RESEARCH REPORT

Assessment of the Transportation Impacts of Current and Fused Grid Layouts

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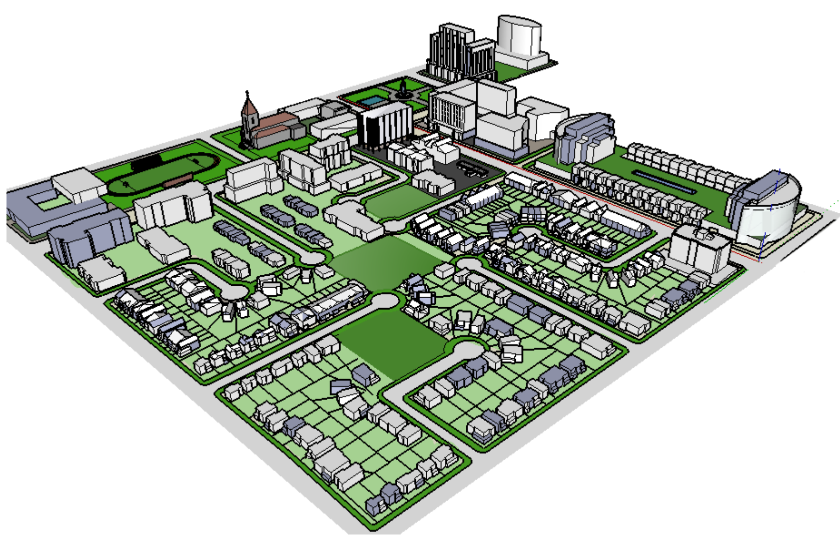
Canada Mortgage and Housing Corporation (CMHC)

ASSESSMENT OF THE TRANSPORTATION IMPACTS OF CURRENT AND FUSED GRID LAYOUTS



FINAL REPORT

AUGUST 2007

RESEARCH HIGHLIGHT

July 2008 Socio-economic Series 08-012

Taming the Flow—Better Traffic and Safer Neighbourhoods

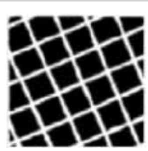
INTRODUCTION

A consensus is emerging that conventional approaches to suburban development are not sustainable. From a transportation perspective, single-use, low-density residential developments with curvilinear, poorly connected road networks limit transportation options to the point that that private automobile is the only choice for many trips. This increases automobile travel and, as a result, fuel use, emissions and transportation costs. With this in mind, municipalities are re-examining neighbourhood layout and land use concepts.

The conventional suburban site layout, the inheritance of the last 50 years of growth, represents one step in the evolution of road network and land use approaches. It was preceded by the grid street pattern, a key feature of the early railway–pedestrian suburbs and of many 19th century cities (figure 1). This progression from the rectilinear, orthogonal, open grid to curvilinear streets and dead ends suggests that there may have been sound reasons for the transition. These reasons include the desire for neighbourhoods and districts that balance the requirements for land-use efficiency, neighbourhood livability and effective transportation, though primarily by private automobile.

Street layouts and land use plans need to evolve to encourage the replacement of car trips with walking, cycling or public transit trips. "Walkability" is emerging as a key characteristic of a good neighbourhood plan. Walkability has three main attributes: connectivity, density and mix of uses. However, while encouraging walkability, street network plans should also allow traffic to flow smoothly. Walkability and traffic flow must be balanced.

CMHC examined the historic transformation of street layouts and developed an alternative model, the "Fused Grid," which attempts to blend desirable elements of the conventional and grid-based street layouts. This model gives priority to walking and cycling at the neighbourhood level, and frees automobile movement at the district and regional scale.

	Gridiron (c.1900)	Fragmented parallel (c.1950)	Warped parallel (c.1960)	Loops and lollipops (c.1970)	Lollipops on a stick (c.1900)
Street patterns					

Source: Adapted from Southworth and Owens (1993)

Figure 1 Evolution of street patterns

While initial inferences from other models suggested that the Fused Grid would allow more efficient movement than other street patterns, only detailed analysis could establish comparative performance levels.

This study was initiated to provide a comparative assessment of the transportation impacts of three different district street layouts (that is, "Conventional Suburban," "Neo-traditional," and Fused Grid).

The study's main task was a traffic engineering analysis to compare the performance of these layouts, including local, district, and regional streets. Implications for travel behaviour (for example, transit use) and traffic safety were also considered. The comparative assessment was done using the Barrhaven neighbourhood, an existing built-up area in Ottawa, on which two new layouts were overlaid.

RESEARCH CONTEXT

To frame and direct the traffic analysis, a literature review summarized current discussion about street layout design from a transportation perspective. The literature focuses mostly on issues of connectivity, accessibility, safety and travel behaviour—predominantly in a qualitative manner.

Most current research has focused on walkability as a key indicator of a good neighbourhood plan. However, since street networks must also serve vehicles, a good model should also successfully lessen congestion, reduce travel time and minimize the risk of collisions.

The review also revealed gaps in current research. For example, research is inconclusive about how measures that increase network connectivity may affect other desirable characteristics, such as vehicle movement, delay and safety. Compounding this uncertainty is the fact that most critiques of current street layouts ignore the option for improving pedestrian and cyclist connectivity with pathways and linkages separate from vehicle movement.

In other instances, there appears to be increasing debate and uncertainty about whether street hierarchy is essential for good traffic flow, or whether a more uniform network might improve traffic flow through dispersion. In addition, there is a general lack of empirical data to assess how changes in road network patterns at the local level can affect transit use and vehicular trip generation.

Perhaps the most significant research gap relates to how various street patterns compare in terms of traditional transportation performance measures such as delay, capacity and intersection level of service. The study focused on quantifying the transportation level of service impacts of different street layouts using commonly accepted transportation engineering techniques and models. Insight on questions regarding connectivity, pedestrian linkages and street hierarchy are also provided.

METHOD

To compare street layout concepts, the study used traffic simulation to assess performance under different street layout alternatives and land use scenarios. The method involved:

1. Identifying and characterizing a study area.
2. Selecting alternative street layouts for the study area.
3. Developing land use scenarios.
4. Establishing and applying the transportation demand and traffic modelling approach.

STUDY AREA

Barrhaven, the study area, is a suburb of Ottawa about 17 km (10.5 mi.) southwest of downtown and on the outer edge of a greenbelt. The 520 ha (1,285 acres) study area is mostly residential. Single-detached dwellings are the dominant land use. In 2001, the area supported about 22,000 residents and 2,300 jobs, corresponding to an average gross population density of 42 residents per hectare and gross employment density of 4.5 jobs per hectare.

A comparison with five other Ottawa neighbourhoods showed that Barrhaven characterizes conventional suburban development in many ways (for example, street layout and road density, employment density, transportation mode splits and so on), but is at the upper end of population density range. It can therefore be assumed that if traffic performance for a given street layout is acceptable in Barrhaven, it will likely perform satisfactorily for other locations with similar land use.

Table 1 Comparison of alternative street layouts

	Conventional Suburban	Neo-traditional	Fused-Grid
			
Street hierarchy	Hierarchical street pattern of arterials, major collectors, minor collectors and local streets.	Hierarchical street pattern of arterials, major collectors, minor collectors and local streets arranged in orthogonal geometry.	Hierarchical street pattern of arterials, major collectors, minor collectors and local streets arranged in an orthogonal manner; one-way couplets for major collectors and twinned arterials.
Block length	Very long blocks (up to 600 m [1,968 ft.]), discontinuous streets with no breaks between lots for pedestrians.	Block sizes of 60–120 m (197–394 ft.) by 120–240 m (394–787 ft.).	Most block lengths are under 200 m (656 ft.), but reach a maximum of 600 m.
Cross-section design	Wide (11 m [36 ft.]) two-lane road cross-sections.	3.5 m (11.5 ft.) lanes and 2.4 m (8 ft.) for parking.	3.5 m (11.5 ft.) lanes and 2.4 m (8 ft.) for parking.
Intersection type	Extensive use of 3-way intersections (T-intersections) and few 4-way intersections; a ratio of 14:1.	Dominant use of 3-way over 4-way intersections in a ratio of 2.6:1.	A predominance of 3-way over 4-way intersections; a ratio of 4.7:1.
Arterial connection	Eight connections.	14 connection roads	11 major roads connecting to arterials.
Bicycle, pedestrian infrastructure	Pedestrian and cycling paths are confined to the school grounds and train tracks.	Integrated pedestrian and cycling path system within the neighbourhood.	Active infrastructure (path network) within neighbourhoods. Clearly defined residential quadrants framed by collectors that do not support through-traffic.

ALTERNATIVE STREET LAYOUTS

Alternative street layouts—Conventional Suburban and Neo-traditional—were chosen to represent current typical street networks. A third was added: CMHC's new Fused Grid model.

The Conventional Suburban layout is most often associated with discontinuous, curvilinear street networks, typified by the existing Barrhaven street network. The Neo-traditional layout, for the purpose of this analysis, is based on the traditional grid, but has been adapted to incorporate a hierarchical network of roads. The Fused Grid adopts the traditional grid at the neighbourhood and district scales while adopting the discontinuous street network approach at the block scale. It also includes strategically located pathways and parks creating connections for non-motorized traffic. Table 1 illustrates and describes the three alternative street layouts for Barrhaven.

In addition to the street networks, a variety of other elements needed to be developed for each layout. This included the functional classification of road facilities and associated designs (for example, number of lanes, speed limit, pavement width and so on), transit service and the location of intersections with traffic signals and stop signs.

LAND USE SCENARIOS

Five land use scenarios were developed, representing increasing levels of population and employment, to explore the transportation performance of each layout under increasing numbers of trips into and out of the district. (Table 2)

In all but Scenario 2, which mirrors existing conditions, population densities were uniformly distributed across the entire Barrhaven district. This uniformity removes irregularities that are not related to the development pattern itself, but reflect site-specific land use. In Scenarios 1–4, employment densities and schools were distributed according to prevailing conditions. In Scenario 5, the large employment increase rendered it impractical to limit employment to the original areas; therefore, it was distributed to areas closest to transit corridors.

TRANSPORTATION MODELLING APPROACH

A two-stage modelling approach responded to the challenges of the study. The first stage relied on the Emme/2 TRANS travel-demand model developed by the City of Ottawa. This model was used for the four-stage modelling procedure to determine the overall traffic volumes expected to travel to, from and within Barrhaven given the varying land use scenarios.

The second stage involved more detailed micro-simulation using the *Corsim* modelling software. *Corsim* was chosen because it simulates many detailed traffic characteristics, such as queuing, acceleration and the tendency for cars to stagger while driving on multilane roads. Accordingly, the *Corsim* model can reflect the differences in traffic performance for the three street layouts.

The modelling and simulation was based on weekday afternoon peak hour conditions for each of the 15 street layout–land use scenario combinations. Modelled results include transit mode splits, vehicle kilometres travelled, delay (that is, congestion plus intersection delay) and intersection level of service.

KEY FINDINGS

- **All layouts exhibit acceptable traffic performance under most land use scenarios**
  The assessment showed that for a wide range of population and employment densities, each street layout allows for acceptable traffic flow. This is evident in the relatively low average trip delay (figure 2), minimal non-local traffic infiltration and acceptable intersection level of service for Scenarios 1 to 4.
- **The Fused Grid layout exhibits the best traffic performance, particularly with increasing density of development**
  The Fused Grid layout exhibits the lowest delay and best signalized intersection level of service under all scenarios, but particularly under the high density–mixed-use land use conditions of the Scenario 5.

  These lower relative levels of delay range from 15 per cent less delay than the poorest performing layout under existing population and employment levels, to 35 per cent less delay for the high density–mixed use scenario.

This is due to two primary factors:

First, the strict hierarchical street system in the Fused Grid layout provides for efficient traffic flow into and out of the neighbourhood.

Second, the Fused Grid's major collectors are designed as one-way couplets. This reduces the number of signalized intersections required and streamlines traffic signal cycle timings.

Table 2 Land use scenarios

Scenario	Description	Population	Gross population density (pop/ha)	Employment	Gross employment density (jobs/ha)
1	Existing population and employment (uniform density)	13,680	40.6	1,640	4.9
2	Existing population and employment (non-uniform density based on prevailing/expected conditions)	13,680	40.6	1,640	4.9
3	Neo-traditional population (uniform density)	20,949	62.2	2,510	7.4
4	Transit-supportive population densities (uniform density)	30,330	90	3,640	10.8
5	Commercial intensification (uniform density)	30,330	90	16,850	50

- **A hierarchical network layout can improve traffic performance**
  All three layouts are characterized by a hierarchical network structure to varying degrees. Of the three, the Fused Grid layout follows the strictest hierarchy, followed by the Conventional Suburban and then by the Neo-traditional layout. The strict hierarchical street system allows for efficient traffic flow into and out of the neighbourhood. The relative benefits of the Fused Grid are most evident in Scenario 5 under elevated traffic volumes.

- **One-way couplets improve traffic flow on arterials and deserve further consideration in neighbourhood design**
  The improved intersection level of service and traffic flow along arterials due to conversion of major collectors into one-way couplets for the Fused Grid layout confirms recent proposals for their use by prominent planners. However, these improvements in traffic flow must be balanced with the tendency for one-way streets to promote higher traffic speeds and more circuitous travel patterns. Cyclists and transit vehicles are particularly sensitive to the latter.

- **The Fused Grid reduces traffic volumes on lower classification streets**
  Looking at the performance of local streets and minor collectors, the analysis shows that the Fused Grid restricts the amount of traffic on them more effectively than the Conventional Suburban and Neo-traditional plans. This is particularly evident in the scenario with the highest traffic volume—Scenario 5, the high population and employment scenario (figure 3).

- For the street layouts considered, intersection density (that is, connectivity) and the presence of loops and cul-de-sacs do not have a strong correlation with traffic performance.

  For example, the high connectivity Neo-traditional layout (0.87 intersections per hectare) provides lower delay than the Conventional Suburban layout (0.48 intersections per hectare), but does not outperform the Fused Grid layout (0.51 intersections per hectare).

  This is in contrast to the literature, which suggests that level of service, particularly on arterials, should improve with increasing connectivity as there are more available routings to motorists. This suggests that other factors, such as the spacing and number of connections to the arterial network, may be more important to traffic performance than overall connectivity or the presence of loops and cul-de-sacs.

- **Increased connectivity reduces average trip distances within a neighbourhood**
  While average trip distances are similar across layouts for each scenario, Vehicle Kilometres of Travel (VKT) for trips within the district are approximately 10 per cent shorter in the Neo-traditional layout than other layouts. This is a result of the higher connectivity in the Neo-traditional layout, which allows for more direct trips. Ideally, intra-neighbourhood car trips should be displaced by walking and biking in a neighbourhood that is laid out to favour active transportation modes.

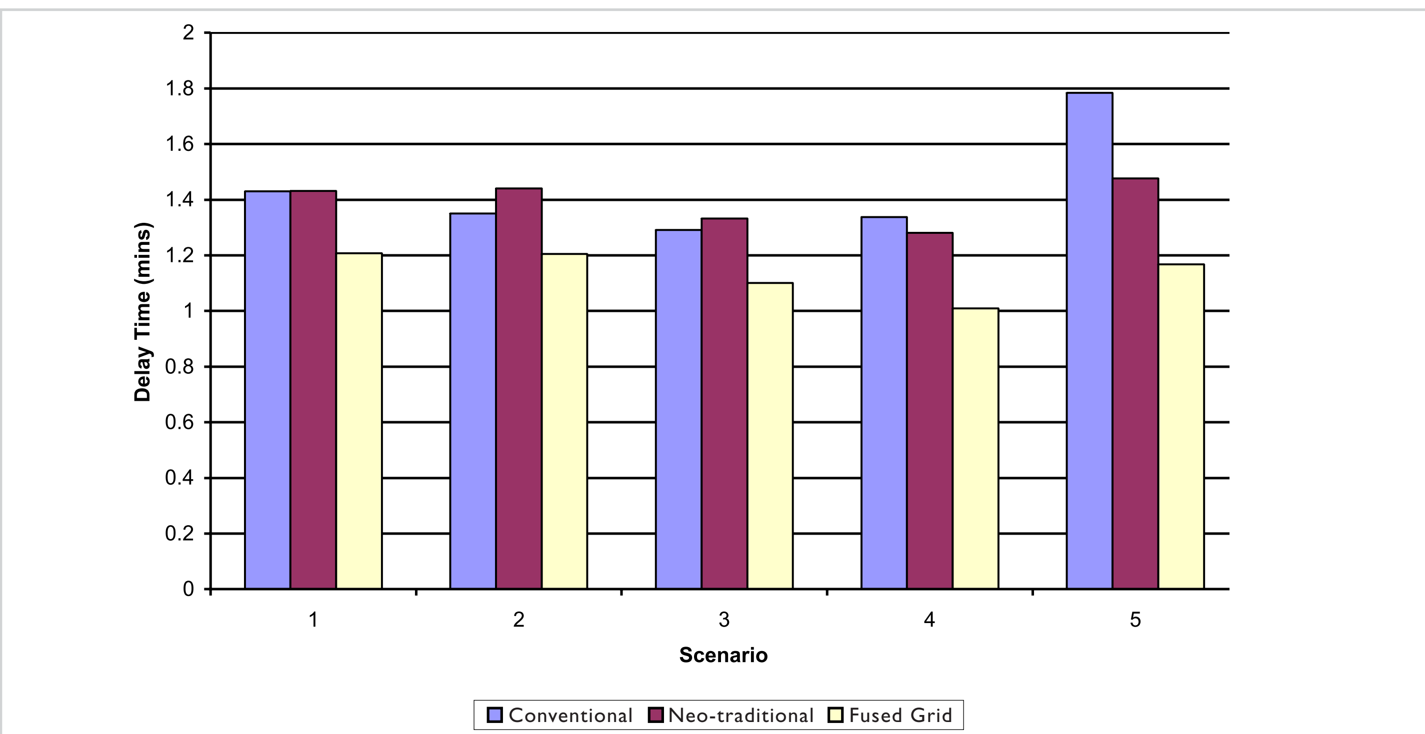


Figure 2 Average vehicle delay time per trip

- **Non-local traffic infiltration is more dependent on route directness and travel time savings offered by specific facilities than generic measures of connectivity**
  Traffic simulations revealed little to no non-local traffic infiltration for every layout and land use scenario. Non-local traffic that did "cut through" the district on non-arterial roads primarily did so using major collectors. Despite the lower overall connectivity of the Conventional Suburban layout, this layout exhibited the highest amount of through-movements by non-local traffic. This is in part due to the fact that a single major collector in this layout is oriented diagonally and provides an efficient routing across the district. These results indicate that, at the individual neighbourhood level, the amount of non-local traffic within the neighbourhood is less related to generic measures of connectivity (for example, intersection density) than to route directness and travel time savings offered by specific facilities.

- **Modal shares are affected more by land use density and mix of uses than by the street layout**
  Estimated transit mode split ranged from 11 per cent to 16 per cent of afternoon peak hour trips between the existing and high density–mixed use land use scenarios. For each land use scenario, however, there are only marginal differences in transit mode split across the street layouts. This supports results from other studies that indicate that although neighbourhood design (including street layout) influences travel decisions, locational and socio-economic variables have a stronger relationship with auto ownership, transit mode choice and vehicles kilometres travelled. Though not quantified in this study, it is expected that differences in street layout may have a stronger influence on the propensity to walk or cycle than they do on transit use.

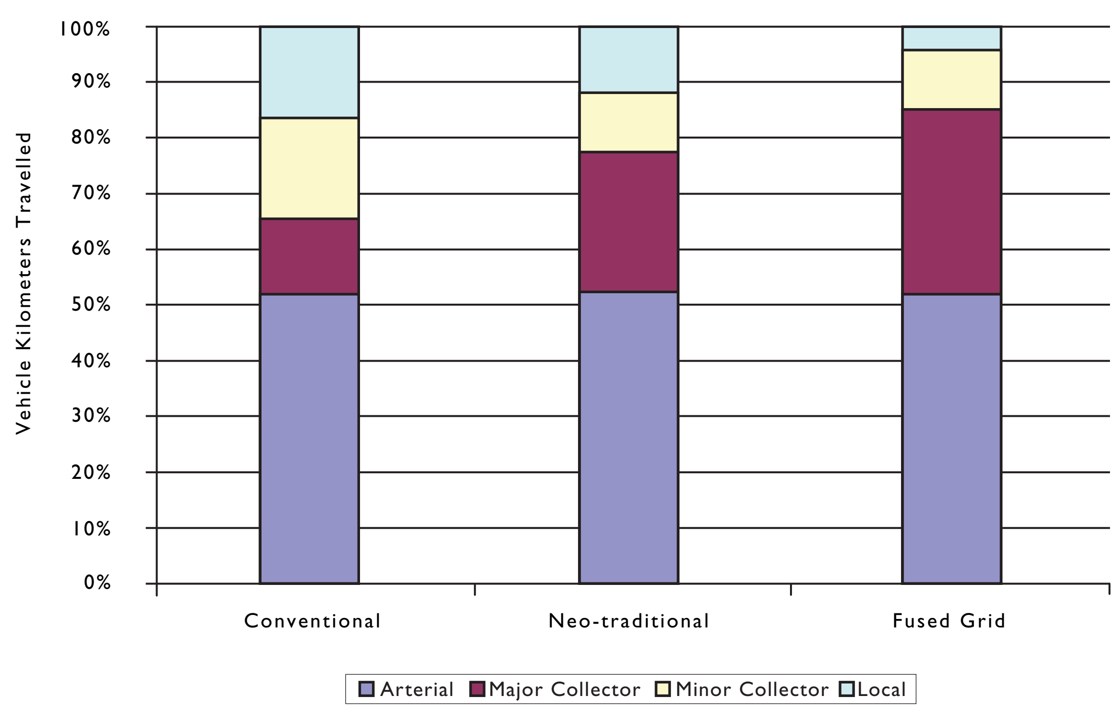


Figure 3 Share of vehicle travel by road type in Scenario 5

CONCLUSIONS

While previous studies have assessed the traffic impacts of increasing street connectivity or commented on the traffic performance of Neo-traditional networks, this the first study to look at the performance of the Fused Grid model and compare it to current alternatives.

This study contributes to neighbourhood design and traffic literature by adding both a new network layout model to the existing repertoire along with an assessment of its performance. Several general conclusions can be drawn from this study:

- Street network hierarchy and the presence of looping streets and cul-de-sacs do not necessarily lead to traffic congestion. Other factors, such as intersection design and the number and quality of arterial connections, must also be considered.
- Differences in traffic performance are most evident in high-density, mixed-use scenarios. Typical suburban land use conditions provide a poor basis for testing and contrasting network patterns.
- The Fused Grid can provide adequate traffic flow over a variety of land use forms.
- The Conventional Suburban layout provides the poorest traffic performance under increasing population and employment densities.
- The search for networks that balance the needs of pedestrians and drivers should continue. Few empirically based answers exist. Inherited network models should be rigorously re-examined.

