DE

ture, and there will be no other traffic signals close enough to result in overlapping areas of influence. P_1 and P_2 should simply be assigned the maximum values of GRAPH B-1 or GRAPH B-2.

d) Desirable progression speed along the leg. (for two-way streets only).

Working Terms

1. V_{ew} is the average annual daily total vehicular volume on each individual leg of the east-west street, divided by 1 000.
2. V_{ns} is the average annual daily total vehicular volume on each individual leg of the north-south street, divided by 1 000.
3. F_{ew} is an expansion factor to account for the increase in vehicular volume which would occur within one year on the east-west street of the study intersection, due to the installation of a traffic signal.
4. F_{ns} is an expansion factor to account for the increase in vehicular volume which would occur within one year on the north-south street of the study intersection, due to the installation of a traffic signal.

V_{ew} and V_{ns} are meant to be representative figures for the twenty-four hour volume of vehicular traffic using the study intersection during the part of the year the proposed traffic signal would be operated. Normally, a traffic signal would operate all year long, and the appropriate figure would be the Average Annual Daily Total. These figures are derived by expanding short-term traffic counts to a twenty-four hour total, and then modifying this total further by the use of day-of-the-week and month-of-the-year adjustment factors. For this purpose, the short-term counts should be at least 7 hours long, and should include both the morning and evening rush hour periods. The appropriate expansion factors should be determined from data derived from permanent counting stations at key locations.

In areas having abnormal seasonal fluctuations, such as resort areas and their connecting roadways, it may be appropriate to operate a traffic signal for only a few months of the year, in which case representative figures for those few months should be used.

F_{ew} and F_{ns} are judgment factors for the purpose of reflecting the probable increase in vehicular volume on each street of the study intersection, due to an anticipated re-routing of motorists to use the newly signalized route. These factors may also be used to account for predictable increases in volume due to projected roadway widenings, new connections, etc. A catalogue of past experience should be compiled in order to improve judgment for future proposed traffic signal installations. The following general conditions will be found to exist.

- a) Traffic volumes on the former "through" street will not usually increase except for normal growth, and the factor for the "through" street is usually close to 1.0.
- b) In cases in which the former "stop" street had no undue delay problems, or was the only alternative for motorists on the route, the factor for the "stop" street may range from 1.0 to 1.3.
- c) In cases in which the former "stop" street motorists experienced appreciable delay, and other alternative routes suffered the same problems, the factor may range from 1.5 (low) to 2.0 (average) to 2.5 (high).

1. V_{aew} is the average annual daily total vehicular volume approaching the intersection on each individual leg of the east-west street, divided by 1 000
2. V_{ans} is the average annual daily total vehicular volume approaching the intersection on each individual leg of the north-south street, divided by 1 000.
3. P_{ew} is the average annual daily total pedestrian volume crossing the intersection in the east-west direction, divided by 1 000
4. P_{ns} is the average annual daily total pedestrian volume crossing the intersection in the north-south direction, divided by 1 000

(Average annual twenty-four-hour figures for V_{aew} , V_{ans} , P_{ew} and P_{ns} are derived as described above for V_{aew} and V_{ans} .)

5. F_r (determined from GRAPH C, for one-way through streets only) is a qualitative factor representing the probable randomness of arrival at the study intersection of a platoon of vehicles which has passed straight through the nearest up-stream traffic signal on a one-way street. (NOTE: For signal spacing beyond 450 m this factor becomes unity, and has no effect.)
6. F_l (determined from GRAPH C, for one-way through streets only) is a qualitative factor representing the effect of out-of-phase vehicular volumes in reducing the length of the gaps otherwise available between through platoons on a one-way street. (NOTE: For signal spacing beyond 450 m, this factor becomes 0, and has no effect.)
7. F_{ow} is a factor expressing the increased safety, capacity and facility of movement at the intersection of one-way streets, due to the smaller number of conflict points, as compared with two-way street intersections

If both streets are two-way, $F_{ow} = 1.0$

If the through street is two-way and the cross-street is one-way, $F_{ow} = 0.9$

If the through street is one-way and cross-street is two-way, $F_{ow} = 0.7$

If both streets are one-way, $F_{ow} = 0.6$

8. P_3 (determined from GRAPH D, for one-way through streets only) is a quantitative index which expresses the degree and amount of difficulty experienced by vehicles and pedestrians crossing a through one-way street at a study intersection downstream from an existing traffic signal, due to the through-street gap being interrupted by out-of-phase turns from the upstream traffic signal or other intermediate significantly large traffic generators, and by through-street pedestrians crossing the cross-street at the study location.