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Research Report: *Assessment of the Transportation Impacts of Current and Fused Grid Layouts*

Consultant: IBI Group

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LE POINT EN RECHERCHE

Juillet 2008 Série socio-économique 08-012

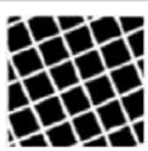
Aménager la circulation – Une meilleure circulation et des quartiers plus sûrs

APERÇU DU PROJET

Un consensus émerge selon lequel les approches traditionnelles à l'aménagement suburbain ne respectent pas les principes du développement durable. Sur le plan du transport, les aménagements résidentiels de faible densité monovalents, dont les réseaux routiers sont curvilignes et mal connectés, limitent les options de transport au point où la voiture est le seul choix pour de nombreux déplacements. Il s'ensuit une augmentation de l'usage de l'automobile et, par le fait même, de la consommation de carburant, des émissions de gaz à effet de serre et des coûts de transport. C'est dans ce contexte que les municipalités réexaminent la configuration des quartiers et la manière d'utiliser les terres.

La configuration suburbaine classique, héritage de la croissance des 50 dernières années, représente une étape dans l'évolution des façons d'aménager les réseaux routiers et d'utiliser les terres. Elle a été précédée par le tracé de rues en quadrilatères, une importante caractéristique des premières banlieues ferroviaires-piétonnières et de nombreuses villes du XIXe siècle (figure 1). Cette progression des rues orthogonales formant des quadrilatères vers les tracés curvilignes et les culs-de-sac indique que cette transition peut avoir été motivée par de bonnes raisons – le désir de créer des quartiers et des districts qui atteignent un équilibre entre les impératifs d'une utilisation efficace des sols, de l'habitabilité des quartiers et de l'efficacité des déplacements, surtout par l'entremise des voitures.

Les configurations de rues et les plans d'occupation des sols doivent évoluer pour favoriser le remplacement des déplacements en voiture par la marche à pied, le vélo et le transport en commun. Le « potentiel piétonnier » émerge comme une caractéristique importante d'un bon plan de quartier. Cette caractéristique présente trois attributs principaux : connectivité, densité et usages mixtes. Or, tout en encourageant la « marche », les plans des réseaux routiers doivent également permettre une circulation efficace. Ces deux aspects doivent être équilibrés.

	Quadrillage (c. 1900)	Parallèle fragmenté (c. 1950)	Parallèle déformé (c. 1960)	Boucles et culs-de-sac (c. 1970)	Culs-de-sac sur un fil (c. 1980)
Tracés des rues					

Source : Adapté de Southworth et Owens (1993)

Figure 1 Évolution des quadrilatères

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La SCHL a examiné la transformation historique des configurations de rues et a élaboré un modèle de remplacement, « l'îlogramme mixte », qui tente de mélanger les éléments désirables des tracés classiques et des quadrilatères. Ce modèle accorde la priorité aux piétons et aux cyclistes au sein du quartier, et libère le mouvement des automobiles à l'échelle du district ainsi qu'à l'échelle régionale.

Même si les premières inférences fondées sur les autres modèles laissaient entrevoir que l'îlogramme mixte permettrait un mouvement plus fluide que les autres tracés de rues, seule une analyse détaillée pouvait vraiment en établir le rendement.

Cette étude a été entreprise pour obtenir une évaluation comparative des impacts sur le transport de trois différentes configurations des rues (banlieue classique, aménagement néo-traditionnel et îlogramme).

La principale tâche des auteurs de l'étude a été de procéder à une analyse de l'ingénierie de la circulation pour comparer le rendement de ces configurations, analyse qui a touché les voies de circulation locales, de district et régionales. Les répercussions sur les comportements liés aux déplacements (par exemple, l'utilisation du transport en commun) et sur la sécurité de la circulation ont également été considérées. L'évaluation comparative a été faite à l'aide du quartier de Barrhaven, un secteur bâti d'Ottawa, sur lequel deux nouvelles configurations ont été superposées.

CONTEXTE DE LA RECHERCHE

Pour encadrer et diriger l'analyse de la circulation, un examen de la documentation a résumé le débat en cours sur la conception des tracés de rues dans l'optique du transport. La documentation porte principalement sur les problèmes de connectivité, d'accessibilité, de sécurité et des comportements liés aux déplacements, et ce, d'une manière surtout qualitative.

La plupart des recherches récentes ont porté sur le « potentiel piétonnier » comme un indicateur important d'un bon plan de quartier. Toutefois, puisque les réseaux routiers doivent également servir aux véhicules, un bon modèle devrait également réduire avec succès la congestion, le temps de déplacement et minimiser le risque de collisions.

L'examen a également révélé des lacunes dans ces recherches. Ainsi, elles ne sont pas concluantes quant à la manière dont les mesures qui augmentent la connectivité du réseau peuvent agir sur d'autres caractéristiques souhaitables comme le mouvement des véhicules, les ralentissements et la sécurité. Le fait que la plupart de ceux qui critiquent les configurations de rues actuelles ne prennent pas en considération l'option d'améliorer la connectivité pour les piétons et les cyclistes au moyen de sentiers et de liens séparés du mouvement des véhicules complique cette incertitude.

Dans d'autres cas, on se demande de plus en plus si une hiérarchie des rues est essentielle pour assurer une bonne circulation ou si un réseau plus uniforme pourrait améliorer le débit par la dispersion des véhicules. De plus, il existe peu de données empiriques pour évaluer quelle incidence les changements apportés aux modèles de réseaux routiers au niveau local pourrait avoir sur le transport en commun et les déplacements en véhicule.

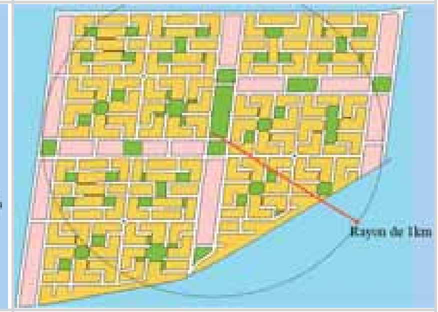
La lacune la plus importante de la recherche a probablement trait à la façon dont les diverses configurations des rues se comparent sur le plan de la mesure du rendement du transport traditionnel, notamment en ce qui concerne les ralentissements, la capacité et le service aux intersections. L'étude dont il est ici question visait à quantifier les impacts sur le niveau de service de transport pour différentes configurations de rues à l'aide de techniques et de modèles d'ingénierie du transport généralement acceptés. Il en ressort également des idées sur les questions de connectivité, de liens piétonniers et de hiérarchie des rues.

MÉTHODE

Pour comparer les concepts de tracé des rues, les chercheurs ont fait appel à une simulation de la circulation visant à évaluer le rendement selon différentes configurations de rues et divers scénarios d'utilisation des terres. La méthode consistait à :

1. déterminer et caractériser une zone d'étude;
2. sélectionner des tracés de rechange pour la zone à l'étude;
3. élaborer des scénarios d'utilisation des terres;
4. établir et appliquer la méthode de la demande de transport et de modélisation de la circulation.

Tableau 1 Comparaison de trois types de tracés de rues

	Banlieue classique	Néotraditionnelle	Îlogramme
			
Hiérarchie des rues	Tracé de rues hiérarchique d'artères, de collecteurs majeurs, de collecteurs mineurs et de rues locales.	Tracé de rues hiérarchique d'artères, de collecteurs majeurs, de collecteurs mineurs et de rues locales disposé en géométrie orthogonale.	Tracé de rues hiérarchique d'artères, de collecteurs majeurs, de collecteurs mineurs et de rues locales disposé de manière orthogonale; couplets à sens unique pour les collecteurs majeurs et artères jumelées.
Longueur des îlots	Très longs îlots (jusqu'à 600 m [1 968 pi]), rues discontinues sans arrêt entre les lots pour les piétons.	Îlots de 60 à 120 m (197–394 pi) sur 120 à 240 m (394–787 pi).	La plupart des îlots sont de moins de 200 m (656 pi), mais peuvent atteindre un maximum de 600 m.
Conception des profils en travers	Largeur (11 m [36 pi]), profils en travers à deux voies.	Voies de 3,5 m (11,5 pi) et 2,4 m (8 pi) pour le stationnement.	Des voies de 3,5 m (11,5 pi) et 2,4 m (8 pi) pour le stationnement.
Type d'intersection	Utilisation intensive d'intersections à trois voies (intersections en T) et quelques intersections à 4 voies; ratio de 14:1.	Utilisation dominante d'intersections à 3 voies plutôt que 4 selon un ratio de 2.6:1.	Prédominance d'intersections à 3 voies plutôt que 4; ratio de 4.7:1.
Connexions des artères	Huit connexions	14 connexions	11 routes majeures se reliant aux artères.
Infrastructure cycliste et piétonnière	Sentiers récréatifs (piétons et cyclistes) confinés aux terrains des écoles et le long des voies ferroviaires.	Réseau de sentiers réacréatifs intégré dans le quartier.	Infrastructure active (réseau de sentiers) dans les quartiers. Quadrants résidentiels définis clairement encadrés par des collecteurs qui ne permettent pas la circulation directe.

ZONE À L'ÉTUDE

Barrhaven, la zone à l'étude, est une banlieue d'Ottawa située à environ 17 km (10,5 milles) au sud-ouest du centre-ville et du côté extérieur de la ceinture verte. Cette zone de 520 ha (1 285 acres) est surtout à vocation résidentielle, et les maisons individuelles dominent. En 2001, la zone accueillait environ 22 000 résidents et 2 300 emplois, pour une densité démographique brute moyenne de 42 résidents par hectare et une densité d'emploi de 4,5 emplois par hectare.

Une comparaison avec cinq autres quartiers d'Ottawa a montré que, à bien des égards, Barrhaven est caractéristique de l'aménagement suburbain traditionnel (notamment par son tracé de rues et sa densité routière, sa densité d'emploi, sa répartition des modes de transport, etc.), mais en étant à la limite supérieure du spectre de la densité de population. On peut donc supposer que si le rendement de la circulation pour un tracé de rues donné est acceptable à Barrhaven, ce tracé fonctionnera probablement de façon satisfaisante pour d'autres endroits ayant une utilisation des terres comparable.

AUTRES TRACÉS DE RUES

D'autres tracés de rue – banlieue classique et néotraditionnelle – ont été choisis pour représenter les réseaux routiers typiques actuels. Un troisième a été ajouté : le nouvel îlogramme mixte de la SCHL.

Le tracé de la banlieue classique est le plus souvent associé à des réseaux routiers curvilinéaires discontinus, caractérisé par celui de Barrhaven. Aux fins de cette analyse, le tracé néotraditionnel est basé sur le quadrilatère traditionnel, mais a été adapté pour intégrer un réseau hiérarchique de routes. L'îlogramme adopte le quadrilatère traditionnel au niveau du quartier et du district tout en adoptant le réseau discontinu à l'échelle des îlots. Il comprend également des pistes et des parcs situés de façon stratégique qui créent des liens pour la circulation non motorisée. Le tableau 1 illustre et décrit les trois configurations possibles pour Barrhaven.

En plus des réseaux de rues, divers autres éléments sont nécessaires pour établir chaque configuration, notamment la classification fonctionnelle des installations routières et des conceptions connexes (par exemple, le nombre de voies, la limite de vitesse, la largeur de la chaussée, etc.), les services de transport en commun et l'emplacement des intersections avec les feux de circulation et les panneaux d'arrêt.

SCÉNARIOS D'UTILISATION DES TERRES

Cinq scénarios d'utilisation des terres ont été élaborés, représentant les niveaux croissants de population et d'emploi, pour explorer le rendement du transport de chaque tracé selon le nombre croissant de déplacements à l'intérieur et à l'extérieur du district (tableau 2).

Dans tous les scénarios sauf le scénario 2, qui reflète les conditions actuelles à Barrhaven, les densités de population ont été distribuées uniformément dans tout le district de Barrhaven. Cette uniformité enlève les irrégularités qui ne sont pas associées au modèle d'aménagement lui-même, mais elle reflète une utilisation des terres spécifique au site. Dans les scénarios 1-4, les densités d'emploi et les écoles ont été réparties selon les conditions qui prévalent. Dans le scénario 5, la grande augmentation de l'emploi a rendu ce scénario peu pratique pour limiter l'emploi aux zones originales; elles ont donc été réparties aux zones les plus proches des corridors de transport en commun.

APPROCHE DE MODÉLISATION DU TRANSPORT

Une approche de modélisation en deux étapes a répondu aux défis de l'étude. La première étape comptait sur le modèle de demande de déplacement Emme/2 TRANS mis au point par la Ville d'Ottawa. Ce modèle a été utilisé pour la procédure de modélisation en quatre étapes afin de déterminer les volumes de circulation globaux prévus pour se déplacer vers et à partir de Barrhaven, ainsi qu'à l'intérieur du secteur, étant donné les divers scénarios d'utilisation des terres.

La deuxième étape a consisté en une micro-simulation plus détaillée à l'aide du logiciel de modélisation Corsim. Corsim a été choisi parce qu'il simule de nombreuses caractéristiques détaillées de la circulation, comme les files d'attente, l'accélération et la tendance des voitures à s'espacer sur les routes à multiples voies. En conséquence, le modèle Corsim peut refléter les différences du rendement de la circulation pour les trois tracés routiers.

La modélisation et la simulation ont été basées sur les conditions d'heure de pointe l'après-midi en semaine pour chacune des 15 combinaisons d'utilisation des terres et de tracé routier. Les résultats modélisés comprennent les partages des modes de transport en commun, les kilomètres parcourus par les véhicules, les ralentissements (c'est-à-dire la congestion plus les ralentissements aux intersections) et le niveau de service aux intersections.

Tableau 2 Scénarios d'utilisation des terres

Scénario	Description	Population	Densité brute de la population (pop./ha)	Emploi	Densité brute de l'emploi (trav./ha)
1	Population et emploi actuels (densité uniforme)	13 680	40,6	1 640	4,9
2	Population et emploi actuels (densité non uniforme d'après des conditions prévalentes et prévues)	13 680	40,6	1 640	4,9
3	Population néotraditionnelle (densité uniforme)	20 949	62,2	2 510	7,4
4	Densités de population soutenant le transport en commun (densité uniforme)	30 330	90	3 640	10,8
5	Intensification commerciale (densité uniforme)	30 330	90	16 850	50

PRINCIPALES CONCLUSIONS

- **Tous les tracés montrent un rendement acceptable de la circulation selon la plupart des scénarios d'utilisation des terres.** L'évaluation montre que pour un vaste éventail de densités de population et d'emploi, chaque tracé des rues permet un débit acceptable de la circulation. C'est évident dans le ralentissement de déplacement moyen relativement faible (figure 2), minime pour l'infiltration non locale et acceptable au niveau de service aux intersections pour les scénarios de 1 à 4.

- **Le tracé de l'îlogramme affiche le meilleur rendement pour ce qui est de la circulation, en particulier avec l'accroissement de la densité de l'aménagement**
  Le tracé de l'îlogramme permet le ralentissement le plus faible et le meilleur niveau de service pour la signalisation aux intersections pour tous les scénarios, mais particulièrement selon les conditions d'utilisation des terres mixte à densité élevée du scénario 5.

  Ces niveaux de ralentissement relativement inférieurs vont d'un ralentissement de 15 % inférieur au tracé offrant le plus faible rendement, selon les densités de population et d'emploi existantes, à un ralentissement de 35 % inférieur pour le scénario d'utilisation mixte à densité élevée.

Cela est attribuable à deux facteurs principaux :

Premièrement, le système hiérarchique strict du tracé de l'îlogramme offre un débit de la circulation efficient pour entrer dans le quartier et en sortir.

Deuxièmement, les collecteurs majeurs de l'îlogramme sont conçus comme couplets à sens unique, ce qui réduit le nombre d'intersections avec feux de circulation et rationalise la synchronisation des feux de circulation.

- **Un tracé de réseau hiérarchique peut améliorer le rendement de la circulation**
  Les trois tracés sont caractérisés par une structure de réseau hiérarchique à des degrés divers. Des trois tracés, celui de l'îlogramme mixte permet la hiérarchie la plus stricte, suivi de celui de la banlieue classique et du tracé néotraditionnel. Le système hiérarchique strict permet un débit efficient de la circulation pour entrer dans le quartier et en sortir. Les avantages relatifs de l'îlogramme sont les plus évidents dans le scénario 5 selon des volumes de circulation élevés.

- **Les couplets à sens unique améliorent le débit de la circulation sur les artères et méritent plus de considération dans la conception des quartiers**
  Le niveau de service amélioré aux intersections et le meilleur débit de la circulation le long des artères grâce à la conversion des collecteurs majeurs en couplets à sens unique pour le tracé de l'îlogramme confirment les récentes propositions pour leur application par des urbanistes éminents. Toutefois, ces améliorations du débit de la circulation doivent être équilibrées avec la tendance que les rues à sens unique favorisent la vitesse supérieure et des modèles de déplacement plus détournés. Les cyclistes et les véhicules de transport en commun sont particulièrement sensibles à ces modèles.

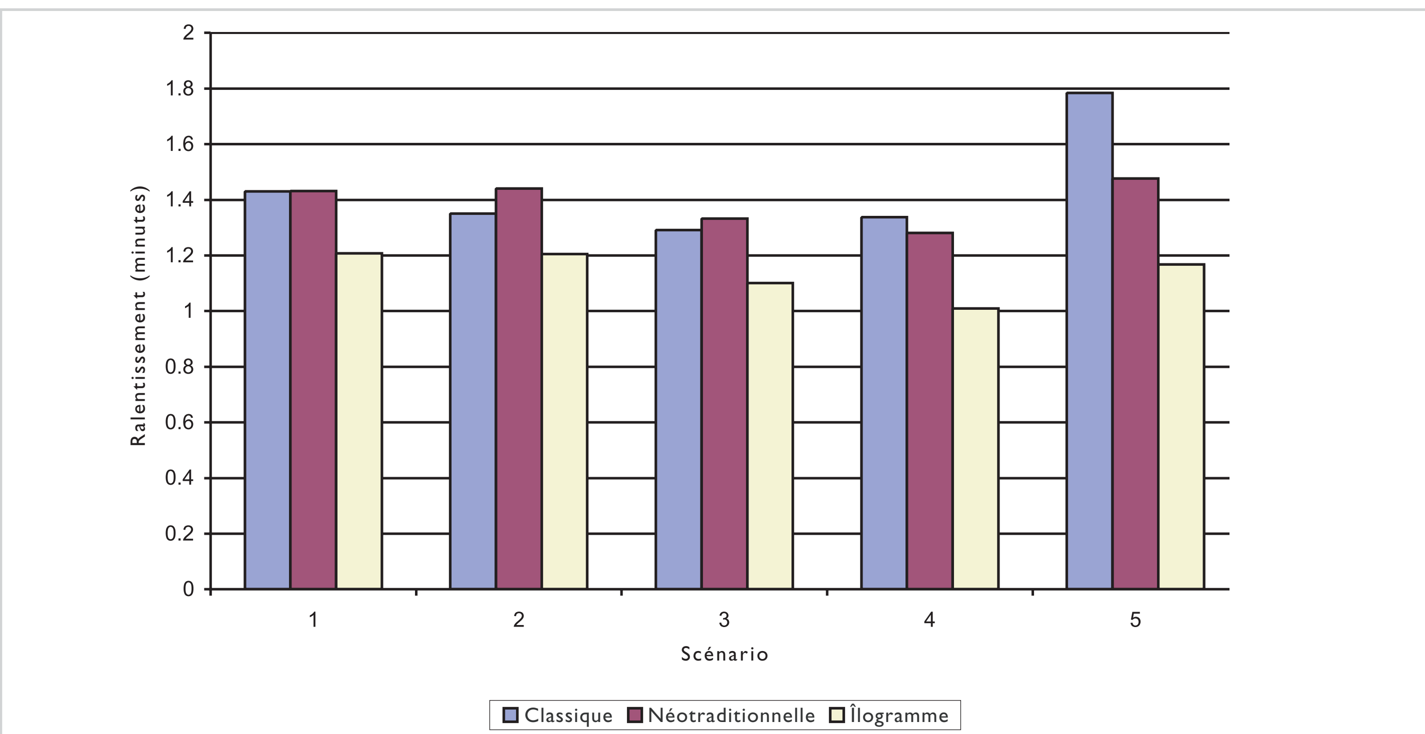


Figure 2 Ralentissement moyen des véhicules par déplacement

- **L'îlogramme réduit les volumes de circulation dans les rues de classification inférieure**
  Si l'on examine le rendement des rues locales et des collecteurs mineurs, l'analyse montre que l'îlogramme limite la quantité de circulation dans ces rues et collecteurs plus efficacement que le tracé de la banlieue classique et les plans néotraditionnels. C'est particulièrement évident dans le scénario présentant le volume de circulation le plus élevé (scénario 5), le scénario de la plus haute densité de population et d'emploi (figure 3).

- Pour les tracés considérés, la densité aux intersections (c'est-à-dire la connectivité) et la présence de boucles et de culs-de-sac n'ont pas une forte corrélation avec le rendement de la circulation.

  Par exemple, le tracé néotraditionnel à connectivité élevée (0,87 intersection par hectare) offre un ralentissement inférieur à celui du tracé de la banlieue classique (0,48 intersection par hectare), mais ne dépasse pas celui de l'îlogramme (0,51 intersection par hectare).

  Cela est contraire à la documentation qui laisse supposer que le niveau de service, particulièrement sur les artères, devrait s'améliorer avec une connectivité accrue, car il y a plus d'itinéraires possibles pour les automobilistes. Cela suggère que d'autres facteurs, comme l'espacement et le nombre de connexions au réseau des artères, peuvent être plus importants pour le rendement de la circulation que la connectivité globale ou la présence de boucles et de culs-de-sac.

- **La connectivité accrue réduit les distances de déplacement moyennes dans un quartier**
  Bien que les distances de déplacement moyennes soient semblables, dans chaque scénario, les kilomètres parcourus en voiture (KPV) pour les déplacements dans le district sont d'environ 10 % plus courts dans le tracé néotraditionnel que dans les autres tracés. C'est le résultat d'une meilleure connectivité dans le tracé néotraditionnel qui permet des déplacements plus directs. Idéalement, les déplacements en voiture dans le quartier devraient être remplacés par la marche ou le vélo dans un quartier qui est configuré pour favoriser des modes de transport actifs.

- **L'infiltration de la circulation non locale dépend davantage du caractère direct de l'itinéraire et du temps économisé lors des déplacements qu'offrent des installations spécifiques que des mesures génériques de connectivité**
  Les simulations de la circulation ont révélé peu ou pas d'infiltration non locale pour chaque tracé et chaque scénario d'utilisation des terres. La circulation non locale qui « traverse » le district sur les routes secondaires emprunte surtout les collecteurs majeurs. Malgré la connectivité globale inférieure du tracé de la banlieue classique, ce tracé affiche le plus grand nombre de mouvements de circulation non locale traversant le disctrict, ce qui est attribuable en partie au fait qu'un seul collecteur majeur dans ce tracé est orienté en diagonale et offre un itinéraire efficace pour traverser le district. Ces résultats indiquent qu'au niveau de chaque quartier, le volume de circulation non locale est moins associé aux mesures génériques de connectivité (par exemple, densité aux intersections) qu'au caractère direct de l'itinéraire et au temps économisé lors des déplacements qu'offrent des installations spécifiques.

- **Les parts modales sont touchées davantage par la densité de l'utilisation des terres et la diversité des usages que par le tracé des rues**
  On estime que la proportion des déplacements effectués en transport en commun varie entre 11 % et 16 % à l'heure de pointe en après-midi entre les scénarios à densité existante et élevée et à usage mixte des terres. Toutefois, pour chaque scénario d'utilisation des terres, il y a seulement des différences marginales de l'usage du transport en commun pour les tracés des rues. Cela vient confirmer les résultats d'autres études qui indiquent que bien que la conception du quartier (y compris le tracé des rues) influe sur les décisions des voyageurs, les variables d'emplacement et socio-économiques présentent une relation plus forte avec la propriété d'une auto, le choix du transport en commun et le nombre de kilomètres parcourus en voiture. Bien qu'elles ne soient pas quantifiées dans cette étude, on prévoit que les différences dans le tracé des rues peuvent exercer une influence plus forte sur la propension à marcher ou à se déplacer en vélo qu'à utiliser le transport en commun.

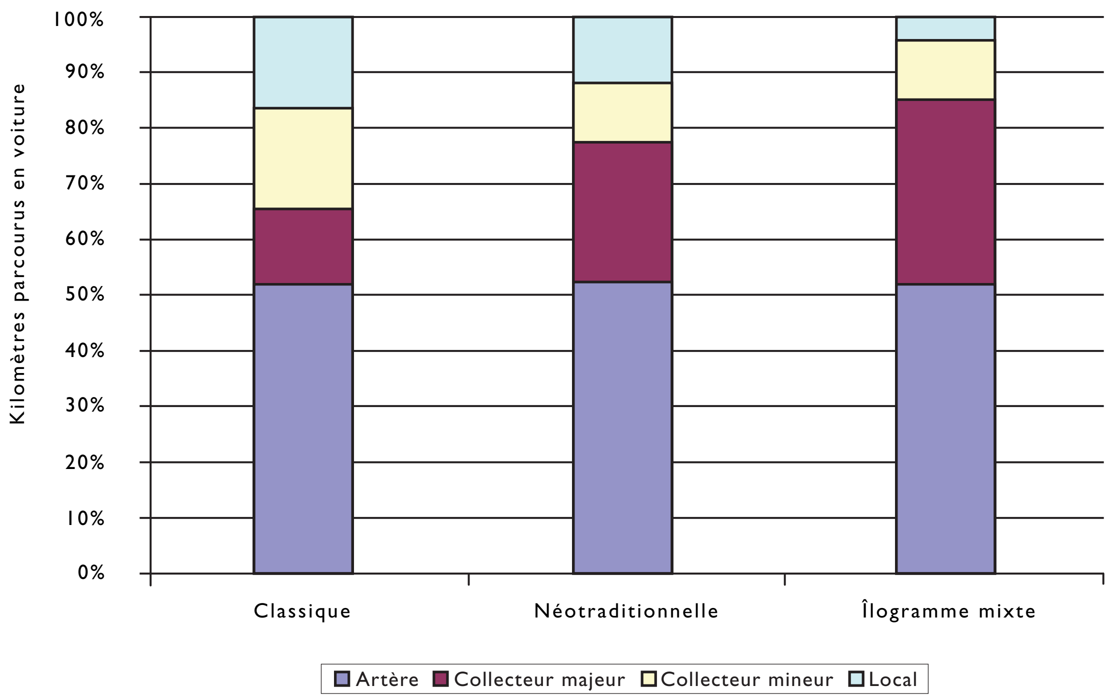


Figure 3 Part du déplacement des véhicules par type de route dans le scenario 5

CONCLUSIONS

Bien que des études antérieures aient évalué les impacts d'une augmentation de la connectivité des rues sur la circulation ou formulé des commentaires sur le rendement des réseaux néotraditionnels, cette étude est la première à examiner le rendement du modèle de l'îlogramme et à le comparer aux solutions de rechange actuelles.

Cette étude contribue à la documentation sur la conception des quartiers et la circulation en ajoutant un nouveau modèle de tracé des réseaux au répertoire existant, ainsi qu'une évaluation de son rendement. Plusieurs conclusions générales peuvent être tirées de cette étude :

- La hiérarchie des réseaux routiers et la présence de boucles et de culs-de-sac ne conduisent pas nécessairement à la congestion de la circulation. D'autres facteurs, comme la conception des intersections et le nombre et la qualité des connexions par les artères, doivent également être considérés.
- Les différences au chapitre du rendement de la circulation sont les plus évidentes dans les scénarios à haute densité et à usage mixte. Les conditions d'utilisation des terres dans une banlieue typique offrent une faible base pour vérifier et mettre en contraste les types de réseaux.
- L'îlogramme peut offrir un débit de circulation adéquat pour diverses formes d'utilisation des terres.
- Le tracé de la banlieue classique offre le rendement le plus faible de la circulation lorsque les densités de population et d'emplois augmentent.
- La recherche de réseaux qui équilibrent les besoins des piétons et des conducteurs automobiles devrait se poursuivre. Il existe peu de réponses empiriques. Les modèles de réseaux antérieurs devraient être réexaminés rigoureusement.

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Rapport de recherche : *Assessment of the Transportation Impacts of Current and Fused Grid Layouts*

Consultants pour le projet de recherche : IBI Group

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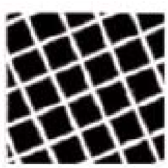
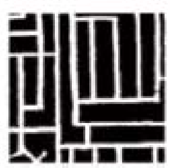
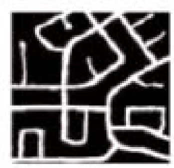
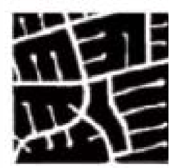
EXECUTIVE SUMMARY

Study Description

A consensus is emerging that conventional approaches to suburban development are not sustainable. From a transportation perspective, single-use, low-density residential developments with curvilinear, poorly connected road networks limit transportation options to their residents such that private automobiles are the only choice for many trips. This restriction increases automobile travel and correspondingly, levels of fuel consumption, emissions, and auto ownership costs. High auto dependence has negative environmental, social, and economic consequences, including climate change, degraded public health, and reduced housing affordability.

With this in mind, municipalities are re-examining neighbourhood layout and land use concepts. The conventional suburban site layout, the inheritance of the last fifty years of growth, represents one step in the evolution of road network and land use approaches. It was preceded by the grid street pattern, a key feature of the early railway/pedestrian suburbs and also many 19^{th} century cities (Exhibit ES-1). This progression from the rectilinear, orthogonal open grid to the curvilinear streets and dead ends suggests that there may have been sound reasons for this transition. These reasons include the desire for neighbourhoods and districts that balance the requirements for land-use efficiency, neighbourhood liveability, and effective transportation, primarily by private automobiles. However, planning policy is now starting to focus on designing neighbourhoods to significantly reduce the need for car use, in response to environmental and social concerns. Consequently, neighbourhood street layouts and land use plans need to evolve with these changing policies to encourage the replacement of car trips with walking, cycling or transit trips.

Exhibit ES-1: Evolution of Street Patterns

	Gridiron (c. 1900)	Fragmented parallel (c. 1950)	Warped parallel (c. 1960)	Loops and lollipops (c. 1970)	Lollipops on a stick (c. 1980)
Street patterns					

Source: Adapted from Southworth and Owens (1993)

Canada Mortgage and Housing Corporation (CMHC) has completed an analysis of the transformations of street layouts and subsequently developed an alternative model, the Fused Grid, which attempts to blend desirable elements of the conventional and grid-based street layouts. This model gives priority to walking and cycling at the neighbourhood level, and frees automobile movement at the district and regional scale. It has sparked interest in Canada[1] and similar approaches have been adopted in the United States and Australia. While initial inferences from other models suggested that the Fused Grid would work at least as well, if not better, than other street patterns with respect to efficiency of movement, more detailed analysis was considered

[1] Examples of site plans that incorporate the Fused Grid model in Canada include The Stratford Plan, an approved secondary plan for 300 acres of land recently annexed to the City of Stratford and The Saddleton Plan, a site plan for a 160 acre subdivision in the northeast section of Calgary currently under consideration by the City.

necessary if widespread adoption of this model is to occur. Traffic planners and engineers need to be assured with evidence that such a network will deliver satisfactory traffic performance and related outcomes such as safety and emissions.

This study was initiated to provide a comparative assessment of the transportation impacts of current and Fused Grid approaches to street network layout. Its main task was to conduct a traffic engineering analysis to compare the performance of three different district street layouts (i.e., Conventional Suburban, Neo-traditional, Fused Grid) including local, district, and regional streets. Implications for travel behaviour (e.g., transit use) and traffic safety would also be discussed. The comparative assessment is carried out using an existing built up area, the Barrhaven district in the City of Ottawa, on which two new layouts are overlaid.

Research Gaps

To frame and direct the traffic analysis, a literature review was conducted to summarize the current discussion about the potential advantages and disadvantages of Conventional, Neo-Traditional and Fused Grid development approaches from a transportation perspective. The review revealed that the literature has mostly focused on issues such as connectivity, accessibility, safety, and travel behaviour – predominantly in a qualitative manner. Most of the current research has focused on walkability as key indicator of a good neighbourhood plan. However, since street networks must also serve vehicular traffic, the search for a good model includes abating congestion, reducing trip time and reducing risk of collisions.

The review also revealed gaps in current research. For example, research is inconclusive about how measures that increase network connectivity may have a negative influence on others desirable characteristics, such as safety or vehicle movement and level of service. Compounding this uncertainty is the fact that most critiques of current plans ignore the possibility of a different approach, which could involve the provision of pedestrian linkages that are distinct from vehicular movement. In other instances, there appears to be increasing debate and uncertainty on whether street hierarchy is essential for good traffic flow, or whether a more uniform network might improve traffic flow through dispersion. In addition, there is a general lack of empirical data to assess how changes in road network patterns at the local level can affect vehicular trip generation.

Perhaps the most significant research gap that exists relates to how various street patterns compare in terms of traditional transportation performance measures such as delay, capacity and level of service. Therefore, the primary research gap that this study attempted to address relates to quantifying the transportation level of service impacts of different street layouts using commonly accepted transportation engineering techniques and models. Additional traffic-related research questions raised in the literature review include:

- Does increased vehicular path connectivity reduce travel distances within a district?
- Does increased connectivity affect traffic volumes on local streets?
- How does the spacing of arterial connections affect arterial traffic level of service?
- Does increased connectivity lead to increased non-local traffic infiltration into the district?
- How do road network features, such as the presence of loops and cul-de-sacs or regularly spaced intersections, affect traffic flow?
- Does a hierarchical network configuration improve or degrade traffic performance?

- Do one-way couplets improve traffic performance?

This study attempted to address many of these questions through the traffic analysis. In addition, other issues, such as the importance of street layout and connectivity on mode split were also considered.

Method

To permit comparability across street layout concepts, traffic simulation was used to assess the traffic performance of a given area under different street layout alternatives. The simulation for each street layout was performed for a variety of land use scenarios to test the robustness of each layout and assess differences in other factors (e.g. transit mode split) with changes in population and employment density. As such, the method adopted in this study involved four steps: (1) identifying and characterizing a study area, (2) selecting alternative street layouts for this study area, (3) developing land use scenarios, and (4) establishing and applying the transportation demand and traffic modelling approach.

STUDY AREA

The study area, Barrhaven, is a suburb of Ottawa located approximately 17 kilometres south-west of the downtown and on the outer border of a greenbelt. It was chosen because it typifies conventional suburban development and has been studied in the past by CMHC. The 520 hectare study area is primarily a residential area with single-detached residential dwellings being the dominant land use. It supports approximately 22,000 residents and 2,300 jobs corresponding to an average gross population density of 42 residents per hectare, and gross employment density of 4.5 jobs per hectare.

To assess whether the transportation analysis of this study area will be transferable to other districts, Barrhaven was compared with five other Ottawa districts, with a focus on determining if it is representative of conventional suburban neighbourhoods from a traffic perspective. Overall, this analysis demonstrated that Barrhaven characterizes conventional suburban development in many ways (e.g., street layout and road density, employment density, transportation mode splits, etc.), but is at the upper end of population density range. Barrhaven's higher population density is expected to result in somewhat more trips and more congested conditions during the peak periods. Thus, if traffic performance for a given street layout is acceptable in Barrhaven, it will likely perform satisfactorily for other locations with similar land use. However, it is noted that the nature and orientation of arterial roadways and traffic has a substantial influence on local traffic flows. Thus, the transferability of results from Barrhaven may be compromised if, in the area of interest, the relationship between residential streets and arterial roadways and the regional traffic flows on arterial facilities are significantly different from Barrhaven conditions.

ALTERNATIVE STREET LAYOUTS

Alternative street layouts were chosen to represent the typical street networks in current use and include Conventional Suburban and Neo-Traditional (TND) layouts. Added to these two layouts was the CMHC model – the Fused Grid. The first two basic development patterns are characterized by distinct network configurations, but also inherent land use and streetscape design approaches to neighbourhood development. The Conventional Suburban layout is most often associated with discontinuous, curvilinear street networks, typified by the existing Barrhaven street network. The Neo-Traditional layout, for the purpose of this analysis, is based on the traditional grid, but has been adapted to incorporate a hierarchical network of roads. The Fused Grid adopts the traditional grid at the neighbourhood and district scales while adopting the discontinuous street network approach at the block scale, with strategically located pathways and parks creating connections for non-motorized traffic. Exhibit ES-2 provides a high level overview of these development types.

Exhibit ES-2: Comparative Characteristics of Conventional, Neo-Traditional and Fused Grid Neighbourhoods

Category	Conventional Suburban Design	Neo-Traditional Neighbourhood Design	Fused Grid Neighbourhood Design
Transportation Network	Circuitous, meandering streets; missing sidewalks; hierarchical street pattern (arterials, collectors); limited access streets to arterials; wide streets without street parking; predominantly auto-based	Interconnected, grid-like street patterns; integrated pedestrian and cycle paths; narrow streets; on-street parking; reduced speed limits; many access streets to arterials; many modes successful; easy transit accessibility	Interconnected grid network of larger streets surrounding neighbourhood quadrants with looping and dead-end streets; strong hierarchy of streets; green spaces designed to improve pedestrian mobility; easy transit accessibility
Land Use	Segregated, clustered land uses; access to a limited number of “highly desirable” land uses; low residential densities	Mixed land uses; close proximity of land uses; high residential densities; access to parks, recreation and distinct neighbourhood “centres”	Mixed land uses; close proximity of land uses; high residential densities; access to parks, recreation and distinct neighbourhood “centres”

Adapted from McNally and Kulkarni, 1997

The three alternative street layouts for Barrhaven are illustrated and described in Exhibit ES-3. Layouts are compared in terms of street classification systems, street directness, block length, road cross-section, intersection type (i.e., 3-way vs. 4-way), arterial connections, network connectivity, and active transportation infrastructure. The street layout patterns and land use are varied only within the boundaries of the district, consistent with previous CMHC studies.

Other elements of the alternative street layouts developed through the study include the functional classification of road facilities and associated designs (e.g., number of lanes, speed limit, pavement width, etc.), transit service, and the location of signalized intersections and stop signs. These roadway characteristics where then used in combination with the layouts to determine other metrics such as road density and lane kilometres.

Exhibit ES-3: Alternative Street Layouts

Street Layout		Road Network Characteristics
Conventional Suburban (existing)		• Hierarchical street pattern of arterials, major collectors, minor collectors, and local streets; • Very long blocks (up to 600 m), discontinuous streets with no breaks between lots for pedestrians; • Wide (11 m) two-lane road cross-sections; • Extensive use of 3-way intersections and few 4-way intersections; a ratio of 14:1; • 8 connections to the arterials • Pedestrian and cycling paths are confined to the school grounds and train tracks; and, • Intersection density of 0.48 intersections per hectare. • Street density of 0.35 lane-km/ha and total lane km of 117
Neo-Traditional (TND)		• Hierarchical street pattern of arterials, major collectors, minor collectors, and local streets arranged in orthogonal geometry • Blocks sizes of 60-120 metres by 120-240 metres; • 3.5-metre lanes and 2.4-metres for parking; • Dominant use of 3-way over 4-way intersections in a ratio of 2.6:1; • 14 connection roads to arterials; • Integrated pedestrian and cycling path system within the neighbourhood district; and, • Intersection density of 0.87 intersections per hectare. • Street density 0.48 lane-km/ha and total lane-km of 163
Fused Grid		• Hierarchical street pattern of arterials, major collectors, minor collectors, and local streets arranged in an orthogonal manner; • Most block lengths are under 200 metres, but reach a maximum of 600 metres • Street cross sections follow the principles set forth in NTD; • A predominance of 3-way (i.e. T-intersections) over 4-way intersections - at a ratio of 4.7:1; • 11 major access roads to the surrounding arterials; • Clearly defined residential quadrants framed by collectors that do not support through traffic; • One-way couplets for major collectors and twinned arterials • Active infrastructure (path network) within neighbourhoods • Intersection density of 0.51 intersections per hectare. • Street Density 0.36 lane-km/ha and total lane-km of 123

LAND USE SCENARIOS

Five land use scenarios were developed, representing increasing levels of population and employment, to explore the transportation performance of each layout under increasing numbers of trips into and out of the district (Exhibit ES-4). To enable meaningful comparisons, land use assumptions were held constant for all three layouts for each scenario. In addition, in all but Scenario 2, which mirrors existing conditions, population densities were uniformly distributed across the entire Barrhaven district. This uniformity removes irregularities that are not related to the development pattern itself, but reflect site-specific land use. In Scenarios 1-4, employment densities and schools are distributed according to prevailing conditions. In Scenario 5, the large employment increase renders it impractical to limit employment to the original areas; therefore, it is distributed to areas closest to transit corridors.

Exhibit ES-4: Land Use Scenarios

Scenario	Description	Population	Gross Population Density (Pop/ha)	Employment	Gross Employment Density (Jobs/ha)
1	Existing Population and Employment (Uniform Density)	13,680	40.6	1,640	4.9
2	Existing Population and Employment (Non-uniform Density based on prevailing/expected conditions)	13,680	40.6	1,640	4.9
3	TND Population (Uniform Density)	20,949	62.2	2,510	7.4
4	Transit Supportive Population Densities (Uniform Density)	30,330	90.0	3,640	10.8
5	Commercial Intensification (Uniform Density)	30,330	90.0	16,850	50.0

TRANSPORTATION MODELLING APPROACH

A two-staged modelling approach was adopted to respond to the challenges of the study. The first stage relied on the Emme/2 TRANS travel demand model developed by the City of Ottawa. This model was utilized to perform the four-stage modelling procedure to determine the overall traffic volumes expected to travel to, from and within Barrhaven given the varying land-use scenarios. The second stage involved more detailed micro-simulation using the Corsim model. Corsim is a microscopic modelling software in which individual cars are modelled on the street network guided by intricate and complex car following and lane changing logic. A distinction between microscopic models as compared to macroscopic models (e.g. Emme/2) is that queuing, acceleration, the tendency for cars to stagger while driving on multilane roads and other detailed traffic characteristics are explicitly considered in microscopic models. Accordingly, the Corsim model can reflect the differences in traffic performance for the three street layouts.

Results and Conclusions

The primary research gap addressed by this study relates to **quantifying the transportation level of service impacts of different street layouts using commonly accepted transportation engineering techniques and models and assessing how and why these results vary across the street layouts**. Results are based on the modelling and simulation of weekday PM peak hour conditions for each of the 15 street layout and land use scenario combinations and include transit mode splits, vehicle kilometres travelled, delay (i.e., congestion plus intersection delay), and intersection level of service.

Key findings based on the analysis of these results are as follows:

- **All layouts exhibit acceptable traffic performance under most land use scenarios:** The assessment showed that for a wide range of population and employment densities, each street layout allows for acceptable traffic flow. This is evident in the relatively low average trip delay (about 1.4 minutes on average for all trips in the district), minimal non-local traffic infiltration, and acceptable intersection level of service for Scenarios 1 to 4, which represent gross densities ranging from approximately 45 to 100 residents plus jobs per hectare. These land use characteristics are typical of most built up urban areas with the exception of Central Business Districts, which can exceed 100 residents plus jobs per hectare.

- **The Fused Grid layout exhibits the best traffic performance, particularly with increasing density of development:** The Fused Grid layout exhibits the lowest delay and best signalized intersection level of service under all scenarios, but particularly under the high density/mixed-use land use conditions of Scenario 5, “Commercial Intensification”. With increasing density, the Fused Grid performs increasingly better in terms of total delay for local trips compared to the other layouts. These lower relative levels of delay range from 15% less delay than the poorest performing layout under existing population and employment levels, to 35% less delay for the high density/mixed use scenario. This is due to two primary factors. First, the strict hierarchical street system in the Fused Grid layout provides for efficient traffic flow into and out of the neighbourhood, as discussed above. Secondly, the Fused Grid’s intersections provide the best level of service compared to other layouts, since it includes one-way couplets for major collectors, which reduces the number of signalized intersections required and streamlines traffic signal cycle timings.

- **A hierarchical network layout can improve traffic performance:** All three layouts are characterized by a hierarchical network structure to varying degrees. Of the three, the Fused Grid layout follows the strictest hierarchy, followed by the Conventional suburban and lastly by the Neo-traditional layout. The analysis indicates that, assuming the current land use (Scenario 2), the Fused Grid layout outperforms both the Conventional and Neo-traditional plan in terms of delay and signalized intersection level of service. In Scenario 5, under elevated traffic volumes, the relative benefits of the Fused Grid are even more evident. These results are largely due to the strict hierarchical street system in the Fused Grid layout provides for efficient traffic flow into and out of the neighbourhood.

- **One-way couplets improve traffic flow on arterials and deserve further consideration in neighbourhood design:** The improved intersection level of service and traffic flow along arterials due to conversion of major collectors into one-way couplets for the Fused Grid layout, as discussed above, corroborates recent proposals for their use by prominent planners. However, these improvements in traffic flow must be balanced with the tendency for one-way streets to promote higher traffic speeds and more circuitous travel patterns. Cyclists and transit vehicles are particularly sensitive to the latter.

- **The Fused Grid reduces traffic volumes on lower classification streets:** Looking at the performance of local streets and minor collectors, the analysis shows that the Fused Grid restricts the amount of traffic on them more effectively than the Conventional and Neo-traditional plans. Only 14% of the traffic in the Fused Grid Plan uses these roads as opposed to 24% and 17% for the Conventional and Neo-traditional plans, respectively, based on Scenario 1 results. Under the higher density scenario (Scenario 5), the proportion of traffic on lower classification streets for the Conventional and Neo-traditional Neighbourhoods increases while the Fused Grid holds constant at 14%.

- **For the street layouts considered, intersection density (i.e. connectivity) and the presence of loops and cul-de-sacs do not have a strong correlation with traffic performance:** Two of the three plans, the Conventional and the Fused Grid, have considerably lower intersection density than the Neo-traditional plan (i.e., 0.48 and 0.51 intersections per hectare vs. 0.87 intersections per hectare). This is largely because the former places cul-de-sac and loop street types, which have the effect of reducing the number of intersections and generally increasing the number of T-junctions. Overall network performance, however, had poor correlation with intersection density. For example, in the highest density scenario, the performance of the Conventional layout (as measured by delay per trip) is higher than the TND whereas the Fused Grid exhibits the lowest delay. This is in contrast to literature, which suggests that level of service, particularly on arterials, should improve with increasing connectivity, as there are more available routings to motorists. This suggests that other factors, such as the spacing and number of connections to the arterial network, may be more important to traffic performance than the presence of loops and cul-de-sacs or overall connectivity.