(Average annual twenty-four-hour vehicle and pedestrian volumes for use in GRAPH D are derived as described above for V_{aew} and V_{ans} .)

In order to determine the number of through-street pedestrians crossing the cross-street during the vehicle gap, for use in GRAPH D, it is assumed that pedestrian arrivals at the intersection are random, and that the number of pedestrians crossing the cross-street during the gap in through street traffic is

$$= \frac{\text{TOTAL THROUGH-STREET PEDESTRIANS CROSSING THE STREET} \times \text{CROSS-STREET VEHICLE PHASE LENGTH AT UP-STREAM TRAFFIC SIGNAL}}{\text{CYCLE LENGTH AT UP-STREAM TRAFFIC SIGNAL}}$$

CYCLE LENGTH AT UP-STREAM TRAFFIC SIGNAL

B2.20

TRAFFIC SIGNAL WARRANT AND PRIORITY RATING WORK SHEET (FORM B-1)

The basic data described above are combined and manipulated as indicated on the work sheet, (FORM B-1).

Complete I, the appropriate equation for each leg of the intersection in II A and/or II B, and either III A or III B.

Note that in II A and II B, for 4-leg intersections, only the four appropriate equations are calculated, and for 3-leg intersections only the three appropriate equations are calculated. For intersections having more than 4 legs, additional equations may be inserted. (It will often be found, however, that such complex intersections should be simplified by the closure of one or more legs, since the operation of such intersections, with or without traffic signals, is usually very inefficient.)

B2.21

Satisfaction of Installation Warrant

The installation of traffic signals at a study intersection is warranted when the total priority points equal or exceed 100 points.

The relative need or priority for traffic signal installations at a number of possible locations is indicated by the relative number of total priority points.

While the installation warrant and priority rating system provides a realistic technical analysis of the net effect of the installation of a traffic signal at a specific location, it is recognized that it can serve only as a tool to sharpen the judgment of the traffic engineer, and not as an irrefutable, complete and final answer which would obviate the need for experienced and objective analysis.

At intersections which satisfy the installation warrant for only part of the year, such as those at summer recreation areas, the traffic signal should be operated only during that part of the year during which conditions meet the installation warrant. At other times of the year, the traffic signal should be taken out of service, by removing or bagging the signal heads.

TRAFFIC SIGNAL INSTALLATION WARRANT AND PRIORITY RATING WORK SHEET

Location _____ Year _____ Date of Count _____

I Accidents (GRAPH A)

Priority points = P_a _____

II Crossing Gaps, Progression, Delay and Vehicular Stops

A. One-Way Street (GRAPH B-1)

Priority points	= $P_1 \times V_{lew} \times F_{ew}$
E-W street — E of int.	= _____ x _____ x _____ = _____
E-W street — W of int.	= _____ x _____ x _____ = _____
Priority points	= $P_1 \times V_{lms} \times F_{ms}$
N-S street — N of int.	= _____ x _____ x _____ = _____
N-S street — S of int.	= _____ x _____ x _____ = _____

B. Two-Way Street (GRAPH B-2)

Priority points	= $P_2 \times V_{lew} \times F_{ew}$
E-W street — E of int.	= _____ x _____ x _____ = _____
E-W street — W of int.	= _____ x _____ x _____ = _____
Priority points	= $P_2 \times V_{lms} \times F_{ms}$
N-S street — N of int.	= _____ x _____ x _____ = _____
N-S street — S of int.	= _____ x _____ x _____ = _____