- **Increased connectivity reduces average trip distances within a neighbourhood:** Looking at trips that begin or end within the study neighbourhood, increased connectivity was found to reduce average trip distances. While average trip distances are similar across layouts for each scenario, Vehicle Kilometres of Travel (VKT) for local trips in the Neo-Traditional layout are approximately 10% lower than Conventional Suburban and Fused Grid layouts. This is a result of the higher connectivity in the Neo-traditional plan, which allows for more direct trips. These results suggest a VKT reduction of approximately 1.0%-1.5% per 10% increase in intersection density, which are within the range of VKT reductions suggested in the literature; however, this VKT reduction only refers to travel within the neighbourhood. Ideally, intra-neighbourhood car trips should be displaced by walking and biking in a neighbourhood that is laid out so as to favour active transportation modes.

- **Non-local traffic infiltration is more dependent on route directness and travel time savings offered by specific facilities than generic measures of connectivity:** Traffic simulations revealed little to no non-local traffic infiltration for every layout and land use scenario. Of the non-local traffic that used non-arterial neighbourhood facilities, the vast majority of this non-local traffic was through traffic on major collectors. Despite the lower overall connectivity of the Conventional Suburban layout (45% lower intersection density than the Neo-traditional layout), this layout exhibited the highest amount of through-movements by non-local traffic. This is in part due to the fact that a single major collector in this layout is oriented diagonally and provides an efficient routing across the neighbourhood. These results indicate that, at the individual neighbourhood level, the amount of traffic on major collectors is less related to generic measures of connectivity (e.g., intersection density) than it is to route directness and travel time savings offered by specific facilities.

- **Modal shares are affected more by land use density and mix of uses than by the street layout in this analysis:** Estimated transit mode split increased by 45% in absolute terms (i.e., 11% to 16%) between the existing and high density/mixed use land use scenarios; however, there are only marginal differences in transit mode split across the street layouts for each land use scenario. This supports results from other studies, which indicate that although neighbourhood design (including street layout) influences travel decisions, locational and socio-economic variables have a significantly stronger relationship with auto ownership, transit mode choice, and vehicles kilometres travelled. Though not quantified in this study, it is expected that differences in street layout may have a stronger influence on the propensity to walk or cycle than they do on transit use.

Further Research

The study identified several issues and questions that require further research. Additional supplemental analysis could include using speed profiles from the simulation to conduct detailed air emissions modelling, and using data generated by the traffic simulation to evaluate road safety with a macro-level prediction model. It is also uncertain whether or not varying the traffic zone systems for each layout might introduce an inherent bias in the results. It may therefore be insightful to carry out a similar analysis, but using a consistent traffic zone system for all three layouts.

Research topics, which may require significant new analysis, include:

- Comparing alternative transportation layouts in terms of traffic performance and efficiency of infrastructure, and using these insights to speculate on what might be an optimal road layout from a transportation perspective.
- Performing a detailed assessment of the impact of the spacing of arterial connections on arterial traffic flow;
- Assessing the effect of connectivity on non-local traffic infiltration for other study areas and arterial configurations;
- Investigating changes in travel behaviour that are influenced by the street layout; and,
- Studying the pedestrian safety tradeoffs provided by segregated pathways versus sidewalks.

While previous studies have assessed the traffic impacts of increasing street connectivity or commented on the traffic performance of Neo-traditional networks, this the first study to look at the performance of the Fused Grid model and compare it to current alternatives. As such, this study presents a contribution to the neighbourhood design and traffic literature, in that it adds both a new network layout model to the existing repertoire along with an assessment of its performance.

1. INTRODUCTION

1.1 Background and Study Objectives

It has become overwhelmingly obvious that traditional community development approaches are not sustainable or desirable. Most major residential developers are recognizing this and starting to promote “reduced traffic” and “safe and friendly streets” in their marketing information. Articles often appear in newspapers across Canada about the lack of travel options and travel hardships experienced by transit dependent people residing in auto-oriented developments. However, significantly more work is required to move beyond tweaking contemporary community designs and road network layouts. Many communities are now re-examining issues such as street layout and street design, but progress on actual implementation of new approaches has been held back due to a lack of information and a general tendency to go with the status quo.

For several years, CMHC has been promoting an alternative model called the Fused Grid, and this concept is now starting to receive significant interest across Canada, and even in the United States. However, widespread consideration of this model will only occur when traffic planners and engineers can be assured of the transportation network performance impacts and related outcomes such as safety and emissions.

In addition to traffic implications, the characteristics of community transportation systems can also have an effect on modal choice. In particular, the distance between activities and quality of linkages connecting them can influence whether a person is likely to walk, cycle, take transit or drive. In many current suburban neighbourhoods with loops and cul-de-sacs, people must rely on the car to make all regular trips such as getting a bag of milk or a paper. Moreover, children’s activities are severely constrained due to a lack of suitable facilities to walk, cycle or play on the street.

Recognizing the above gaps in knowledge, this study was initiated to conduct a comparative assessment of the transportation impacts of current and fused grid approaches to road layout. The primary purpose of this study is to compare the traffic performance of different neighbourhood street layouts including district and regional streets.

The comparative assessment is carried out using the community of Barrhaven in the City of Ottawa as a test site. A further description of this community and its characteristics is provided below in the following section.

1.2 Study Area

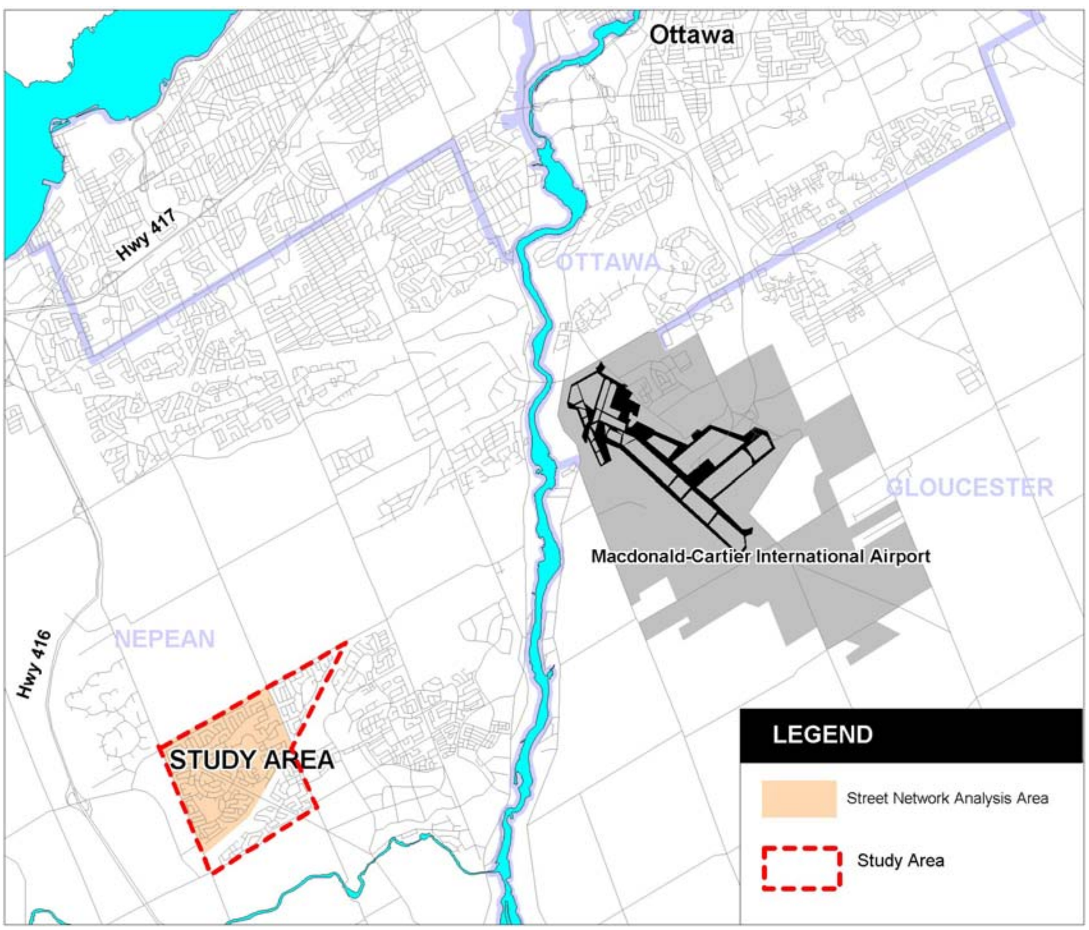
Barrhaven is located in the Census Metropolitan Area of Ottawa-Carleton. The general study area, commonly referred to as Old Barrhaven or Barrhaven proper, is bounded by Fallowfield Road, Cedarview Drive, Strandherd Drive, Greenbank Road and the CN railway Line (Exhibit 1-1). This study area is slightly larger than the study area identified in the Terms of Reference, but was defined to correspond with the traffic zone boundaries in the Ottawa TRANS Model, an important consideration given that the TRANS Model is used to develop transportation activity and related data. While most of the data in this report is presented for this larger study area, the street layout patterns and land use are only varied within the shaded area shown on the map below. This area corresponds to the area that has been studied in the past by CMHC and for which the three road network layouts have been developed. This area is herein referred to as the Street Network Analysis Area.

1.2.1 HISTORY

Mel Barr, for whom the neighbourhood is named, bought the land originally to build a horse racing facility but due to the construction of the Rideau Carleton Raceway decided instead to build a residential community. The community grew quickly in the 1960s; but growth in the surrounding areas was minimal until the 1990s when "big box" stores, malls, and high-tech companies began to arrive. The only major development within the study area since the 1960s has been John McCrea Secondary School, which was built in 1999. The addition of the high school to the neighbourhood as well as the construction of the Fallowfield Transitway Station just outside of the study area in 2000 altered the travel characteristics and patterns within the neighbourhood but they have likely remained constant since this time. This transition from a purely residential district to one that includes retail, employment and higher-level public transit, indicates the natural evolution of suburban districts that occurs over a 30-year period after build-out. Ideally, street patterns in the new neighbourhoods should anticipate such evolution to avoid the negative effects of traffic and costly retrofits.

The existing street network typifies conventional suburban development.

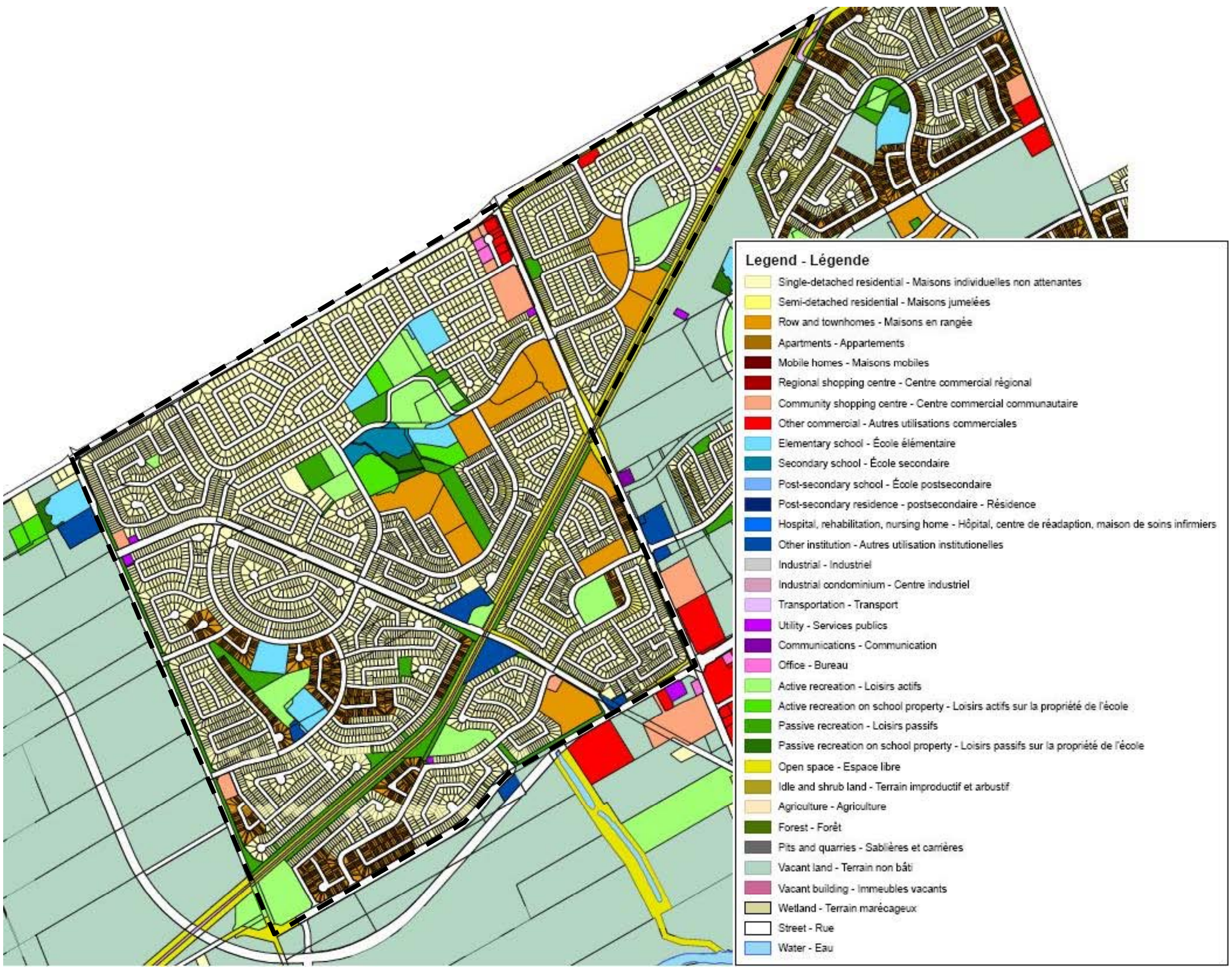
Exhibit 1-1: Study Area Location



1.2.2 LAND USE

As illustrated in Exhibit 1-2, which shows land use for each parcel of land, the Barrhaven study area is a primarily a residential neighbourhood. Thus, it generates many more trips than it attracts. Single-detached residential dwellings represent the dominant land use, while row houses and town homes are another significant land use feature in several isolated areas. In 2001, the larger study area encompassing 520 hectares supported approximately 21,829 residents[2] corresponding to an average gross population density of 42 residents per hectare. The Street Network Analysis area, at 338 hectares, had a population of 13,680 and a corresponding density of 40.5 residents per hectare, not accounting for vacant land.

Exhibit 1-2: Existing Land Use Map



Six elementary schools and one secondary school and their associated active recreational lands make up the majority of the non-residential land in the study area. These schools support a student

[2] Population data come from Statistics Canada, 2001 Census of Canada. Dissemination Areas are a subset of Census Tracts and are defined by Statistics Canada.

population of approximately 3,800. Commercial and other institutional uses are also distributed sparsely throughout the study area.

Employment sources in the study area consist of:

- 7 commercial areas;
- 5 elementary schools;
- 1 secondary school; and
- 3 other institutional uses (e.g. Walter Baker Centre).

Including home-office employment, the average study area employment density is approximately 4.5 jobs per hectare, which is higher than most suburban districts examined in this study but lower than a mature first ring suburb (like Westboro), which is within 5 km of the Central Business District, CBD, and has evolved for at least 50 years (See Appendix A).

1.3 Report Organization

The report is organized into seven (7) chapters. Following this introductory chapter, **Chapter 2** reviews the findings of previous studies relating to suburban neighbourhood street layout and discusses the gaps in research that can be filled by this study and other studies in the future. **Chapter 3** looks at the characteristics of the three street layouts that affect traffic conditions, including street characteristics, traffic zones and public transit routing. **Chapter 4** describes the five land-use scenarios that each street layout was tested under. **Chapter 5** describes the modelling procedure used to test the three layouts under the five land-use scenarios. **Chapter 6** contains the results and the discussion of the results obtained through the modelling procedure. **Chapter 7** is the final chapter, which details the overall conclusions borne out by the results and discusses further research gaps.

Appendix A contains a study conducted during the development of this study regarding the transferability of this study's conclusions to other neighbourhoods by means of showing that Barrhaven is in fact a typical conventional suburban neighbourhood. Appendix B includes figures on road cross-sections for conventional and neo-traditional layouts.

2. LITERATURE REVIEW

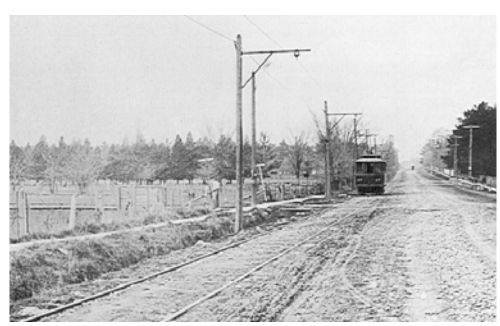
This literature review looks at neighbourhood design issues through a “transportation lens” and is intended to set the stage for the traffic analysis in the subsequent sections. It provides both background material relevant to the understanding of different road network patterns, and broadly outlines the how alternative road network patterns have been shown to influence a variety of factors ranging from traffic level of service, to public health, to land use. A variety of research questions are identified thought the literature review, which are summarized at the end of this section. Some of these questions can be addressed through the traffic analysis detailed later in the report, while other questions are outside of the scope of this study and must be reserved for future work.

Specifically, the literature review:

- Provides a brief commentary on the history and “transportation logic” of different road network patterns;
- Documents known empirical or revealed impacts of alternative network layouts as well as outstanding research questions as they pertain to:
  - Street Connectivity
  - Traffic Level of Service
  - Travel Behaviour
  - Alternate Transportation Infrastructure
  - Public Health
  - Liveability and Safety
  - Accessibility / Mobility Issues
  - Fuel Use and Emissions
  - Land Use; and,
- Identifies gaps that could be filled in by the current study and/or further research.

2.1 Evolution of Road and Street Networks

Many studies have attempted to describe the evolution of how local and regional neighbourhood street patterns have changed over time, several of which have been prepared by CMHC (e.g., Pogharian et al., 2000, Marshall, Stephen, 2005). What is overwhelmingly clear is that local street patterns have been heavily influenced by transportation means and transportation preferences. In recent times, transportation infrastructure has largely been comprised of rail and automobile systems. There is also a strong relationship between urban form at the macro-level and local neighbourhood patterns.

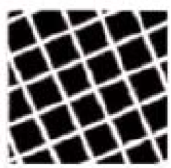
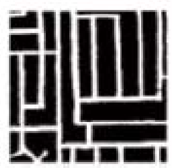
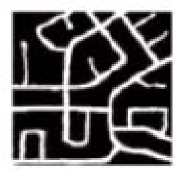


Example of early rail to suburbs

Most of the development activity in North American and some European cities in the last century has focused on “suburbs”, which themselves are dynamic entities. In North America the first suburbs mimicked the street layout of the central core; they were typically laid out in a grid pattern, usually surrounding a railway stop, some attempted to shorten the walking distances by introducing diagonal streets emanating from the station (Mount Royal in Montréal is an example). City blocks were usually 300 feet (980 feet) long to make access easier. Walking was the only mode of transportation for most people within the suburb and within the city core, which was reached by railway or streetcar. For that reason, suburbs had a diameter of about 1,000 metres centered around the station.

The grid street pattern, which was a key feature of the early suburbs, dominated the suburban landscape until people no longer had to rely on rail transportation into the city. Inexpensive cars provided blue-collar workers the option to move into the country while still working in the city. In the 1920s the Regional Planning Association of America (RPAA) was formed and began shaping new developments. Street hierarchy was created to match the traffic demand; neighbourhoods were developed with cul-de-sacs and narrow residential streets surrounded by wider arterials (Handy et al., 2003). Southworth and Owens (1993) diagrammed the evolution of street patterns from a gridiron network to "Lollipops on a Stick" as shown in Exhibit 2-1 below.

Exhibit 2-1: Evolution of Street Patterns (Southworth and Owens, 1993)

	Gridiron (c. 1900)	Fragmented parallel (c. 1950)	Warped parallel (c. 1960)	Loops and lollipops (c. 1970)	Lollipops on a stick (c. 1980)
Street patterns					

In the late 1930s the Federal housing Administration (FHA) published standards for subdivision design that specified 600 to 1,000 feet long blocks, a maximum density of 12 units per acre and encouraged the use of cul-de-sacs while rejecting the grid pattern. The housing construction boom that occurred after World War II was guided by these standards (Handy et al., 2003). The suburban landscape changed and became dominated by curving roads, designed to create quiet, picturesque streets for residential use. These new neighbourhoods had limited access and succeeded in eliminating through traffic. Non-local traffic was shifted to wide multilane arterials that surrounded the pocketed neighbourhoods.

It was in the late 1960s, after a report was published by Harold Marks demonstrating that the FHA design reduced accidents, that the Institute of Transportation Engineers (ITE) published a new document praising the FHA design and called for increasing the right-of-way to a minimum of 60 feet (Handy et al., 2003). As urbanization continued at an accelerated pace, the size of suburban developments grew to several times that of their railway-based predecessors. Traffic generators such as retail and employment centres were removed from residential streets and placed at the periphery of neighbourhoods. The result of a conscious effort to improve the quality of life of residents was low density, predominantly or exclusively residential neighbourhoods serviced by a sparsely connected street network of wide streets that, inherently, discourage walking and bicycling, and render driving as the only feasible option.

Canada Mortgage and Housing Corporation (CMHC) has completed an analysis of the transformations of street layouts and subsequently developed an alternative model, the Fused Grid, which attempts to blend desirable elements of the conventional and grid-based street layouts. This model, described further in the sections below, seeks to give priority to walking and cycling at the neighbourhood level, and free automobile movement at the district and regional scale.

2.2 Classification of Road Pattern Layouts

At the broadest level, there are two basic development patterns that 'bookend' the range of alternatives, which are the Conventional Suburban layout and Traditional neighbourhood layout. The former is most often associated with discontinuous, curvilinear street networks, typified by the existing Barrhaven street network, while the latter is typically associated with grid networks; between these two 'bookends' lie the neo-traditional and fused-grid designs. Neo-traditional street pattern adopts a hierarchical road network and the grid, provides easier access to transit and places major streets and retail at the edge of a small neighbourhood. The fused-grid adopts the traditional grid at the neighbourhood and district scales while adopting the discontinuous street types at the block-group (16 ha.) scale. This is discussed later in Section 2.3.3. Exhibit 2-2 provides a high level overview of these development types.

Exhibit 2-2: Comparative Characteristics of Conventional, Neo-Traditional and Fused-Grid Neighbourhoods

Category	Conventional Suburban Design	Neo-Traditional Neighbourhood Design	Fused-Grid Neighbourhood Design
Transportation Network	Circuitous, meandering streets; missing sidewalks; hierarchical street pattern (arterials, collectors); limited access streets to arterials; wide streets without street parking; predominantly auto-based	Interconnected, grid-like street patterns; integrated pedestrian and cycle paths; narrow streets; on-street parking; reduced speed limits; many access streets to arterials; many modes successful; easy transit accessibility	Interconnected grid network of larger streets surrounding neighbourhood quadrants with looping and dead-end streets; strong hierarchy of streets; green spaces designed to improve pedestrian mobility; easy transit accessibility
Land Use	Segregated, clustered land uses; access to a limited number of "highly desirable" land uses; low residential densities	Mixed land uses; close proximity of land uses; high residential densities; access to parks, recreation and distinct neighbourhood "centres"	Mixed land uses; close proximity of land uses; high residential densities; access to parks, recreation and distinct neighbourhood "centres"

Source: Adapted from McNally and Kulkarni, 1997

2.3 Road Layout Concepts for Detailed Assessment

The primary purpose of this overall study is to compare three distinct road network and land-use approaches:

- Conventional suburban development (featuring loops and cul-de-sacs);
- Neo-traditional neighbourhood development; and
- Fused-grid development.

A road layout of each concept has been developed for Barrhaven. These specific layouts, described in detail in Section 3, will serve as the basis for the analysis of traffic performance and related characteristics by street layout type. The discussion here outlines the defining characteristics of each road layout concept in a general sense.

2.3.1 CONVENTIONAL LOOP AND CUL-DE-SAC

Conventional suburban developments are typically characterized by hierarchical street layouts ranging from quiet loops and cul-de-sacs to wide, busy feeder streets. Conventional neighbourhoods typically have the following defining characteristics:

- Neighbourhoods are predominantly residential but often contain schools and churches; surrounding the neighbourhoods are minor or major collectors, also framed with houses. Employment and retail facilities are located by the arterial streets and generally beyond pedestrian reach for most neighbourhood residents.
- Large lots, greater than 11 meters in width, resulting in a low net residential density (i.e., not considering vacant land/open space) of approximately 20-25 units per hectare and gross residential density of approximately 10-15 units per hectare (CMHC, 1997);
- Very long blocks (up to 600 m), discontinuous streets with no breaks between lots for pedestrians;
- Wide (11 m) two-lane road cross-sections;
- An extensive and persistent use of 3-way intersections and avoidance of 4-way intersections;
- Few access points with surrounding arterials; and,
- Reduced road lane metres by over 30% compared to the classic railway suburb (and, shows in the analysis later, the TND which is patterned on the classic grid).

The development shown in Exhibit 2-3 is an archetypical conventional loop and cul-de-sac layout, defined by the numerous looping streets and dead ends that serve only the dwellings along them. The discontinuous street layout is also characterized by a preponderance of T-intersections and few cross intersections. In addition, there are few access roads to the inner neighbourhood that all traffic must use to enter and exit from surrounding arterials.

The predominant use of T-intersections is expected to result in fewer non-local trips entering the neighbourhoods as well as increase the local traffic's kilometres travelled; this is investigated through this study. A question related to intersection type is: which serves vehicular traffic better, and if both types are necessary, what is an appropriate ratio to enable traffic to move smoothly. Both of these questions are answered in the analysis carried out in this study, as discussed in Chapter 6 and Chapter 7.

Exhibit 2-3: Illustration of Conventional Loops and Cul-de-sacs

2.3.2 NEO-TRADITIONAL GRID

Neo-traditional neighbourhoods are based on the traditional grid but have a hierarchical network of roads composed of a large proportion of 4-way intersections, continuous roads and many access points to the surrounding arterial streets. Exhibit 2-4 illustrates one example of a neo-traditional layout, which is a modified grid. Neo-traditional neighbourhood designs, often grouped under New Urbanism, aim to use higher residential densities and mixed land use to encourage walking and transit use. They may also exhibit the following:

- A mix of commercial uses located at neighbourhood centres within the neighbourhood districts – not solely at the periphery as with the Conventional design;
- Net residential densities of approximately 40-45 units per hectare and gross residential density of approximately 20-25 units per hectare (CMHC, 1997);
- Smaller block lengths than the conventional suburban approach (e.g., 60-120 metres x 120-240 metres, vs. 600 metre block lengths);
- Frequent access points to the surrounding arterials;
- Street cross sections that incorporate, narrower lane widths, bike lanes, and on-street parking; and
- Higher road lane metres compared to conventional suburbs (See Section 3.1.2).

A mix of uses may affect travel behaviour if they are accessible on foot. Small blocks would encourage pedestrian utilitarian trips, assuming the presence of destinations. Smaller setbacks work to crowd the streetscape encouraging drivers to maintain a slower speed. Narrower street pavements also encourage slower driving and make crossings easier for pedestrians. Although not all of these effects can be tested extensively by comparing three layouts, this study does attempt to shed light on some of the major characteristics with TND as compared to the other layouts, including frequency of access points and road lane density.

Exhibit 2-4: Illustration of Neo-Traditional Grid

2.3.3 FUSED-GRID MODEL

The central idea of the fused grid is to combine the accessibility and ease of navigation of the traditional grid with the quietness and land-use efficiency (amount of developed land vs. land used for infrastructure, such as roads) of the conventional loop and cul-de-sac[3]. It has sparked interest in Canada[4] and similar approaches have been adopted in the United States and Australia. The fused-grid shares the same land-use and density principles as the neo-traditional concept. Central to the fused-grid concept is the presence of green space. Green space provides visual relief and a place to relax and for kids to play; it is linked to numerous environmental, social and psychological benefits. Active transportation infrastructure is placed within the green space to improve the mobility of pedestrians and cyclists within the community blocks. Neighbourhood blocks are surrounded by a grid of major and minor collector streets and contain a discontinuous network of local streets. Exhibit 2-5 illustrates a hypothetical fused grid layout.

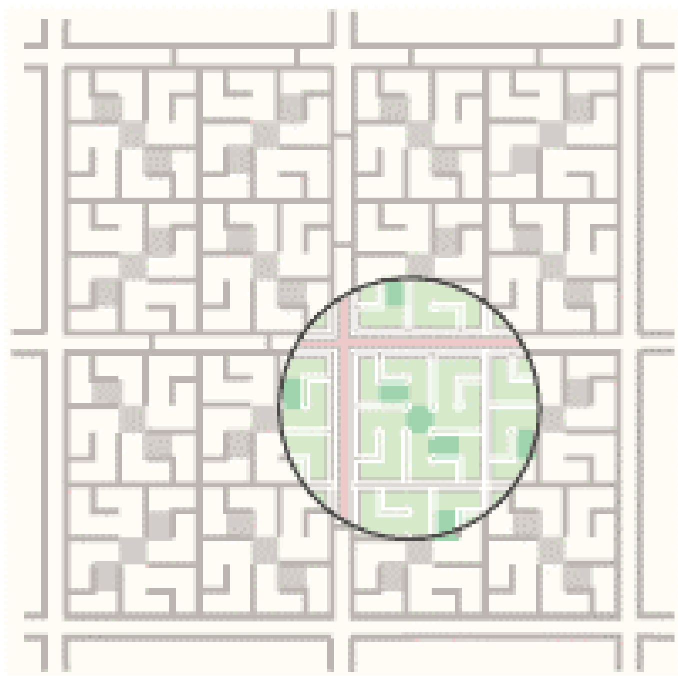
The Fused Grid exhibits the following characteristics:

- Predominately residential land use with commercial land uses contained in the major corridors within the neighbourhood district;
- It is a hierarchical orthogonal grid of roads – at the collector and major collector level scale it imitates the gridiron network of earlier cities while the local streets are discontinuous, looping or cul-de-sac streets;
- Street cross sections that follow the principals set forth in the Neo-Traditional design;

[3] In previous work comparing conventional loop and cul-de-sac, neo-traditional, and fused-grid layouts (CMHC, 2002), it was shown that the fused-grid results in the lowest proportion of land dedicated to streets, leaving the most amount of land for development and open space.
[4] Examples of site plans that incorporate the Fused Grid model in Canada include The Stratford Plan, an approved secondary plan for 300 acres of land recently annexed to the City of Stratford and The Saddleton Plan, a site plan for a 160 acre subdivision in the northeast section of Calgary currently under consideration by the City.

- Most block lengths are under 200 metres but reach a maximum of 600 metres – larger blocks are divided by pedestrian paths;
- Frequent access points to the surrounding arterials;
- Predominance of T-intersections over cross-intersections;
- Clearly defined neighbourhoods by virtue of the collectors that frame them and their opaqueness to through traffic;
- Encourage public transport by placing roads capable of supporting transit routes at five minute walking distance from all neighbourhood points; and,
- Place non-residential uses along major thoroughfares.

Exhibit 2-5: Illustration of Fused Grid

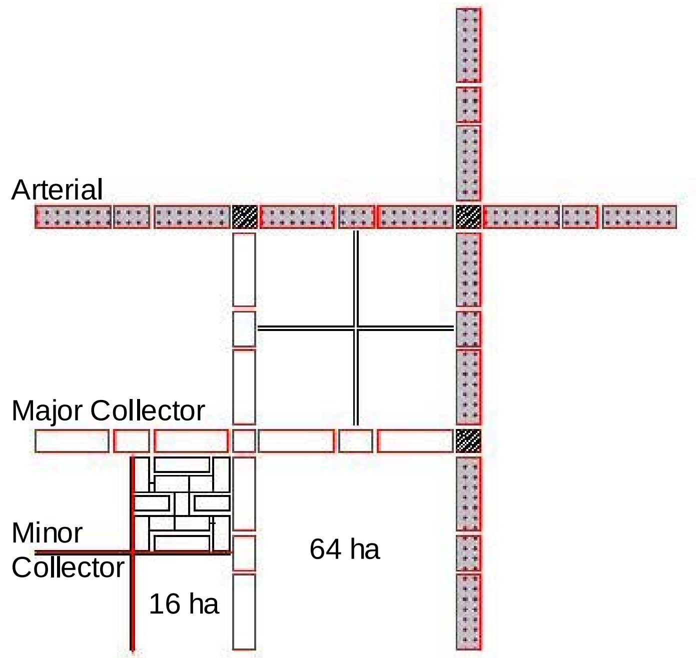


Below, Exhibit 2-6 illustrates an abstraction of the fused-grid layout, which is divided into:

- **Quadrants**: 16 hectare residential areas, which are served internally by cul-de-sacs and loops to discourage through-traffic;
- **Neighbourhoods**: 64 hectares, made up of 4 quadrants and bounded by arterials and collectors; and
- **Districts**: 256 hectares, made up of 4 neighbourhoods and bounded by arterials.

As the streets decrease in hierarchy they become more disjointed to discourage non-local traffic. The analysis undertaken for this study explores the impact of hierarchy, intersection spacing and other inherent characteristics of the fused grid model on issues such as neighbourhood traffic infiltration and traffic level of service.

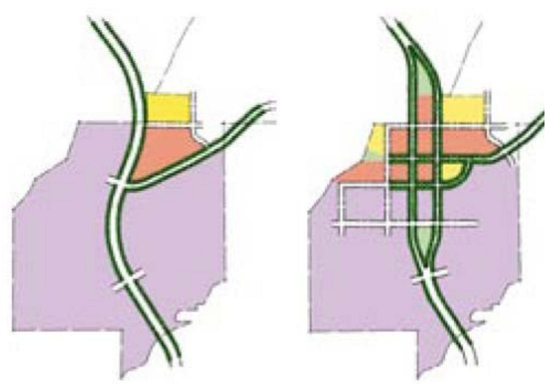
Exhibit 2-6: Fused-Grid Transportation Model



2.4 Additional Recent Models for Structuring Neighbourhoods and Districts

Recent literature cites a number of additional schemes for structuring neighbourhoods and district road networks. Most noteworthy among them are the proposals by Western Australian Planning Commission (WAPC) and Peter Calthorpe. As with the Fused Grid model, both deal with the regional, district and neighbourhood elements of a road network.

Calthorpe proposes a grid network of arterials spaced 1 mile (1.6 kilometres) apart that creates 256 ha districts each of which contains four 64 ha neighbourhoods. This grid includes the occasional use of multi-lane transit boulevards and couplets. Couplets are essentially two one-way streets in place of one two-way street. This option allows development to occur within a busy arterial and within a busy intersection instead of just beside it (Calthorpe, 2002). Besides the development and land-use benefits associated with developing within a busy intersection there are traffic flow benefits associated with couplets.

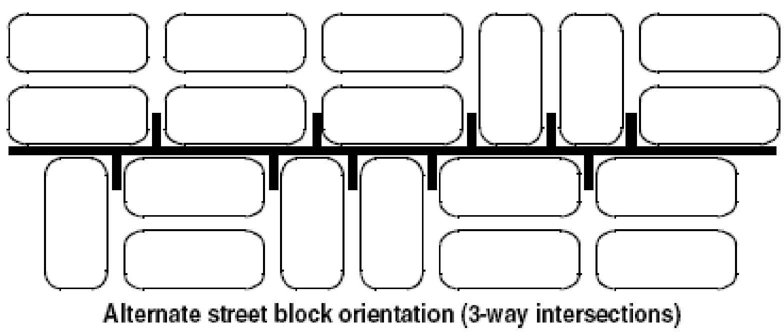


With the implementation of couplets, a busy intersection with long left-turn signals is divided into four simple intersections, each with the possibility of only four movements (two through, one left turn and one right turn). Spreading out the intersection eliminates the need for left turn signals, therefore increasing the time for through traffic. A study in Issaquah Highlands, outside of Seattle, showed 11% timesavings for vehicles travelling through the centre of the city (Calthorpe, 2002). Although more right-of-way is required for sidewalks and services placed around the inside on the intersection, the same number of lanes and pavement surface is required. The fused grid concept developed for Barrhaven includes the implementation of one-way couplets; their use is examined in detail in the subsequent chapters of this study.

Under the Western Australian Planning Commission’s Liveable Communities initiative, a road network a diagram was prepared for use in new developments. It also suggested a 1.6 kilometre grid of arterials that enclose 256 ha districts. These districts are likewise divided into four neighbourhoods of 64 ha. A feature that distinguishes the WAPC model from Calthorpe’s is the discontinuity of the major and minor collector roads at the district and neighbourhood scale (a feature that is also characteristic of the Fused Grid).

To prevent traffic from going through the neighbourhood and to facilitate flow on the collectors surrounding it, the WAPC model proposes alternating block directions as shown in Exhibit 2-7 (WAPC, 2000). These create T-intersections that are permeable by both pedestrians and vehicles but discourage the latter from cutting through. By comparison, loops and cul-de-sacs restrict vehicles from cutting through a neighbourhood, while providing pedestrian connectivity by means of green space and pedestrian / bicycle paths (CMHC, 2002).

Exhibit 2-7: Use of T-Intersections to Create a Fused Grid



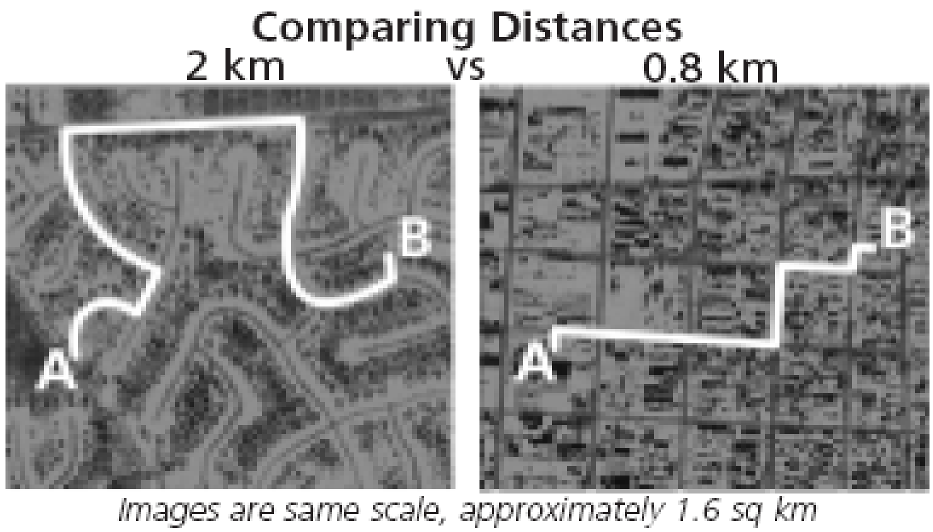
Source: WAPC, 2000

As discussed in Section 6.5.1, the inclusion of one-way couplets (or rather their exclusion) can have an impact on traffic level of service.

2.5 Street Connectivity

Much of the differences between each neighbourhood concept can be described in terms of the connectivity of their transportation networks. Connectivity describes how well the transportation network connects one point to another in a community. It refers to the quantity and quality of the connections, including the number of paths between origin and destination, the directness of the paths, and the modes supported along each path (Handy et al., 2003). The effect of connectivity is illustrated in Exhibit 2-8, which shows the travel distance between two equidistant points for two different neighbourhoods. The actual travel distance is much shorter in the neighbourhood with the grid-based street network. Travel distance is particularly significant to the feasibility of non-motorized trips due to their lower travel speeds.

Exhibit 2-8: Travel Distances in Different Neighbourhood Street Layouts



Source: Sallis et al., 2004 as reported in Frank et al., undated

There is a growing movement in the planning community to increase connectivity at the neighbourhood level, while other parties, often developers, oppose this trend. The key points of this debate are listed in Exhibit 2-9 as summarized by Handy et al. (2003).

Exhibit 2-9: State of the Debate Regarding Increasing Neighbourhood Street Connectivity

Proposed Advantages	Proposed Disadvantages
• Decrease traffic on arterial streets; • Provide for continuous and more direct routes that encourage travel by non-motorized modes and facilitate more efficient transit service; • Provide greater emergency vehicle access and reduced response time; and • Improve the quality of utility connections, facilitate maintenance, and enable more efficient waste collection and other transport-based community services.	• Raise levels of through traffic on existing residential streets; • Increase impervious cover and infrastructure costs; • Increase land consumption per unit; • Decrease housing affordability; and • Threaten profitability of development.

Adapted from Handy et al., 2003

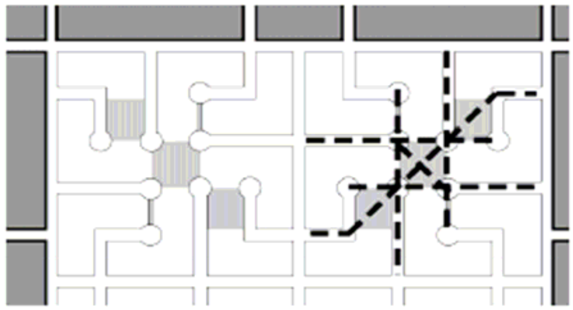
Independent of one's opinion regarding the merits of increasing connectivity, it is clear that street connectivity is an important neighbourhood measure affecting transportation characteristics, land consumption, and the efficiency of infrastructure and service provision, which has received substantial study (Frank et al., 2005; Frank and Hawkins, 2006; Handy et al., 2003; Handy et al., 2005; Daisa et al., undated). Furthermore, it is clear from the general definition of connectivity - the quantity and quality of the connections provided by the transportation network - that the connectivity of the local transportation network varies significantly between conventional suburban neighbourhoods (low connectivity), neo-traditional neighbourhoods (high connectivity), and fused grid designs (varies highly by mode). Thus, connectivity is a key measure for comparing neighbourhood street layouts and connectivity will be an important component in the review of traffic level of service, active transportation infrastructure, and travel behaviour in the following sections.

While there are a variety of studies that investigate the relationship between street connectivity and other characteristics, such as non-motorized travel activity, they do not all define and measure connectivity similarly. Dill (2004) put together a list of the various methods of measuring connectivity:

- **Block Length** – measure of the maximum length of a city block – Longer blocks result in a longer trip to get around them;
- **Block Density** – number of city blocks per square kilometre – the premises is that more blocks result in smaller blocks, which are quicker to navigate around;
- **Intersection Density** – number of intersections per square kilometre or along a kilometre of arterial road – more intersections result from smaller blocks;
- **Street Density** – kilometres of road per square kilometre – travel is done on streets, more streets indicate more route paths for travel;
- **Connected Node Ratio** – number of intersections divided by number of intersections plus cul-de-sacs – cul-de-sacs signify an unconnected network while intersections denote the opposite;
- **Link-Node Ratio** – the number of links divided by the number of nodes – increasing the number of links (street segments) intersecting at a node (intersection) increases the options and mobility at the node, therefore the ratio of links to nodes indicates a sense of mobility in the neighbourhood;
- **Grid Pattern** – number of four-way intersections used as proxy to reflect “neo-traditional” layout – relates connectivity to a scale from conventional loop and cul-de-sac design to traditional grid design.

These measures are universal to all modes in that there are no provisions for mode-restricting paths such as bicycle/pedestrian or transit only routes. The assumption is that these facilities (sidewalks, paths and transit routes) are aligned with the streets. Where this is not the case, different modes will be associated with different connectivity levels and it is suggested to have mode-specific connectivity measures (Frank & Hawkins, draft 2006). This is of particular interest to the fused grid concept, which explicitly assigns some connections to non-motorized modes (Exhibit 2-10).

Exhibit 2-10: Fused-Grid Quadrant Street Pattern and Pedestrian Network



Source: Pogharian et al., 2000

The use of non-motorized modes is very dependant on distance because they are significantly slower than motorized modes. Measures have been created to specifically analyze neighbourhoods for their non-motorized connectivity, which are closely tied to distance.

- **Pedestrian Route Directness** – ratio of route distance to straight line distance between two points – it is suggested that one point be a point of interest to cyclist/pedestrians such as schools, corner stores, green space and public transit (Dill, 2004);
- **Effective Walking Area** – ratio of number of parcels within a one-quarter mile walking distance to the number of parcels within a one-quarter mile radius of the same point (Dill, 2004);
- **Walkability Index** – the normalized sum of three variables (i.e., using z-scores[5]): net-residential density, street connectivity (assuming sidewalks are the only pedestrian paths) and land-use mix; where connectivity is measured by intersection density (Frank et al., 2005).

As mentioned, the connectivity of the local transportation network varies significantly between conventional suburban, neo-traditional, and fused grid street layout concepts. Thus, connectivity is a key measure for comparing neighbourhood street layouts and connectivity will be an important component in the review of traffic level of service, travel behaviour, and active transportation infrastructure in the following sections.

This study explores the issue of street connectivity at the broad level by comparing traffic performance and other measures for the three general layout patterns, which each have different levels of connectivity. A subsequent analysis of the impacts of increasing the number of connecting streets for the Fused Grid is also presented in Section 6.5.2.

2.6 Traffic Level of Service

There are many different ways to measure the level of service of transportation infrastructure. Transportation engineers determine the level of service of highways and freeways by determining

[5] Z scores are sometimes called "standard scores". The z score transformation is especially useful when seeking to compare the relative standings of items from distributions with different means and/or different standard deviations. The z score for an item, indicates how far and in what direction, that item deviates from its distribution's mean, expressed in units of its distribution's standard deviation. The mathematics of the z score transformation are such that if every item in a distribution is converted to its z score, the transformed scores will necessarily have a mean of zero and a standard deviation of one. Z-score for value X = (X-mean)/standard deviation. See http://www.animatedsoftware.com/statglos/sgzscore.htm for more information.

the delay time or volume-to-capacity ratio: an indication of how busy the facility is and what the traffic conditions are like. Signalized intersections effectively decrease the capacity of a congested street because a portion of the signal length (cycle length) is allotted to each direction of traffic (east-west and north-south). As such, the level-of-service of arterials, is limited, for the most part, by the capacity of their signalized intersections. This is typically measured as the number of vehicles through the intersection per hour. Connectivity, often defined by intersection density, can have varying effects on intersection performance as well as the level of service provided by arterials versus internal collector and local streets, as discussed below.