III Crossing Gaps, Intersecting Volumes, and Pedestrian Volumes

A. Through Street One-Way (GRAPHS C and D)

1) Priority points

$$= (V_{aew} + P_{ew}) \times (V_{ans} + P_{ns}) \times F_{pw} \times F_r$$

$$= (_ + _) \times (_ + _) \times _ \times _ = _$$

2) Priority points

$$= P_3 \times F_t = _$$

B. Through Street Two-Way

Priority points

$$= (V_{aew} + P_{ew}) \times (V_{ans} + P_{ns}) \times F_{ow}$$

$$= (_ + _) \times (_ + _) \times _ = _$$

TOTAL PRIORITY POINTS _____

NOTE: Complete I, the appropriate equation for each intersection leg in Section II A and/or II B, and either Section III A or III B

* Maximum points for II = + 80

GRAPH A

ACCIDENT PRIORITY POINTS

VALUE OF INDEX P_a

GRAPH B-1

VALUE OF INDEX P_1
(ONE WAY STREETS).

EXAMPLE

If distance = 330 m
and progression is
attainable, then $P_1 = 2.2$

GRAPH B-2

VALUE OF INDEX P_2 (TWO WAY STREET)

NOTE: For use of this graph with speeds other than 50 km/h multiply
the actual distance by a ratio of $\frac{50}{\text{progression speed (km/h)}}$

GRAPH C

RANDOMNESS AND TURN FACTORS

EXAMPLE

If distance = 150 m
 then $F_t = 0.68$
 and $F_r = 0.32$

ANNEX E

RELEVANT EXCERPTS OF THE UNITED STATES MANUAL
OF UNIFORM TRAFFIC CONTROL DEVICES

R1-1
30" x 30"

R1-3
12" x 6"

R1-4
18" x 6"

2B-4 Stop Sign (R1-1)

STOP signs are intended for use where traffic is required to stop.

The STOP sign shall be an octagon with white message and border on a red background. The standard size shall be 30 x 30 inches. Where greater emphasis or visibility is required, a larger size is recommended. On low-volume local streets and secondary roads with low approach speeds, a 24 x 24 inch size may be used.

At a multiway stop intersection (sec. 2B-6), a supplementary plate (R1-3) should be mounted just below each STOP sign. If the number of approach legs to the intersection is three or more, the numeral on the supplementary plate shall correspond to the actual number of legs, or the legend ALL-WAY (R1-4) may be used. The supplementary plate shall have white letters on a red background and shall have a standard size of 12 x 6 inches (R1-3) or 18 x 6 inches (R1-4).

A STOP sign beacon or beacons may be used in conjunction with a STOP sign as described in section 4E-4.

Secondary messages shall not be used on STOP sign faces.

2B-5 Warrants for Stop Sign

Because the STOP sign causes a substantial inconvenience to motorists, it should be used only where warranted. A STOP sign may be warranted at an intersection where one or more of the following conditions exist:

1. Intersection of a less important road with a main road where application of the normal right-of-way rule is unduly hazardous.
2. Street entering a through highway or street.
3. Unsignalized intersection in a signalized area.
4. Other intersections where a combination of high speed, restricted view, and serious accident record indicates a need for control by the STOP sign.

STOP signs should never be used on the through roadways of expressways. Properly designed expressway interchanges provide for the

continuous flow of traffic, making STOP signs unnecessary even on the entering roadways. Where at-grade intersections are temporarily justified for local traffic in sparsely populated areas, STOP signs should be used on the entering roadways to protect the through traffic. STOP signs may also be required at the end of diverging roadways at the intersection with other highways not designed as expressways. In most of these cases, the speeds will not warrant any great increase in the sign sizes.

STOP signs shall not be erected at intersections where traffic control signals are operating. The conflicting commands of two types of control devices are confusing. If traffic is required to stop when the operation of the stop-and-go signals is not warranted, the signals should be put on flashing operation with the red flashing light facing the traffic that must stop.