2.6.1 ARTERIAL STREETS

As discussed, the level-of-service of arterials, is limited, for the most part, by the capacity of their signalized intersections. With this in mind, Kulash (1998) refers to a deficiency of scale in street size: as streets get larger and there are fewer intersections, overall traffic performance degrades. Conversely, with a greater number of smaller streets and more intersections (i.e., higher connectivity) traffic should be able to flow more smoothly. This occurs primarily due to turning movements, which can be made more efficiently at smaller streets. At a larger intersection, there are more turning movements, and left turns are relegated to long left turn signals, which delay all other traffic. Alternatively, having a number of stop-controlled service road/arterial intersections along an arterial allows drivers to make their left-turn at multiple locations when there is a break in traffic (Kulash, 1998). However, as the arterials become more congested and breaks in traffic become smaller and further apart, the ability for motorist to make a left-turn without a specific left-turn signal decreases. This also holds true as arterials become wider and have more lanes; besides requiring more time to cross multilane facilities, the vehicles travelling on multilane roads tend to stagger therefore giving left-turning motorists less time and fewer gaps to make their turn (Kulash, 1998).

In addition, in neighbourhoods with low connectivity it is not uncommon and sometimes it is even necessary for residents to use arterials for short distance trips. Neighbourhood street layouts that force drivers onto arterial roads because they provide the quickest or *only* route to their destination negatively affect the level-of-service of the arterials that surround them due to the increased volume of traffic on these facilities.

In an experiment to see how connectivity affected arterial streets in Portland, Oregon, it was determined that increasing connectivity did improve the level of service on the arterials (Daisa et al., *undated*). Using a travel demand model, it was found that shorter-distance trips and some longer distance regional traffic will shift off arterials to parallel routes under higher connectivity scenarios, thereby improving arterial level of service. Average trip length, traffic volume, composition of short and long trips and average travel time were used as factors to describe the level-of-service of the arterial streets; all factors decreased when the connectivity was increased. The arterial intersections were evaluated based on approach volumes and service level, which decreased and increased respectively when the connectivity was increased (Daisa et al., *undated*). The study did come to the conclusion that connectivity can only be increased to a certain level before it begins to negatively affect traffic flow. It was determined that between 10 and 16 arterial connections per mile (i.e., average intersection spacing ranging from 100 metres to 160 metres) yielded the best results in terms of improving arterial traffic flow.

The Transportation Association of Canada (TAC) Geometric Design Guidelines for Canadian Roads (TAC, 1999) also provides recommendations regarding intersection spacing. In developed areas, a minimum intersection spacing of 200 metres is recommended along arterials to ensure minimum lengths of storage for left turning vehicles at adjacent intersections. As stated in the Guidelines, where intersections are signalized, 200 m is not sufficient to permit optimal signal progression. Therefore, a number of alternatives are proposed to retrofit roadways with shorter intersection spacings including conversion from two-way to one-way operation, implementation of cul-de-sacs for minor connecting roads, and restriction of turning movements at select intersections to right turns only. On this latter alternative, the TAC Guidelines specifies that, on divided arterial roads, right-in, right-out intersections without a median opening may permitted at a minimum distance of 100 metres from adjacent all-directional intersections.

Although the scope of this study did not permit the testing of a large number of different arterial spacings, a comparison of the traffic performance for the three layout typologies is provided. This analysis includes measures such as VKT and vehicle delay, and shows under what density levels each layout starts to break down.

2.6.2 NEIGHBOURHOOD STREETS

Increasing connectivity has the opposite effect on the level-of-service of neighbourhood streets, consisting of both collectors and local streets, than it does on arterials. Having multiple access points to the arterials allows traffic to penetrate into the community – increasing the traffic on neighbourhood streets. Some of the increase in traffic will be local traffic that is now able to take multiple routes to reach their destination within the community, but much of it may be long distance travellers using the service roads to bypass congested arterials and arterial intersections (WAPC, 2000). Although, average trip length and time will decrease due to increased connectivity, vehicle volume and the decrease in safety associated with an increase in traffic volume may result in a perceived reduction in the liveability of neighbourhood streets.

The micro-simulation model developed for this study makes it possible to estimate the impacts of alternative layout patterns on non-neighbourhood traffic infiltration (See Section 6.3.2).

2.7 Travel Behaviour

The effect of local urban form on urban travel patterns has received significant research attention, but most studies concede that more work needs to be done to describe and test this relationship. Will designing pedestrian, cyclist, and transit-friendly neighbourhoods, such as the neo-traditional or fused grid models, actually encourage travel by more sustainable modes? A review of the effect of neighbourhood design on travel behaviour is provided by Engel-Yan et al. (2005) and this study, among others, informs much of the following discussion.

2.7.1 THE EFFECT OF NEIGHBOURHOOD-SCALE URBAN FORM

While many studies, which have generally been conducted at a broad urban scale, have established that differences in regional travel behaviour can be related to several key factors, including residential and employment density, mix of uses, and urban design (Frank and Hawkins, 2006), the importance of neighbourhood-scale urban form is less certain. Research by Handy (1993) found that residents within traditional neighbourhoods of the San Francisco Bay area would make more non-work trips by walking and cycling within the neighbourhood than those in auto-oriented neighbourhoods. Other studies have also reported that transit use is higher by residents of neo-traditional neighbourhoods than those in suburban areas (Friedman et al. 1994).

Some studies, however, in which other travel demand factors have been taken into account have been less definitive. McNally and Kulkarni (1997) found that differences in trip rates and mode choice between traditional and contemporary, auto-oriented neighbourhoods in Orange County, California were statistically insignificant when the effects of household income were incorporated. Another confounding factor is that of self-selection. Do neighbourhood characteristics actually cause individuals to change their travel characteristics or do individuals choose the neighbourhood because it supports travel characteristics that they already possess (Krizek, 2003)? The effectiveness of alterative neighbourhood concepts is perhaps then contentious.

A significant study demonstrating the link between neighbourhood form and travel behaviour was conducted by Cervero and Radisch (1996). This study made a matched-pair comparison of a conventional suburban and a traditional neighbourhood on the east side of the San Francisco Bay area. Other than differences in their built environments, the neighbourhoods were quite similar: same geographic area, similar distances to downtown San Francisco using the same regional freeway, both had a Bay Area rapid transit station on the same line, and median household incomes differed by only 4%. Residents of the traditional neighbourhood had significantly greater use of non-auto modes (Exhibit 2-11). The differences were particularly large for shopping trips (19% versus 2%) and social-recreational trips (17% versus 5%).

Exhibit 2-11: Percentage of Trips by Non-Auto Modes by Residents of Two Communities in San Francisco Bay Area (Cervero and Radisch, 1996)

Type of Trip	Lafayette (conventional neighbourhood)	Rockridge (traditional neighbourhood)
Shopping	2%	19%
Social-recreational	5%	17%
Work trips (main mode)	21%	37%
Access trips to BART system for work	13% (walking)	31% (walking)

Note: BART=Bay Area Rapid Transit

Clearly, the relationship between neighbourhood urban form and travel behaviour is not straightforward. How can the differences between these studies been explained? Work by Kitamura et al. (1997) suggest that residents' attitudes can be even more significant than land-use characteristics in explaining mode choice. While this may be a factor, it is also important to note that the neighbourhoods in Orange County, California studied by McNally and Kulkarni (1997) do not have the major transit infrastructure in place to which pedestrian friendly neighbourhoods could feed. The San Francisco Bay area, on the other hand, does. Friedman et al. (1994) put it aptly when they noted that if a neo-traditional neighbourhood is built as an "island" surrounded by standard suburban subdivisions then changes in travel behaviour could be limited.

Designing pedestrian, cyclist, and transit friendly neighbourhoods will likely increase non-auto travel within the neighbourhood; however, the effect of neighbourhood design on travel mode choice for longer trips is subject to larger scale constraints, such as the proximity of the neighbourhood with respect to transit stations or stops, the extent and quality of the regional transit network, and the relative location of the neighbourhood with respect to employment and commercial and recreational facilities.

This current study investigates the impact of density on the traffic performance of the three layouts, but is limited in terms of the exploration of urban form on travel behaviour. As discussed further in Section 6.2.2, the modelling approach and subsequent simulation are not sensitive to changes in urban form at the local level(other than density and street patterns). These types of conclusions are perhaps best made through comparative studies of actual neighbourhoods.

2.7.2 THE EFFECT OF STREET NETWORK DESIGN

The relationship between street network design and travel behaviour is highly relevant to this study, since it affects trip generation, which is the first step in the evaluation of the traffic performance of each neighbourhood concept. While trip generation rates will be held constant across street layouts during traffic simulations in order to be able to compare the traffic performance of each street network, the ability of a neighbourhood concept to reduce auto travel will further improve its traffic performance.

Unfortunately, the effect of street networks on travel outcomes is poorly understood and has undergone limited empirical investigation (Ewing and Cervero, 2001). Furthermore, as identified by Frank and Hawkins (2006), most research that has considered street networks has not distinguished between motorized and non-motorized modes. This is a particularly important consideration when the motorized and non-motorized modes have different levels of connectivity, such as in the fused grid concept. This highlights the need to perform separate analyses to assess how well a neighbourhood supports motorized and non-motorized modes.

Building on this need, Frank and Hawkins (2007) have assessed the travel impacts of contrasting pedestrian and vehicular connectivity using regression analysis on travel data for the Seattle Region. They have found that a street pattern that has more direct connections for people traveling on foot is associated with more walking activity. However, the strength of association between connectivity appears to be somewhat less influential than the relative density of walking facilities in a neighbourhood as well as the sheer presence of nearby retail stores. Their regression model demonstrated that, in this study region, a change from a pure small-block grid to a modified grid providing more direct pedestrian connections (i.e., the characteristics of a Fused Grid) can result in an increase in odds of walking for home-based travel of 5.6%. This street pattern configuration was also associated with reduced vehicle travel and a decrease in overall number of trips. Similarly, when total sidewalk length relative to the length of street segments (relative network density) increased by 10% in the area around a household, odds of pedestrian travel increased by at least 7.7% and that of driving drops by 4.6% (Frank and Hawkins, 2007).

Other literature assessing the effect of street network design on travel behaviour exhibits mixed results in terms of the effectiveness of increasing connectivity on reducing auto travel. Using intersection density to describe the street network, Frank et al (2005) found that residential street design did not have a significant influence on walking activity. The SMARTRAQ Project analysis in Atlanta, Georgia (SMARTRAQ, 2004) found that doubling the current regional average intersection density, from 8.3 to 16.6 intersections per square kilometre would reduce average vehicle mileage by about 1.6%, causing a reduction from approximately 32.6 to 32.1 average weekday vehicle miles travelled (VMT) per capita (16+ years old) across the region, all else held constant. The LUTAQH (Land Use, Transportation, Air Quality and Health) research project sponsored by the Puget Sound Regional Council (LUTAQH, undated) also found that per household VMT declines with increased street connectivity, all else held constant. The study indicates that a 10% increase in intersections per square mile reduces VMT by about 0.5%.

In addition, traffic modeling by Kulash et al. (1999) predict that a connected road network reduces VMT within a neighbourhood by 57% compared with conventional designs. This is a significant reduction; however, it should be noted that neighbourhood travel only represents 5-10% of total vehicle travel, and shorter trip distances may be offset somewhat by increased trip making in neighbourhoods with higher connectivity (Crane, 1999).

Overall, these studies point to the potential for higher connectivity street networks to reduce auto travel and encourage non-motorized travel. Intersection density appears to be a common measure for street connectivity, but it does not always exhibit a relationship with walking activity. It may also not be appropriate for street networks where a significant portion of the non-motorized network is separate from the street network, such as fused grid, as shown in the Frank and Hawkins (2007) study where route directness and the density of pedestrian facilities have been used as explanatory variables.

The analysis of street network design on traffic performance is the primary focus of this study. However, further research may be required to quantify the impacts of street network design on alternative modes such as walking and cycling.

2.8 Alternate Transportation Infrastructure

Alternative transportation modes typically share the same transportation corridors as vehicles, namely road right of ways. Transit vehicles usually travel on the same facilities as autos while bikes may travel on the road, on an adjacent lane or path, or on an off-road trail. For the most part, in neo-traditional and conventional designs roads and sidewalks/paths are located in the same right of way. When trails are added to community design they are done so to provide an enjoyable space to stroll, which often does not develop into a time saving route for commuting.

A key characteristic of neo-traditional design (based on the traditional grid) is that it incorporates alternate transportation infrastructure into its design to take advantage of the proposed mixed land-use and higher density development. Neo-traditional design requires that residential and non-residential land-uses be connected via a network of bicycle paths and pedestrian walkways (Friedman, 1994). Developers often make the pathways too narrow and isolated when they pass through residential blocks; these pathways can be unsafe discouraging users from using them (Frank & Hawkins, 2006). It is important that paths and parks can be passively watched by residents to maintain their utility.

In almost every case the fused-grid layout separates the non-motorized transportation network from the motor vehicle street network at the neighbourhood level. Sidewalks along roads and paths through parks create a highly connected network for pedestrians and cyclists while the parks act as barriers to motor vehicle connectivity. Putting as much effort into developing a coherent network for non-motorized modes of travel that put into developing street networks increases the utility and safety of the network.

Alternative transportation modes are not modelled explicitly in this study. However, some of the measures quantified in the neighbourhood comparisons (such as neighbourhood traffic infiltration and average speeds) can provide insights into conditions for alterative modes.

2.9 Public Health

2.9.1 NEIGHBOURHOOD-SCALE URBAN FORM, PHYSICAL ACTIVITY & OBESITY

Recent studies state that, in the last 20 years, the prevalence of obesity has more than doubled in Canada (Katzmarzyk, 2006). In 2003, about 15 percent of Canada’s population was considered obese and one-third was classified as overweight (Vanasse et al., 2005). Based on American figures, over 70% of American adults are not getting the recommended 2.5 hours of moderate physical activity per week. In addition, 25% of trips in America are less than 1 mile and, of these short trips, 75% are made by car (Killingsworth 2003). Encouraging people to make a greater proportion of trips by non-motorized modes, particularly for the shorter trips, to increase activity levels and reduce obesity should be a consideration when planning neighbourhoods. In addition, automobile emissions are associated with many health conditions, so that reduced automobile use improves public health by reducing automobile-related degradation of air quality. Thus, the effect of a neighbourhood concept on public health will depend in part on its ability to support non-motorized modes of transportation and minimize vehicle emissions.

Further work on the subject of public health and neighbourhood design has tried to characterize the relationship between land-use/neighbourhood layout and physical activity. This research is closely related to the studies discussed in Section 2.7. The debate is that conventional loop and cul-de-sac neighbourhoods are less conducive to non-motorized forms of transportation and therefore have a negative effect on the activity level and health level of its residents.

One common approach is to try to relate Body Mass Index (BMI) with neighbourhood design characteristics and the travel activity of residents. In Frank et al. (2004), the neighbourhood characteristics were simplified to a single measure of land-use mix due to its colinearity with connectivity and residential density. The study found that:

- For each additional kilometre walked there was a 4.8% reduction in the odds of being obese (defined as BMI > 30);
- Each additional hour spent in a car added 6% to the odds of an individual being obese; and
- For each quartile (quarter of the difference between minimum and maximum observed) increase in the land-use mix there was a 12.2% decrease in the odds of being obese (Frank et al. 2004).

Handy et al. (2005) support these results conceptually in showing that neighbourhood design can reduce driving activity; however, this study also argues that travel behaviour can be largely explained by attitudes and that travel behaviour is more related to socio-demographic factors than characteristics of the built environment.

In contrast to this latter point, Frank et al. (2005) found that the walkability of a neighbourhood is the most important determinant of pedestrian activity at the neighbourhood level. These results were determined by comparing a personal walkability index, defined as the area able to be covered by walking 1 kilometre on the street network, for each monitored individual, with the measured walking activity of an individual over a week. The walkability index explained more variance in walking activity than any of the demographic characteristics.

In another study, the relationship between a single index of walkability that incorporated land use mix, street connectivity, net residential density, and retail floor area ratios, and health-related outcomes in King County, Washington was evaluated (Frank et al. 2006). Based on this study, a 5% increase in walkability was found to be associated with a per capita 32.1% increase in time spent in physically active travel, 6.5% fewer vehicle miles traveled, a 0.23-point reduction in body mass index, 5.6% fewer grams of oxides of nitrogen (NOx) emitted, and 5.5% fewer grams of volatile organic compounds (VOC) emitted.

Finally, De Nazelle (2006) identifies the potential negative health consequences of encouraging pedestrian activity in neighbourhoods in which it may not be appropriate. In some areas, the benefits of encouraging pedestrian activity may be outweighed by the health impacts of residents exposing themselves to low air quality and a high risk of traffic accidents. Neighbourhood design strategies aimed at improving public health must balance the risks of each approach.

It is beyond the scope of this study to conduct a detailed analysis of the link between neighbourhood form and health. However, some of the measures quantified in the neighbourhood comparisons (such as neighbourhood traffic infiltration and average speeds)

can provide insights into how likely people are to walk and cycle. As noted in Chapter 7, further research is required in the area of detailed emissions modelling.

2.9.2 CHILDREN AND YOUTH

Parents seek out new suburban developments to benefit their children, and find that from a transport perspective there are many shortcomings. Long distances, inadequate provision for pedestrians and cyclists, and poor public transit service mean that most travel is by car. Young children can spend long periods each day in cars, going to and from childcare and with parents on errands. Older children spend long periods in school buses too. Youth, who in the inner city would be independently mobile, rely on parents and older relatives and friends to ferry them around. Older youth work long hours at low-paying jobs to support car purchase and operation, when the car is used chiefly to reach the job, and the whole process interferes with study and leisure.

Spending large amounts of time in vehicles results in several kinds of problems.

- In-vehicle air quality is often poor, including in school buses, and long exposures are potentially harmful, especially to children and youth, who are generally more vulnerable to harm from pollution than adults (WHO, 1996; Elsom, 2003).
- Movement by vehicle can mean lost opportunities for physical exercise, which is especially important for the development of children and youth (Shields, undated).
- Viewing the world through a windshield or a bus or car side window provides a severely restricted perspective on what close up could be an enriching social and natural fabric. Children and youth who travel by car or bus to school and elsewhere are disadvantaged in comparison with children and youth who walk and cycle (Herry Consult, undated).
- Early use of public transit promotes independence and responsibility. But, if there is not an easy, safe way to walk to a main road where buses pass, children and youth may not be encouraged to use public transit (Gilbert and O'Brien, 2005; Bray et al., 2005).

Thus, the availability of safe, direct means of walking and bicycling within a development can make a major difference to the health and well-being of children and youth. Readily accessible common spaces where neighbouring children can play and youth can hang out can be of vital importance in community building and in integrating children and youth into neighbourhoods as well as into families.

A further point is that street layouts likely to encourage lower vehicle speeds will result in less serious harm to children (and adults) if traffic-related injuries occur (Gilbert and O'Brien, 2005).

In 2005, the Centre for Sustainable Transportation finalized *Child- and Youth-friendly Land-Use and Transport Planning Guidelines* for Ontario and draft versions for British Columbia and Nova Scotia.[6] Of the 27 guidelines, the following 13 seem of particular relevance in considering street layouts and amenities for non-motorized transport in a residential neighbourhood:

[6] The 72-page *Guidelines* document for Ontario is available at the Centre's Web site at http://cst.uwinnipeg.ca/documents/Guidelines_ON.pdf. It sets out the rationale for each guideline and other information. Since developing the guidelines in 2005, the Centre has focused on disseminating the *Guidelines* document within Ontario. Support could be forthcoming during 2007 for completion of the drafts for B.C. and Nova Scotia and development of versions for the other provinces.

Guideline 1. In transport and land-use planning, the needs of children and youth should receive as much priority as the needs of people of other ages and the requirements of business.

Guideline 4. Identify where children and youth want to go or need to go and, to the extent possible, provide ways of getting there by foot.

Guideline 5. Explore pedestrian routes used or to be used by children to ensure that they are as usable by them as possible.

Guideline 6. Explore pedestrian routes to be used by children to ensure that they are as safe for them as possible.

Guideline 8. Separate sidewalks used by children and youth from heavily trafficked roads, particularly where traffic moves slowly or vehicles are stationary with engines idling for long periods.

Guideline 9. Ensure that sidewalks are always cleared of snow.

Guideline 10. For older children and youth, ensure that destinations that cannot be a walk away are no more than a bicycle ride away.

Guideline 11. For younger children, ensure that sidewalks are suitable for their tricycles and bicycles.

Guideline 12. For destinations to be reached by bicycle, provide separate bicycle paths, and install bicycle lanes on regular roads only as a last resort.

Guideline 13. Ensure that bicycle riders are well provided for at intersections and have sufficient priority for forward movement.

Guideline 14. At destinations, provide secure, convenient bicycle parking.

Guideline 24. Take all possible steps to reduce amounts of road traffic generally.

Guideline 25. In urban areas, post and enforce much lower speed limits.

All these guidelines deserve consideration in relation to each of the three street layouts under consideration. However, there are two key guidelines in respect to which are pertinent to the comparison of the three layouts.

The first of these is Guideline 6 concerning the safety of pedestrian routes. ‘Safety’ here means safety in respect of both traffic and other hazards, including those involving unwanted contact with other people. Young children will be accompanied at all times, but children aged about 10 years and older may want to and even be expected to travel to school and other destinations in the area without an adult. Being able to make such journeys can be an important part of growing up.

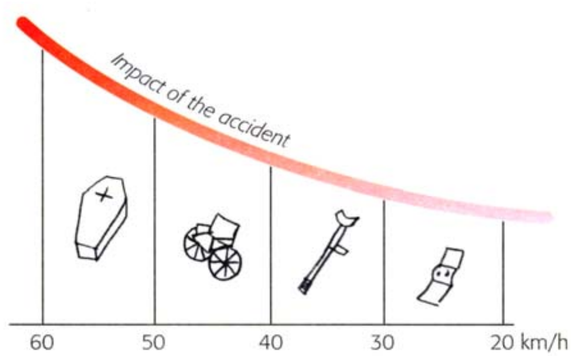
For parents and caregivers to be comfortable about such unaccompanied travel, sidewalks have to be safe in relation to traffic and pedestrian pathways have to be safe in relation to other people. (It goes without saying that there have to be sidewalks.)

Danger points for travel along sidewalks are usually at intersections, where good arrangements should be in place for safe crossing (traffic signals, crossing guards, etc.). Sidewalks should be of an adequate width to reduce inadvertent—or even necessary—stepping on to the pavement. Sidewalks and, especially, intersections should be well lit after dark. They should be visible from houses, yards, and other locations to add to the perceived and actual safety of users, notably children.

The last points are especially important for pedestrian pathways—e.g., those that may run diagonally within fused grid blocks—which unless special steps are taken may be less amenable to informal supervision. Youth—i.e., young people between about 14 and 17 years—present a special challenge. They should be encouraged to use pedestrian pathways, but may also be disposed to ‘hang out’ along them, possibly intimidating—perhaps inadvertently—other users. Design features can address this challenge, by making walkways less conducive to ‘hanging out’ and by providing alternative places to be.

Guideline 25, concerning traffic speeds, presents a challenge in comparing the three layouts because traffic speeds could be higher with a particular layout and therefore more advantageous with respect to energy consumption and emissions, but this conflicts with the safety of children and youth.

On the right is a schematic of the relationship between the severity of an incident involving a moving vehicle and a pedestrian and the speed of the vehicle. Below about 20 km/h the impact is likely to be trivial. Above about 50 km/h the impact is likely to be fatal.[7]



Thus, to protect all pedestrians but particularly children, steps should be taken to ensure that traffic speeds on local streets are kept below 20 km/h. This may seem unnecessarily low, but it is worth pointing out that such low speeds limits are seen increasingly on local roads in Europe and even in Canada. In Austria, speed limits on local roads are often as low as 10 km/h, chiefly to protect children. However, lower speed limits are often insufficient to reduce speeds, rather, roads need to be designed properly via traffic calming techniques to be self-enforcing with respect to speeds.

In general, the fused grid has been found to be more conducive than the other examined street layouts to the needs of children and youth. However, in the latter respect there were two caveats. One is that care should be taken to enhance the appearance and reality of the safety of pedestrian pathways. The other is that steps should be taken to ensure that traffic speeds on local streets remain low.

2.10 Liveability and Safety

The design of the transportation network has many implications for neighbourhood liveability and safety. Lovegrove and Sayed (2006) assess collision data from 577 neighbourhoods across the Greater Vancouver Regional District, and relate collisions to a variety of neighbourhood characteristics including transportation demand, socio-demographic variables, and street network variables. While exposure (i.e., vehicles kilometres travelled) is the dominant variable in collision modelling, increased collision rates were also found to be associated with increases in traffic signal

7 The schematic is a reproduction of Graph 2.2 on Page 25 of European Commission, Directorate-General for the Environment, *Kids on the Move*, Office for Official Publications of the European Communities, Luxembourg, 2002, available at http://ec.europa.eu/environment/youth/original/air/kids_on_the_move_en.pdf (accessed March 18, 2007).

density, intersection density, and total arterial road lane kilometres. In addition, decreased collisions were found to be associated with increases in three-way connections (Lovegrove and Sayed, 2006). These results indicate that conventional suburban, neo-traditional, and fused grid concepts all have characteristics that will increase and decrease collision rates in different ways.

Although all neighbourhood designs can employ T-intersections (instead of 4-way), they are intentionally included in conventional and fused-grid layouts for their safety benefits. The number of 4-way intersections, although beneficial for mobility, can negatively affect the safety of a neighbourhood. Statistically, 4-way intersections are more dangerous than T-intersections; T-intersections reduce the number of accidents caused by a mistaken perception of priority (WAPC, 2000). On the other hand, the neo-traditional layouts, in particular, has higher a intersection density, which was found to be associated with increased collisions (Lovegrove and Sayed, 2006).

Cul-de-sacs provide the safest environment for both pedestrians and vehicles due to the low speeds and volumes of vehicles. Local roads in fused-grid and conventional neighbourhoods are mostly cul-de-sacs and loops and are therefore safer than the local streets in neo-traditional neighbourhoods. There is evidence that supports the notion that conventional loop and cul-de-sac design produces safer neighbourhoods. Local streets in Dayton, Ohio that were converted into cul-de-sacs saw a 67% decline in traffic, 40% decline in accidents and 26% reduction in crime (50% reduction in violent crime)(Southworth & Ben-Joseph, 2004). Homeowners along cul-de-sacs also contend that there is a greater sense of neighbourhood (Southworth & Ben-Joseph, 2004).

Arterials are the most dangerous streets because of their speeds and volumes. Increasing the connectivity is expected to decreases the vehicle volume on arterials and may also reduce traffic speed due to the numerous access points. As such, the safety of arterial facilities, may relate to traffic management and pedestrian infrastructure initiatives. Wide high-speed arterials with great distances between intersections and no pedestrian infrastructure such as sidewalks and crosswalks are the most dangerous streets for pedestrians – 50% of all pedestrian deaths occur on arterials (Ernst, 2004).

Further, walking is the most dangerous form of transportation per mile. As shown in Exhibit 2-12, almost 52,000 pedestrians died in the United States between 1994 and 2003; although only 8.6% of trips are walking trips, pedestrians account for 11.4% of all traffic deaths. Conventional street layouts were designed for automobile traffic and do not encourage pedestrian and bicycle traffic. Wide major collector streets in these neighbourhoods improve vehicle flow and have the effect of increasing vehicle speeds. Increased approach speeds result in more and more serious vehicle-vehicle and vehicle-pedestrian accidents at intersections.

To improve pedestrian mobility, discontinuous networks, such as those found in the fused grid and conventional suburban layouts, tend to have narrow pedestrian paths running through blocks. These paths are segregated from more utilized land-uses and therefore there is no opportunity for passive surveillance. In addition, these paths may cross streets halfway through blocks instead of at an intersection creating a higher risk of collision at these crossings than with regular sidewalks (Frank & Hawkins, 2006). This raises the point that pedestrian infrastructure must be designed with careful safety considerations.

Exhibit 2-12: Transportation Fatalities by Transportation Mode (Ernst, 2004)

Mode Of Transportation	Number Of Deaths Per 100 Million Miles Travelled
Public Transportation	0.75
Passenger Cars & Trucks	1.3
Walking	20.1

Other than this literature review, this study was not able to comment on the impacts of road layout on safety and liveability; however, this topic is currently being explored by others (i.e. Lovegrove).

2.11 Accessibility/Mobility Issues

Accessibility is the ability to reach a desired destination; it is affected by mode of transportation and network connectivity. In a more accessible neighbourhood, residents benefit from the ability to conveniently travel to and from the neighbourhood; however, undesirable visitors are also more likely to access the area. The conventional design has a slew of unintended problems relating to limited accessibility (Phillips, 2005). There have been instances when disaster response teams have incurred significant delays because they had to circumnavigate poorly connected neighbourhoods. Emergency response times also suffer when responding to calls in poorly connected neighbourhoods (Handy et al. 2003).

The lack of street continuity in conventional loop and cul-de-sac neighbourhoods makes it difficult to efficiently service the neighbourhood with public services such as garbage collection and postal delivery. Postal services have sidestepped this problem by grouping the postal boxes and placing them along a more efficient route. Garbage collectors and other private companies such as newspapers do not have this option; their collection/delivery costs are increased.

Neo-traditional design has the reverse problems associated with accessibility. High automobile accessibility in neighbourhoods results in more long distance traffic travelling through neighbourhoods instead of using the arterials.

Accessibility is also related to navigability, that is, if it is difficult to orient oneself in a neighbourhood the ability to reach a destination is reduced. Cul-de-sacs and winding, looping streets are easy to get lost in; alternatively neo-traditional and fused-grid layouts are easy to visualize and drivers stay oriented because changes in direction are obvious, usually involving a turn at an intersection.

This study quantifies connectivity from a vehicular perspective in Section 6.3.1.

2.12 Vehicle Fuel Use and Emissions

Different neighbourhood street layouts affect vehicle fuel use and emissions through their effect on vehicle trip characteristics and propensity to drive. Vehicle fuel use and greenhouse gas (GHG) emissions are highly related. For gasoline-fuelled automobiles, emissions of GHGs are almost precisely correlated with fuel use. Diesel-fuelled vehicles produce fewer GHGs, other things being equal, but among diesel vehicles there is again an almost precise correlation between emitted GHGs and fuel use.

Vehicle emissions of air pollutants, often referred to as criteria air contaminants (CACs) (e.g. NO_x, SO_x, O_3), are not as closely related to vehicle-kilometres travelled as greenhouse gas emissions. CAC emissions are particularly bad during the first few minutes of automobile operation when the engine is cold (i.e. cold start emissions). Furthermore, evaporative emissions may continue to be released after the engine is turned off and the engine is still hot (i.e., hot soak emissions). Thus, CAC emissions are particularly sensitive to the number of trips.

Expected differences in vehicle fuel use and emissions between neighbourhood street layouts are discussed below based on vehicle trip characteristics and propensity to drive.

2.12.1 VEHICLE TRIP CHARACTERISTICS

Fuel use by a vehicle depends on the following operational factors, other things being equal in each case:

- **Distance**: This is the most important factor. The farther a vehicle moves, the more fuel it uses.

- **Speed**: Fuel use typically declines steeply from 0 to about 35 kilometres per hour, it is constant from 35-80 km/h, and then rises as speed increases further (Oak Ridges National Library, 2006). (Note that for vehicles with electric motors, including hybrids, fuel use increases with speed from 0 to the maximum km/h, more steeply at higher speeds.)

- **Acceleration**: More fuel is used at a given speed if a vehicle is accelerating than if its speed is constant. A car that takes 4 seconds to go from 0 to 40 km/h uses about 50% more fuel during acceleration than a car that takes 8 seconds to reach the same speed (Rakha and Ding, 2003).

Other things being equal, the fuel used to travel between two points depends on the route distance and the amount of variation in speed that is required. Layouts that increase one or the other, or both, increase the amount of fuel use. Overall, the conventional layout tends to increase distance and reduce speed variation compared with the neo-traditional layout; the fused grid is a compromise in both respects. The particular effects of these trip characteristics on fuel use require investigation; however, as reported by Crane (1999), neighbourhood travel only represents 5-10% of total vehicle travel time. Thus, the vehicle trip characteristics of distance, speed, and acceleration (i.e., not propensity to drive), are not expected to account for substantial difference in vehicle fuel use and emissions between the neighbourhood street layouts.

Although it is possible to relate vehicle speeds and volumes to emission levels for each neighbourhood, it was felt that the uncertainties inherent to these calculations are likely to outweigh the resolution of the model results. Therefore, recommendations for further research are identified in Section 7.

2.12.2 PROPENSITY TO DRIVE

A more important neighbourhood factor affecting vehicle fuel use and emissions could be the extent to which the different layouts promote automobile use. Existing research, reviewed in Section 2.7 and Section 2.9 indicates that built environment does affect travel behaviour, although the relationship between the street network and vehicle use requires further study (Frank and Hawkins, 2007). The fused grid may provide the most attractive conditions overall for non-motorized movement.

A previous CMHC study (IBI Group, 2000) investigated the effect of neighbourhood design and neighbourhood location on GHG emissions from urban transportation. The study found that, although neighbourhood design (including street layout) influences travel decisions, locational and socio-economic variables have a significantly stronger relationship to vehicles kilometres travelled, and thus to GHG emissions.

This study focuses on traffic analysis and cannot draw definitive conclusions about how each street layout affects the propensity to drive because the more significant locational and socio-economic factors remain unchanged across the layouts.

2.13 Impacts of Land-Use

While conventional loop and cul-de-sac street layout is typically associated with segregated land uses, and neo-traditional neighbourhoods are typically designed with a mix of uses, these land use patterns are not inherent to the street layout.

Integrating different land uses in close proximity (the neighbourhood scale) produces many advantages with respect to transportation and traffic. Locating employment in close proximity to residents results in shorter travel distances and a smaller percentage of auto trips: both beneficial to transportation and traffic. The ability of a layout design to support both residential and commercial land uses in close proximity as well as facilitate short distance travel will result in fewer local automobile trips. However, regional commercial uses located in a neighbourhood may draw significant non-local auto traffic, which is often why local residents oppose such development.

Thus, it is most likely that if commercial uses are integrated into a residential neighbourhood, that they will be more local in nature. The vitality of commercial developments within a predominately residential neighbourhood rests on the ability of the office and shops to attract patrons, which is partly based on accessibility, and the amount of pass-by traffic (both auto and pedestrian). This is where street layout may come into play. If neo-traditional and fused grid layouts are more supportive of non-motorized travel, then local commercial uses become an attractive destination. However, given the lower connectivity offered by the conventional suburban layout, commercial uses along major collectors may receive more pass-by traffic given that much of the auto traffic is forced to use this facility to access surrounding arterials. While land use mix certainly has implications for traffic, assessing the ability each street layout to support local commercial and office uses is beyond the scope of this study.

2.14 Summary and Research Gaps

This literature review has provided a high-level discussion of the potential advantages and disadvantages of conventional, neo-traditional and fused grid development types from a transportation perspective. To date, most of the literature has focused on issues such as connectivity, accessibility, safety and travel behaviour – much in a qualitative manner. In general, traditional and neo-traditional grid networks offer improved connectivity, accessibility, and support for non-auto modes of transportation compared to conventional suburban neighbourhood designs based on loops and cul-de-sacs. In general, this translates into improved public health (i.e., more physical activity) and reduced vehicle emissions in grid-based neighbourhoods.

Impacts of alternative street layouts on traffic safety are mixed. T-intersections reduce the chances of collisions in conventional suburban and fused grid layouts. On the other hand, extensive pedestrian infrastructure, and narrower roadways (which reduce average speeds) improve traffic safety in neo-traditional and fused grid layouts. However, higher intersection densities, which are found in the neo-traditional and fused grid layouts, are also associated with increased collision rates. Cul-de-sacs, found in the fused grid and conventional suburban layouts, provide a safe environmental for pedestrians and vehicles due to low speeds and traffic volumes. The fused grid, which typically has lower intersection density than the neo-traditional model appears to blend the traffic safety-improving features of both the conventional suburban and neo-traditional layouts, and thus may provide the safest neighbourhood environment from a traffic perspective.

Although being a relatively new concept, the fused-grid appears to improve on the conventional grid in several respects (e.g., non-motorized connectivity, developable land, distribution of open space, less cut-through traffic, safety, etc.), though there is currently little empirical data to support this conclusion.

Traffic Level of Service

In particular, there appears to be a lack of research on traditional transportation performance measures such as delay, capacity and level of service. The primary research gaps that can be addressed through this study relate to quantifying the transportation level of service impacts of different street layouts using commonly accepted transportation engineering techniques and models.

Investigation of the literature indicates that it may be necessary to breakdown the analysis of level-of-service for each street layout into arterial streets and neighbourhood streets. It is important to report how each street layout affects the individual components of the neighbourhood as well as the overall neighbourhood because often the street layout can have the opposite effect on each road type. Exhibit 2-13 presents a summary of the expected level of service for each category in a qualitative sense based on the literature review. These ratings do not necessarily reflect findings of the traffic analysis of each layout discussed in later sections.

Exhibit 2-13: Comparison of Traffic Level-of-Service For Street Layout Designs

Street Network Design	Connectivity	Traffic Level-of-Service		
		Arterial	Neighbourhood Streets	Neighbourhood
Conventional	Low	Low	Moderate	Moderate
Neo-Traditional	High	High	Moderate	High
Fused-Grid	Moderate	*	*	*

* Not conclusive based on literature review.

Specific traffic-related research issues raised in the literature review include:

- **Effect of connectivity on travel distances** – Previous studies predict reductions in vehicle kilometres travelled with increases in road network connectivity, including a 0.5% reduction in VKT per 10% increase in intersections per square mile (LUTAQH, undated), a 1.6% reduction in VKT in the Atlanta, Georgia region by doubling the average regional intersection density (SMARTRAQ, 2004), and a 57% reduction in intra-neighbourhood VKT in a high connectivity neighbourhood compared to a conventionally designed neighbourhood (Kulash et al. 1990). Traffic simulation and connectivity assessment will allow the relationship between connectivity and VKT to be assessed for each street network concept.

- **Impact of the arterial connection spacing on arterial traffic level of service**– Kulash (1998), Daisa et al., (undated), and TAC (1999) all offer different recommendations for the spacing of arterial connections for ideal arterial traffic flow. Kulash (1998) asserts that with a greater number of smaller streets and more intersections (i.e., higher connectivity) traffic should be able to flow more smoothly, primarily because turning movements can be made more efficiently at smaller streets. Through modelling activities, Daisa et al., (undated) found that shorter-distance trips and some longer distance regional traffic will shift off arterials to parallel routes under higher connectivity scenarios. The determined that between 10 and 16 arterial connections per mile (i.e., average intersection spacing ranging from 100 metres to 160 metres) yielded the best results in terms of improving arterial traffic flow. On the other hand, the Transportation Association of Canada (1999) recommends a minimum intersection spacing of 200 metres along arterials to ensure minimum lengths of storage for left turning vehicles at adjacent intersections. This spacing can be reduced to 100 metres from adjacent all-directional intersections for right-in, right-out intersections. Traffic simulation of conventional suburban, neo-traditional, and fused grid layouts will provide input on how the spacing of connections along arterials influences arterial level of service. Safety implications will also be investigated.

- **Effect of connectivity on non-local traffic penetration** – Increased connections to arterials coupled with increased internal connectivity may lead to increased non-local traffic penetration (i.e., long distance travellers using the local roads to bypass congested arterials and arterial intersections) (WAPC, 2000). Traffic simulation will be able to indicate the degree to with different street layouts affect cut-through traffic levels, which will be related to connectivity, the use of T-intersections, and other neighbourhood design features.

- **Effect of one-way couplets on traffic performance** - Calthorpe (2000) asserts that there are traffic flow benefits associated with couplets. One-way couplets also relate to Kulash's (1998) idea that by designing street networks with more smaller streets that can operate with fewer signalized intersections, traffic should be able to flow more smoothly, primarily because turning movements can be made more efficiently during gaps in traffic. Since the fused grid layout assessed in this study has one-way couplets for most of its major collectors (see Section 3), the affect of one-way couplets on traffic performance will be assessed in this study.

Travel Behaviour and Mode Choice

A previous CMHC study (IBI Group, 2000) investigated the effect of neighbourhood design and neighbourhood location on GHG emissions from urban transportation. The study found that, although neighbourhood design (including street layout) influences travel decisions, locational and socio-economic variables have a significantly stronger relationship to auto ownership, mode choice, and vehicles kilometres travelled. However, this work did not assess non-motorized travel. Indeed, Frank and Hawkins (2006) assert that most research that has considered street networks has not distinguished between motorized and non-motorized modes. This is a particularly important consideration when the motorized and non-motorized modes have different levels of connectivity, such as in the fused grid concept. This highlights the need to perform separate analyses to assess how well a neighbourhood supports motorized and non-motorized modes.

Frank and Hawkins (2007) have begun to fill this gap with an assessment of the travel impacts of contrasting pedestrian and vehicular connectivity. While they do identify that route connectivity encourages pedestrian activity, more work is required to assess the importance of other covariates including the quality of destinations, qualitative measures of streetscape and pedestrian environment quality, other measures of pedestrian accessibility, and bicycle facilities and transit-pedestrian factors. While the transportation demand modelling and traffic simulation method employed in this study cannot predict changes in non-motorized travel, it does provide basic functionality to assess changes in transit mode split across street layouts concepts and land use scenarios.

Pedestrian Safety

While increasing the amount of pedestrian infrastructure and improving pedestrian route directness is associated with increased levels of walking (Frank and Hawkins, 2007), these changes may have mixed effects on pedestrian safety. According to De Nazelle (2006), the benefits of encouraging pedestrian activity may be outweighed by the health impacts of encouraging residents to expose themselves to low air quality and a high risk of traffic accidents. In addition, narrow pedestrian paths running through blocks, often used in neighbourhoods with discontinuous street networks to improve pedestrian mobility, may cross streets halfway through blocks instead of at an intersection creating a higher risk of collision at these crossings than with regular sidewalks (Frank & Hawkins, 2006). In addition, these paths tend to be segregated from more utilized land-uses and therefore there is no opportunity for passive surveillance. Thus, further studies on pedestrian safety way be warranted that take into account the types of pedestrian infrastructure as well as related characteristics (e.g., road crossing types, opportunities for passive surveillance, air quality, lighting, etc.). Such work is beyond this study's scope, but traffic volumes determined through simulations can provide input on the quality of the pedestrian environment for each street layout.

3. BARRHAVEN EXISTING AND ALTERNATIVE STREET LAYOUT DEVELOPMENT

The purpose of this section is to document the development of the three road layout approaches for testing. It is important to distinguish between the development of the three road layouts vs. the development of alternative scenarios, which is discussed in the next section.

Street Network Layouts: The three street network layouts to be considered include the conventional suburban development as it exists onsite, the grid design of neo-traditional neighbourhood development, and the hybrid fused-grid layout. Layouts for each street network model have been developed for the selected study area in the neighbourhood of Barrhaven in Ottawa. Each layout is described based on the following characteristics:

- Street layout including traffic control and design characteristics;
- Traffic zones, which are used to define land use densities and subsequent travel activity;
- Population and employment; and,
- Transit service.

Scenarios: The purpose of defining and testing alternative scenarios is to test how the three street network layouts perform under alternative land-use scenarios. A total of five land-use scenarios are defined in Section 4.

3.1 Road Network

3.1.1 STREET LAYOUT AND TRAFFIC CONTROL

The street network design is the main feature that changes among each layout. The street layout is varied for the subarea bounded by Fallowfield Road, Cedarview Road, CN Railway, and Greenbank Road, this are is referred to as the *Street Network Analysis Area* and was shown previously in Exhibit 1-1. For the traffic analyses, the road layout is held constant outside of the street network analysis area.

In addition to street network design, traffic control devices have a large effect on travel characteristics, such as average speeds and travel time. The two primary traffic control devices that will be considered in traffic simulations include traffic signals and stop signs. Maps provided by the City of Ottawa identify the locations of current traffic signals and are used as a guide. In most cases, traffic signals are located at the intersections consisting of at least one arterial. Two-way or all-way stop signs are assumed to be located at non-signalized intersections. All way stops are placed at the intersections where two streets of the same class intersect.

Maps showing street layouts, including road functional classifications, and traffic signal locations are presented in the following sections. These maps are based on information provided from the City of Ottawa and CMHC. For the neo-traditional grid and fused-grid scenarios, information provided did not always specify road classification. In these cases, definition of road classification was completed based on CMHC literature supporting the alternatives.

In addition, some changes were made to the road network concepts provided by CMHC for the neo-traditional grid and the fuse-grid scenarios to ensure consistency with the existing conditions. For example, a collector road was added across the CN Rail line to connect with Strandherd Drive, as is the case today.

The layouts are described based on the following characteristics:

- Street Classification System – Hierarchical street systems follow systems found in nature and other engineering applications (circulatory system, river systems, tree branches, water distribution and collection systems, etc.). Hierarchy is a trade off between safety, cost and traffic performance. Large streets (arterials) can easily facilitate high traffic volumes but are not safe to cross, nice to live on, or required within neighbourhoods where traffic volumes are low.

- Street Directness – Loop and cul-de-sac street do not add to traffic performance as they require longer to travel or traverse around.

- Block Length – Longer blocks require more time to traverse around and are barriers to pedestrian movement; they negatively affect traffic performance.

- Road Cross-section – Wider roads can accommodate more vehicles and facilitate vehicle speeds; they improve traffic performance (at the expense of safety).

- Ratio of 3-way to 4-way Intersections – 4-way intersections provide the opportunity to travel in more directions, therefore improving connectivity and traffic performance. 3-way intersections have been found to be safer than 4-way intersections.

- Arterial Connections – The number of connections has been found to improve the traffic performance within a neighbourhood while decreasing the traffic performance of the arterial as it is increased. Overall peak performance can be found in a moderation of arterial connections.