Where two main highways intersect, the STOP sign or signs should normally be posted on the minor street to stop the lesser flow of traffic. Traffic engineering studies, however, may justify a decision to install a STOP sign or signs on the major street, as at a three-way intersection where safety considerations may justify stopping the greater flow of traffic to permit a left-turning movement.

STOP signs should not be installed indiscriminately at all unprotected crossings. The allowance of STOP signs at all such crossings would eventually breed contempt for both law enforcement, and obedience to the sign's command to stop. STOP signs may only be used at selected rail/highway grade crossings after their need has been determined by a detailed traffic engineering study. Such studies should consider approach speeds, sight distance restrictions, volumes, accident records, etc. This application of STOP signs should be an interim use period during which plans for lights, gates or other means of control are being prepared.

Portable or part-time STOP signs shall not be used except for emergency purposes. Also, STOP signs should not be used for speed control.

2B-6 Multiway Stop Signs

The "Multiway Stop" installation is useful as a safety measure at some locations. It should ordinarily be used only where the volume of traffic on the intersecting roads is approximately equal. A traffic control signal is more satisfactory for an intersection with a heavy volume of traffic.

Any of the following conditions may warrant a multiway STOP sign installation (sec. 2B-4):

- 1 Where traffic signals are warranted and urgently needed, the multiway stop is an interim measure that can be installed quickly to control traffic while arrangements are being made for the signal installation.

2. An accident problem, as indicated by five or more reported accidents of a type susceptible of correction by a multiway stop installation in a 12-month period. Such accidents include right- and left-turn collisions as well as right-angle collisions.

3. Minimum traffic volumes:

- (a) The total vehicular volume entering the intersection from all approaches must average at least 500 vehicles per hour for any 8 hours of an average day, and
- (b) The combined vehicular and pedestrian volume from the minor street or highway must average at least 200 units per hour for the same 8 hours, with an average delay to minor street vehicular traffic of at least 30 seconds per vehicle during the maximum hour, but
- (c) When the 85-percentile approach speed of the major street traffic exceeds 40 miles per hour, the minimum vehicular volume warrant is 70 percent of the above requirements.

2B-7 Yield Sign (R1-2)

The YIELD sign assigns right-of-way to traffic on certain approaches to an intersection. Vehicles controlled by a YIELD sign need stop only when necessary to avoid interference with other traffic that is given the right-of-way.

The YIELD sign shall be a downward pointing, equilateral triangle having a red border band and a white interior and the word YIELD in red inside the border band. The standard size shall be 36" x 36" x 36" inches.

R1-2
36" x 36" x 36"

2B-8 Warrants for Yield Signs

The YIELD sign may be warranted:

- 1. On a minor road at the entrance to an intersection where it is necessary to assign right-of-way to the major road, but where a stop is not necessary at all times, and where the safe approach speed on the minor road exceeds 10 miles per hour.

2. On the entrance ramp to an expressway where an acceleration lane is not provided.

3. Within an intersection with a divided highway, where a STOP sign is present at the entrance to the first roadway and further control is necessary at the entrance to the second roadway, and where the median width between the two roadways exceeds 30 feet.

4. Where there is a separate or channelized right-turn lane, without an adequate acceleration lane

5. At any intersection where a special problem exists and where an engineering study indicates the problem to be susceptible to correction by use of the YIELD sign

YIELD signs should not ordinarily be placed to control the major flow of traffic at an intersection. They should not be erected on the approaches of more than one of the intersecting streets or highways or used at any intersection where there are STOP signs on one or more approaches, except, under special circumstances, to provide minor movement control within complex intersections.

YIELD signs should not be used on the through roadways of expressways. They may be used on an entering roadway without an adequate acceleration lane, but in a well designed interchange, the sign would interfere with the free merging movement, and it should not be used under those circumstances.

C. WARRANTS

4C-1 Advance Engineering Data Required

A comprehensive investigation of traffic conditions and physical characteristics of the location is required to determine the necessity for a signal installation and to furnish necessary data for the proper design and operation of a signal that is found to be warranted. Such data desirably should include:

1. The number of vehicles entering the intersection in each hour from each approach during 16 consecutive hours of a representative day. The 16 hours selected should contain the greatest percentage of the 24-hour traffic.

2. Vehicular volumes for each traffic movement from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, and public-transit vehicles), during each 15-minute period of the two hours in the morning and of the two hours in the afternoon during which total traffic entering the intersection is greatest.

3. Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in paragraph (2) above and also during hours of highest pedestrian volume. Where young or elderly persons need special consideration, the pedestrians may be classified by general observation and recorded by age groups as follows:

- (a) under 13 years
- (b) 13 to 60 years
- (c) over 60 years.

4. The 85-percentile speed of all vehicles on the uncontrolled approaches to the location.

5. A conditions diagram showing details of the physical layout, including such features as intersectional geometries, channelization, grades, sight-distance restrictions, bus stops and routings, parking conditions, pavement markings, street lighting, driveways, location of nearby railroad crossings, distance to nearest signals, utility poles and fixtures, and adjacent land use.

6. A collision diagram showing accident experience by type, location, direction of movement, severity, time of day, date, and day of week for at least one year.

The following data are also desirable for a more precise understanding of the operation of the intersection and may be obtained during the periods specified in (2) above:

1. Vehicle-seconds delay determined separately for each approach.

2. The number and distribution of gaps in vehicular traffic on the major street when minor-street traffic finds it possible to use the intersection safely.

3. The 85-percentile speed of vehicles on controlled approaches at a point near to the intersection but unaffected by the control.

4. Pedestrian delay time for at least two 30-minute peak pedestrian delay periods of an average weekday or like periods of a Saturday or a Sunday.

Adequate roadway capacity at a signalized intersection is desirable. Widening of both the main highway and the intersecting roadway may be warranted to reduce the delays caused by assignment of right-of-way at intersections controlled by traffic signals. Widening of the intersecting roadway is often beneficial to operation on the main highway because it reduces the signal time that must be assigned to side-street traffic. In urban areas, the effect of widening can be achieved by elimination of parking at intersectional approaches. It is always desirable to have at least two lanes for moving traffic on each approach to a signalized intersection. Additional width may be necessary on the leaving side of the intersection, as well as the approach side, in order to clear traffic through the intersection effectively. Before an intersection is widened, the additional green time needed by pedestrians to cross the widened streets should be checked to ensure that it will not exceed the green time saved through improved vehicular flow.

IC-2 Warrants for Traffic Signal Installation

Traffic control signals should not be installed unless one or more of the signal warrants in this Manual are met. Information should be obtained by means of engineering studies and compared with the requirements set forth in the warrants. If these requirements are not met, a traffic signal should neither be put into operation nor continued in operation (if already installed).

For the purpose of warranting signalization, a wide-median intersection should be considered as one intersection.

When a traffic control signal is indicated as being warranted, it is presumed that the signal and all related traffic control devices and markings are installed according to the standards set forth in this Manual. It is further presumed that signal indications are properly phased, that roadways are properly designed, that adjacent traffic signals are properly coordinated, that there is adequate supervision of the operation and maintenance of the signal and all of its related devices, and that the traffic signal controller will be selected on the basis of engineering study and judgment.

An investigation of the need for traffic signal control should include where applicable, at least an analysis of the factors contained in the following warrants:

- Warrant 1—Minimum vehicular volume
- Warrant 2—Interruption of continuous traffic.
- Warrant 3—Minimum pedestrian volume.
- Warrant 4—School crossings.
- Warrant 5—Progressive movement.
- Warrant 6—Accident experience.
- Warrant 7—Systems.
- Warrant 8—Combination of warrants.

1C-3 Warrant 1, Minimum Vehicular Volume

The Minimum Vehicular Volume warrant is intended for application where the volume of intersecting traffic is the principal reason for consideration of signal installation. The warrant is satisfied when, for each of any 8 hours of an average day, the traffic volumes given in the table below exist on the major street and on the higher-volume minor-street approach to the intersection. An "average" day is defined as a weekday representing traffic volumes normally and repeatedly found at the location.

MINIMUM-VEHICULAR VOLUMES FOR WARRANT 1

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume mi- nor-street approach (one direction only)
Major Street	Minor Street		
1	1	500	150
2 or more	1	600	150
2 or more	2 or more	600	200
1	2 or more	500	200

These major-street and minor-street volumes are for the same 8 hours. During those 8 hours, the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

When the 85-percentile speed of major-street traffic exceeds 40 mph in either an urban or a rural area, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the Minimum Vehicular Volume warrant is 70 percent of the requirements above.

1C-4 Warrant 2, Interruption of Continuous Traffic

The Interruption of Continuous Traffic warrant applies to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or hazard in entering or crossing the major street. The warrant is satisfied when

for each of any 8 hours of an average day, the traffic volumes given in the table below exist on the major street and on the higher-volume minor-street approach to the intersection, and the signal installation will not seriously disrupt progressive traffic flow.

MINIMUM VEHICULAR VOLUMES FOR WARRANT 2

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume mi- nor-street approach (one direction only)
Major Street	Minor Street		
1	1	750	75
2 or more	1	900	75
2 or more	2 or more	900	100
1	2 or more	750	100

These major-street and minor-street volumes are for the same 8 hours. During those 8 hours, the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

When the 85-percentile speed of major-street traffic exceeds 40 mph in either an urban or a rural area, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the Interruption of Continuous Traffic warrant is 70 percent of the requirements above.

1C-5 Warrant 3, Minimum Pedestrian Volume

The Minimum Pedestrian Volume warrant is satisfied when, for each of any 8 hours of an average day, the following traffic volumes exist:

1. On the major street, 600 or more vehicles per hour enter the intersection (total of both approaches), or where there is a raised median island 4 feet or more in width, 1,000 or more vehicles per hour (total of both approaches) enter the intersection on the major street; and
2. During the same 8 hours as in paragraph (1) there are 150 or more pedestrians per hour on the highest volume crosswalk crossing the major street.

When the 85-percentile speed of major-street traffic exceeds 40 mph in either an urban or a rural area, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the Minimum Pedestrian Volume warrant is 70 percent of the requirements above.

A signal installed under this warrant at an isolated intersection should be of the traffic-actuated type with push buttons for pedestrians crossing the main street. If such a signal is installed at an intersection within a signal system, it should be equipped and operated with control devices which provide proper coordination.

Signals installed according to this warrant shall be equipped with pedestrian indications conforming to requirements set forth in other sections of this Manual.

Signals may be installed at nonintersection locations (mid-block) provided the requirements of this warrant are met, and provided that the related crosswalk is not closer than 150 feet to another established crosswalk. Curbside parking should be prohibited for 100 feet in advance of and 20 feet beyond the crosswalk. Phasing, coordination, and installation must conform to standards set forth in this Manual. Special attention should be given to the signal head placement and the signs and markings used at nonintersection locations to be sure drivers are aware of this special application.

1C-6 Warrant 4, School Crossing

A traffic control signal may be warranted at an established school crossing when a traffic engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at the school crossing shows that the number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period (see 7A-3).

When traffic control signals are installed entirely under this warrant:

1. Pedestrian indications shall be provided at least for each crosswalk established as a school crossing.
2. At an intersection, the signal normally should be traffic-actuated. As a minimum, it should be semi-traffic-actuated, but full actuation with detectors on all approaches may be desirable. Intersection installations that can be fitted into progressive signal systems may have pretimed control.
3. At non-intersection crossings, the signal should be pedestrian-actuated, parking and other obstructions to view should be prohibited for at least 100 feet in advance of and 20 feet beyond the crosswalk, and the installation should include suitable standard signs and pavement markings. Special police supervision and/or enforcement should be provided for a new non-intersection installation.

1C-7 Warrant 5, Progressive Movement

Progressive movement control sometimes necessitates traffic signal installations at intersections where they would not otherwise be warranted, in order to maintain proper grouping of vehicles and effectively regulate group speed. The Progressive Movement warrant is satisfied when

1. On a one-way street or a street which has predominantly unidirectional traffic, the adjacent signals are so far apart that they do not provide the necessary degree of vehicle platooning and speed control, or

2. On a two-way street, adjacent signals do not provide the necessary degree of platooning and speed control and the proposed and adjacent signals could constitute a progressive signal system.

The installation of a signal according to this warrant should be based on the 85-percentile speed unless an engineering study indicates that another speed is more desirable.

The installation of a signal according to this warrant should not be considered where the resultant signal spacing would be less than 1000 feet.

4C-8, Warrant 6, Accident Experience

The Accident Experience warrant is satisfied when:

1. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; and
2. Five or more reported accidents, of types susceptible to correction by traffic signal control, have occurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of \$100 or more; and
3. There exists a volume of vehicular and pedestrian traffic not less than 80 percent of the requirements specified either in the Minimum Vehicular Volume warrant, the Interruption of Continuous Traffic warrant, or the Minimum Pedestrian Volume warrant; and
4. The signal installation will not seriously disrupt progressive traffic flow.

Any traffic signal installed solely on the Accident Experience warrant should be semi-traffic-actuated (with control devices which provide proper coordination if installed at an intersection within a coordinated system) and normally should be fully traffic-actuated if installed at an isolated intersection.

4C-9, Warrant 7, Systems Warrant

A traffic signal installation at some intersections may be warranted to encourage concentration and organization of traffic flow networks. The Systems warrant is applicable when the common intersection of two or more major routes has a total existing, or immediately projected, entering volume of at least 800 vehicles during the peak hour of a typical weekday, or each of any five hours of a Saturday and/or Sunday.

A major route as used in the above warrant has one or more of the following characteristics:

1. It is part of the street or highway system that serves as the principal network for through traffic flow;
2. It connects areas of principal traffic generation;

3. It includes rural or suburban highways outside, entering or traversing a city.
4. It has surface street freeway or expressway ramp terminals;
5. It appears as a major route on an official plan such as a major street plan in an urban area traffic and transportation study.

4C-10 Warrant 8. Combination of Warrants

In exceptional cases, signals occasionally may be justified where no single warrant is satisfied but where two or more of Warrants 1, 2, and 3 are satisfied to the extent of 80 percent or more of the stated values.

Adequate trial of other remedial measures which cause less delay and inconvenience to traffic should precede installation of signals under this warrant.

ANNEX F

EXAMPLE OF THE DEVELOPMENT OF THE EFFECTIVENESS MATRIX FOR A GOALS ACHIEVEMENT BASED SELECTION SYSTEM

In order to illustrate the goals achievement concept, appropriate calculations have been undertaken assuming the following typical intersection conditions:

average hourly traffic volume	350 vehicles per hour
current annual accident frequency	2 accidents per year

For illustration purposes three goals were considered; these were safety, delay and cost. Development of appropriate effectiveness measures for each of these goals and for each of the five possible forms of intersection control follow.

A. Safety

The average hourly traffic volume corresponds to an annual traffic volume of:

$350 \times \text{conversion to AADT} \times 365 = 1,916,250 \text{ vehicles per year}$

Expected annual accident frequencies for each type of control have been developed previously. Hence the expected accident frequency at the subject intersection is:

$1,916,250 \times 10^{-6} \times \text{accident rate} = \text{expected frequency}$

The results of this follow:

Intersection Control	Rate	Expected Frequency
No Control	.482	.923
Yield Control	.199	.381
Stop	.182	.348
Multi-way Stop	.245	.469
Traffic Signal	1.149	2.201

From a safety standpoint the type of control giving the greatest accident reduction was considered to be most effective. Effectiveness values were constrained to be between 0 and 1.

Intersection Control	Expected Accident Reduction	Effectiveness
No Control	-1.077	.65
Yield	-1.619	.98
Stop	-1.652	1.00
Multi-way Stop	-1.531	.92
Traffic Signal	.201	0

B. Delay

Delay levels for differing types of intersection control have been developed in Exhibit 18. In order to calculate the total seconds of delay per hour for each type of intersection control a traffic split of 70 percent major and 30 percent minor was assumed. In practice such data could be available. Further, as the type of intersection control having the greatest delay per hour is considered least effective arithmetic manipulations were undertaken to develop effectiveness measures between 0 and 1. As traffic signals were least effective the formula developed was:

$$\text{effectiveness} = 1 - \frac{\text{intersection delay}}{\text{intersection delay with traffic signals}}$$

The results are summarized below.

Type of Control	Assumed Delay	Street Affected	Total Delay (Sec/Hr)	Effectiveness
No Control	0 sec/veh	Minor	0	1
Yield	4 sec/veh	Minor	420	.85
Stop	5 sec/veh	Minor	525	.81
Multi-way Stop	5 sec/veh	Both	1750	.35
Traffic Signal	23 sec/veh	Minor	2695	0
	2 sec/veh	Major		

C. Cost

For the purposes of this analysis cost of operation was considered to include annual fuel cost and annual vehicle maintenance cost only. The traffic splits noted earlier also apply in this case, further the vehicle maintenance and fuel cost appropriate for each form of intersection control have been noted earlier. In order to develop an effectiveness between 0 and 1 the following formula was used:

$$\text{effectiveness} = 1 - \frac{\text{cost of control being studied}}{\text{cost of most expensive control}}$$

The results follow:

Type of Control	Fuel Cost*	Maintenance Cost	Total Cost	Effectiveness
No Control	0	0	0	1.00
Yield	\$4455	0	\$4455	.88
Stop	6970	\$4139	11109	.70
Multi-way Stop	23234	13797	37031	0
Traffic Signal	8829	5242	14071	.62

*Cost of fuel assumed to be \$1.25 per gallon

Based on the foregoing work the appropriate effectiveness matrix follows:

.65	1.00	1.00
.98	.85	.88
1.00	.81	.70
.92	.35	0
0	0	.62

ANNEX G

GLOSSARY OF RELEVANT TERMS

- AADT - average annual daily traffic - the total yearly volume on a given road section divided by the number of days per year
- FREE FLOW CONDITION - a term used in the Ontario MUTCD to describe traffic flow having rural characteristics, namely, an 85th percentile speed of 40 miles per hour and lying in a built-up community of less than 10,000
- GAP - the length of time, usually in seconds, between successive vehicles on a given roadway
- HALF SIGNALS - a device consisting of traffic control signals facing traffic on the major roadway, and a stop sign on the minor street implemented as a pedestrian priority measure
- ITE - Institute of Transportation Engineers
- LAG - the length of time, usually in periods, between the arrival of a side street vehicle and the first vehicle arrival on the major roadway
- MEAN - the average value of a group of observations

MODAL	-	the value selected most frequently within a given distribution
MUTCD	-	the Manual of Uniform Traffic Control Devices
NCHRP	-	the National Co-operative Highway Research Program
PPH	-	pedestrians per hour or pph, pedestrians per day
PREVENTABLE ACCIDENTS	-	The number of accidents occurring at a location which are considered to be preventable, through the application of a particular type of intersection control. Such accidents usually include pedestrian collisions with vehicles and angle type vehicle accidents. Any accidents which occur between conflicting traffic movements which will be separated by the proposed control measure are preventable.
PEDESTRIAN CROSSOVER	-	A device which gives pedestrians priority over vehicular traffic at designated locations on the road system. This device is peculiar to Ontario.
RTAC	-	the Roads and Transportation Association of Canada
RMOC	-	the Regional Municipality of Ottawa-Carleton

- RESTRICTED - A term used in the Ontario MUTCD to describe urban conditions. The condition which exists in all instances other than free flow is defined earlier.
- SAFE - A description of visibility conditions at a location. The maximum speed at which a vehicle can approach an intersection and still have adequate time to see and react to a conflicting vehicle to avoid an accident.
- APPROACH SPEED
- VPH - vehicles per hour or vpd vehicles per day

END

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FIN