- Active Transportation Infrastructure – A complete and congruent network of paths does not impact directly on the traffic performance but does provide alternative options for travel and can help reduce the number of vehicles on the road, therefore increasing the performance of those vehicles on the road.

3.1.1.1 Conventional Suburban Layout

A map for the conventional suburban scenario showing street layout, including road functional classifications, and traffic signal locations is presented in Exhibit 3-1. The street network is characterized by:

- Hierarchical street pattern of arterials, major collectors, minor collectors, and local streets with only one major collector;

- Curvilinear, loop and cul-de-sac pattern of local streets;

- Very long blocks (up to 600 m), discontinuous streets with no breaks between lots for pedestrians;

- Wide (11 m) two-lane road cross-sections;

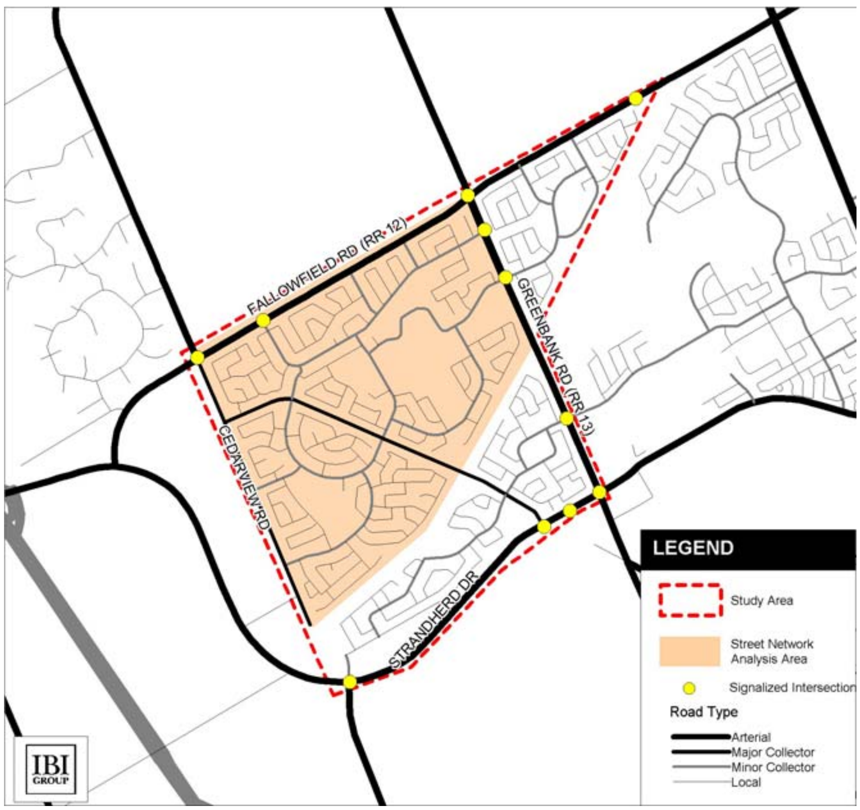
- An extensive and persistent use of 3-way intersections and avoidance of 4-way intersections; a ratio of 14 to 1;

- Infrequent connections (8) to the arterials by major and minor collectors; and,

- Pedestrian and cycling paths are contained limited to the school grounds and one trail running parallel to the train tracks along the southeast edge of the Street Network Analysis Area.

Overall, this design exhibits low vehicle and pedestrian connectivity, compared to the other layouts, with an intersection density of 0.48 intersections per hectare and a street density of 0.35 lane kilometres per hectare. Also due to the long curvilinear lower class roads a majority of travel distance and time takes place on local roads and minor collectors to access or exit the neighbourhood.

Exhibit 3-1: Conventional Suburban Street Layout and Signalized Intersections



3.1.1.2 Neo-Traditional Grid

The neo-traditional neighbourhood design for the study area was created in a previous study under the direction of the CMHC[8]. The study team developed the design under the principles of Neo-Traditional Neighbourhood Design (TND) and Transit Oriented Development (TOD) collectively known as "New Urbanism." The Neo-traditional layout consists of:

- Hierarchical street pattern of arterials, major collectors, minor collectors, and local streets arranged in a orthogonal manner;
- Blocks sizes of 60-120 metres by 120-240 metres;

[8] CMHC (1997) *Conventional and Alternative Development Patterns Phase 1: Infrastructure Costs*. Ottawa, Canada.

- 3.5-metre lanes, 1.2-metre bike lanes and 2.4-metres for parking;
- The use of both 3-way and 4-way intersections in a ratio of 2.6 to 1;
- A fair number (14) connection roads to the surrounding arterials;
- High road lane metres compared to conventional suburbs and comparable to the Ottawa central district; and,
- Integrated pedestrian and cycling path system within the neighbourhood district.

The result of TND is a neighbourhood made up of small communities defined by a radius of 400 metres (or 5 minutes of walking). The community centres are connected by a single major collector. In the Barrhaven context, the connectivity of the layout is an improvement over that of the conventional design due to the existence of a major collector linking Cedarview with Greenbank as well as the grid-like layout of the local streets. The Neo-traditional layout has an intersection density of 0.87 intersections per hectare and a street density of 0.48 lane kilometres per hectare.

A map for the neo-traditional grid design showing street layout, including road functional classifications, and traffic signal locations is presented in Exhibit 3-2.

Exhibit 3-2: Neo-Traditional Neighbourhood Street Layout and Signalized Intersections

3.1.1.3 Fused-Grid

The fused-grid neighbourhood design for the study area was also created in a previous study under the direction of the CMHC[9]. A map for the fused-grid scenario showing street layout, including road functional classifications, and traffic signal locations is presented in Exhibit 3-3. The street network is characterized by:

- Hierarchical street pattern of arterials, major collectors, minor collectors, and local streets arranged in a orthogonal manner;
- Discontinuous loop or cul-de-sac local roads;
- Most block lengths are under 200 metres but reach a maximum of 600 metres – larger blocks are divided by pedestrian paths;
- Street cross sections that follow the principals set forth in the Neo-Traditional design;
- A predominance of T-intersections over cross-intersections - at a ratio of 4.7 to 1;
- 11 major access roads to the surrounding arterials, each neighbourhood has 4 main access roads and an additional 16 secondary access roads to the major collectors that surround them;
- Clearly defined neighbourhoods by virtue of the collectors that frame them and their opaqueness to through traffic;
- Twinned arterials with minor collectors for Greenbank Road and Cedarview Drive;
- Twinned grid (couplets of one-way streets) of major collectors; and
- Active infrastructure (path network) within residential quadrants.

The Fused-grid had little to no connectivity within the residential quadrants but has high connectivity among the collector streets. Overall the Fused-grid has an intersection density of 0.51 intersections per hectare and a street density of 0.36 lane kilometres per hectare.

[9] Pogharian, S., Tasker-Brown, J., and Grammenos, F. (2005) *Residential Street Pattern Design: A Proposal.* CMHC. Ottawa, Canada.

Exhibit 3-3: Fused-Grid Street Layout

3.1.1.3.1 Defence of Lanes

Laneways have been incorporated into the Fused-grid layout. The Fused-grid layout incorporates both rear and front lanes. They are in place along Fallowfield to serve the housing along this arterial. The network of one-way streets and divided arterials proposed in the layout makes lanes a necessity. The divided arterials and one-way major collectors mean that driveways and local roads are restricted to right-in right-out channelization at the intersection with these streets. Without lanes, residents would be forced to circle their residential district before entering their local street as illustrated in Exhibit 3-4.

Exhibit 3-4: Travel Distance With and Without Lanes

3.1.2 NEIGHBOURHOOD LAYOUT COMPARISON

A table comparing the layout characteristics is shown below in Exhibit 3-5.

Exhibit 3-5: Neighbourhood Layout Characteristics Comparison

Road Type	Neighbourhood Layout	Road Segments		# of Lanes	Intersections		# of right angle turns	Back-lot or lanes	Driveways	# of Traffic Lights	# of All-way stops
		Number	Lane Metres		Cross	T					
Arterial	Existing	25	37,095	1 to 2	6	4	0	BL	NO	9	0
	NTD	30	38,005		6	14	0	Lanes	NO	9	0
	Fused-Grid	37	36,875		6	16	0	Lanes	NO	8	0
Major Collector	Existing	10	8,450	1	2	5	0	BL	NO	0	1
	NTD	67	29,580	2	16	43	0	Lanes	NO	0	3
	Fused-Grid	8x2way/63x1way	20,478	2	10	48	0	-	Yes	0	8
Minor Collector	Existing	80	16,950	1	2	59	4	-	Yes	0	9
	NTD	64	13,176	1	19	31	4	-	Yes	0	1
	Fused-Grid	89	23,710	1	11	59	2	-	Yes	0	3
Local	Existing	268	55,150	1	1	82	68	-	Yes	0	83
	NTD	367	82,222	1	42	124	7	-	Yes	0	166
	Fused-Grid	131	41,314	1	0	23	57	-	Yes	0	0
Network	Existing	383	117,645	1 to 2	11	150	72	N/A	N/A	9	93
	NTD	528	162,983	1 to 2	83	212	11			9	170
	Fused-Grid	328	122,377	1 to 2	27	146	59			8	11

The table below illustrates the comparison among the connectivity measurements for each layout.

Exhibit 3-6: Neighbourhood Layout Connectivity Comparison

Street Layout	Intersection Density (Intersections/ha)	Street Density (lane-km/ha)
Conventional suburban	0.48	0.35
Neo-traditional	0.87	0.48
Fused-grid	0.51	0.36

3.1.3 STREET DESIGN CHARACTERISTICS

Street design characteristics include features such as number of lanes, pavement width, the presence of on-street parking, and the speed limit affect the capacity of the roadway, which in turn has a large influence on traffic conditions. Based on a review of conventional suburban and neo-traditional grid road characteristics in City of Ottawa GIS street maps and CMHC publications[10], street design characteristics were determined for each layout by road functional classification (Exhibit 3-7). In general, the fused-grid layout is assumed to have the same street design characteristics as the neo-traditional grid layout. As the exhibit shows, the only differences in road characteristics relate to the major collectors type, which in the conventional layout runs diagonally and does not serve the entire district. Minor collectors have a large pavement width to accommodate parked vehicles.

[10] CMHC (1997) *Conventional and Alternative Development Patterns Phase 1: Infrastructure Costs*. Ottawa, Canada.

Exhibit 3-7: Street Design Characteristics by Road Functional Classification

Road Functional Classification	Layout	No. Lanes Per Direction	Speed Limit (km/h)	On-Street Parking (Y/N)	Pavement Width
Arterial	All Three	1-2, widening at intersections	60-80	N	3.5m - 4.75m/lane
Major Collector	Conventional	1, widening at intersections	50-60	N	3.5 m/lane
	NTD and FG	2	50-60	N	3.6m/lane
Minor Collector	All Three	1	40-50	Y	5.5m/lane
Local	All Three	1	40	Y	3.5m - 4.5m/lane

NTD = Neo-traditional Design FG = Fused-grid

While conventional suburban and neo-traditional grid road cross-sections may differ in terms of overall right-of-way widths, building setbacks, and the presence of sidewalks, the primary characteristics affecting vehicle flow do not change significantly among neighbourhood types. As studies have shown (Larry Frank) sidewalks may be critical in encouraging pedestrian travel, that might displace vehicular trips, but in themselves are not sufficient causes of increased pedestrian trips. As shown in Exhibit 3-7, for each road classification, the same street design characteristics can be used for each layout, except for major collectors, which have 1 lane in each direction in the conventional suburban layout and 2 lanes in each direction in the other layouts. The underlying rationale for having two lanes per direction for the Neo-traditional and Fused-grid layouts is to allow for on-street parking, which may or may not be restricted in the peak. This is particularly pertinent in the Fused-grid layout that foresees most amenities and services being located between the paired major collectors. The need for two travelled lanes is reviewed as part of the traffic analysis/simulations discussed later in the report.

In Appendix B, sample street cross-sections for major collectors and local streets are illustrated, as defined by CMHC (1997). Narrower street cross sections and the presence of on-street parking play a role in decreasing vehicle speeds and increase safety but do not necessarily affect traffic performance. Therefore, these cross sections, if desirable, can be applied to any layout that performs well from a traffic perspective.

3.2 Traffic Zones

Traffic Zones (TZs) allow travel behaviour to be evaluated at an aggregate level and are commonly used in travel demand modelling and traffic simulation. This is due to the fact that it computationally intensive to simulate trips for every household. Therefore, in most traffic simulation programs, the trips originating from or destined to anywhere in a traffic zone are considered as coming from or going to a single node, which has one or more connections (i.e. centroid connectors) to the simulated road network. This is concept is illustrated in (Exhibit 3-8).

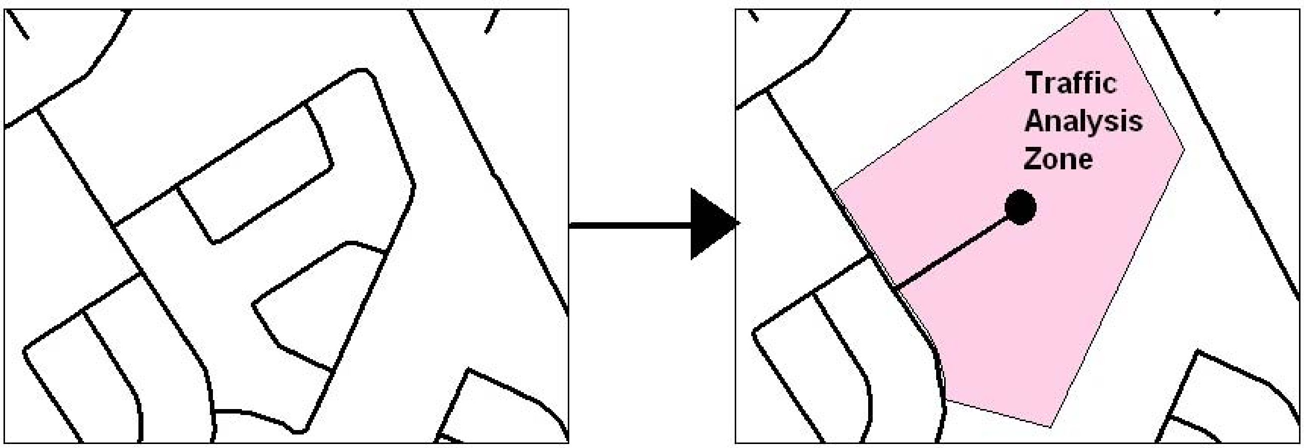
TZs need to be carefully developed based on local conditions to ensure that the TZ system:

- Only groups together trip makers who use similar road facilities;
- Only groups together trip makers with similar travel characteristics; and
- Is sufficiently fine to capture the differences among each road layout.

The land use of Barrhaven is mostly residential, therefore, the layout of the road network is the primary consideration in developing the TZ system. Given the differences in street networks, separate TZs need to be developed for each layout.

In the initial stages, where trip generation and distribution is determined, the TZ system is utilized at the macro-simulation level. The TZs are sub-divided further for the micro-simulation analysis to enable analysis on all streets. The remainder of this chapter presents information on the courser traffic zones to be used in the macro-analysis. For the conventional suburban layout, there are 45 such zones. The micro-simulation further sub-divides these zones into 68 zones to allow for the assignment of trips to all streets.

Exhibit 3-8: Development of Traffic Zones for Macro-analysis



3.2.1 CONVENTIONAL SUBURBAN

As discussed previously, the Ottawa TRANS Model only includes 3 traffic zones within the study area. A more detailed traffic zone system is required for the traffic simulation. Thus, a detailed TZ system was developed for the conventional suburban scenario, which consists of 45 zones (Exhibit 3-9). Zones 30-45 are outside of the street network study area and, hence, do not change among layouts. As discussed in the previous section, households are grouped together based on their access and egress roads as well as their travel characteristics.

Exhibit 3-9: Conventional Suburban Traffic Zones

3.2.2 NEO-TRADITIONAL GRID

Traffic Zones are dependent on the street network and therefore differ among scenarios. Due to the high connectivity of the grid network in the neo-traditional design, the TZ system for this scenario could have been developed in many different ways. The 48 zones developed for this scenario loosely follow those constructed for the conventional suburban design (Exhibit 3-10).

Exhibit 3-10: Neo-Traditional Neighbourhood Traffic Zones

3.2.3 FUSED-GRID

Due to the nature of the fused-grid design the Traffic Zones are limited to residential areas contained within minor collectors, and commercial areas bounded by major collectors and minor collectors. The TZ system for the fused-grid layout consists of 55 zones (Exhibit 3-11). Although the TZs do not follow those in the conventional suburban scenario, the general distribution of population and employment is retained as discussed in the following section.

Exhibit 3-11: Fused-Grid Traffic Zones

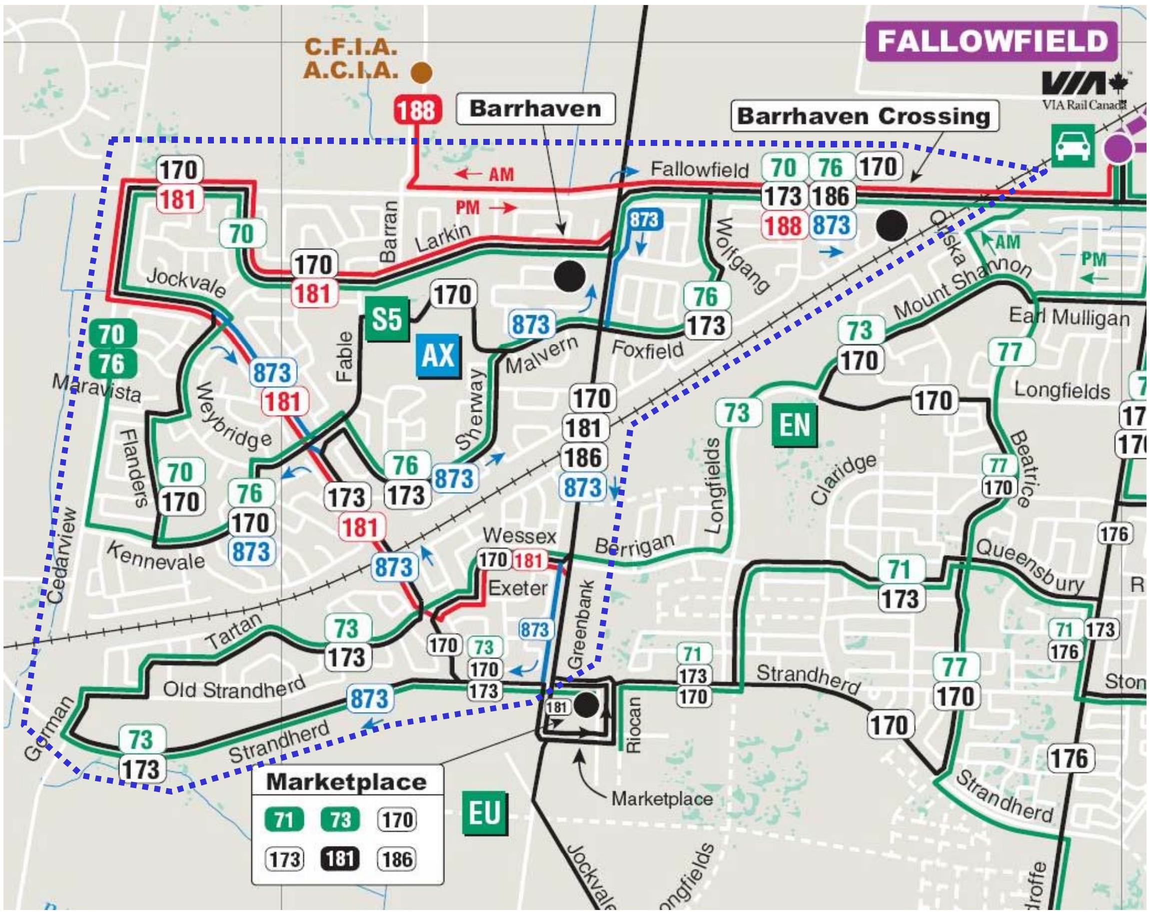
3.3 Public Transit

Public transit service affects neighbourhood traffic performance by reducing the number of vehicles on the road. Important characteristics influencing travel behaviour include the proximity of bus service to trip origin and destination, the frequency of service, and the cost. Public transit service is currently provided in the study area by several OC Transpo routes. Main routes serving the study area include:

- 70, 73 and 76 Express; and,
- 170 and 173 Local.

The express routes run on 15-minute headways in the peak periods and serve primarily commuter trips. The local routes run on 30-minute headways in the peak periods and serve a variety of trip types, including intra-neighbourhood trips. As shown in the OC Transpo map in Exhibit 3-12, for both types of service, transit routes do not remain on arterials, rather they travel through the residential area of the neighbourhood to collect and drop off local residents. This may be due to the fact that the existing street pattern does not allow people to easily walk out to the major arterials

Exhibit 3-12: Existing Public Transit Service in the Study Area



Source: OC Transpo Service Map, August 2006.

Transit service concepts have been determined for each scenario building on existing conditions. Exhibit 3-13, and Exhibit 3-14 show the location and type of transit service for the neo-traditional grid, and fused-grid layouts, respectively. Transit service for the conventional suburban layout is the same as the existing as shown on Exhibit 3-12.

Exhibit 3-13: Transit Service in the Neo-Traditional Layout

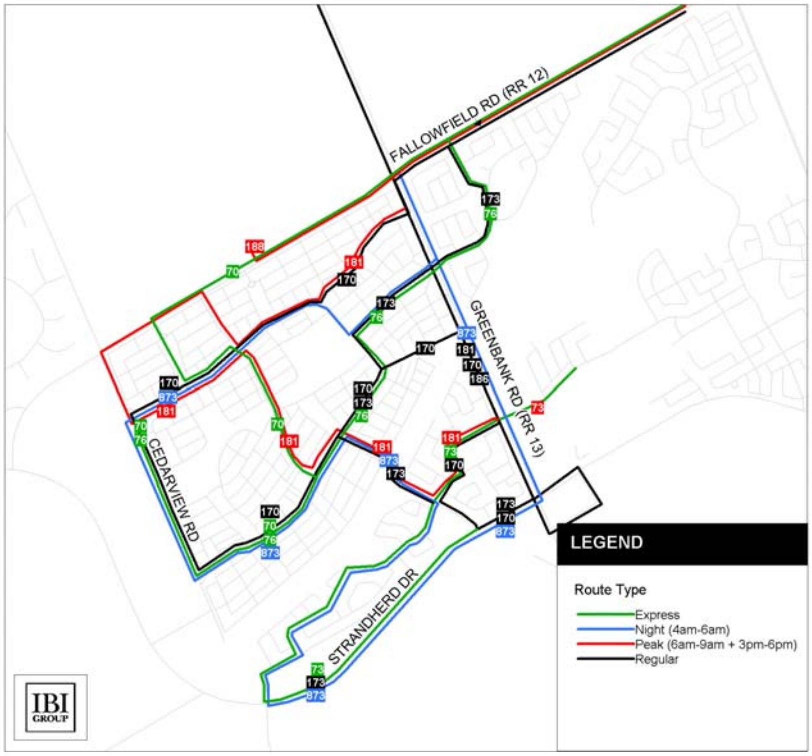
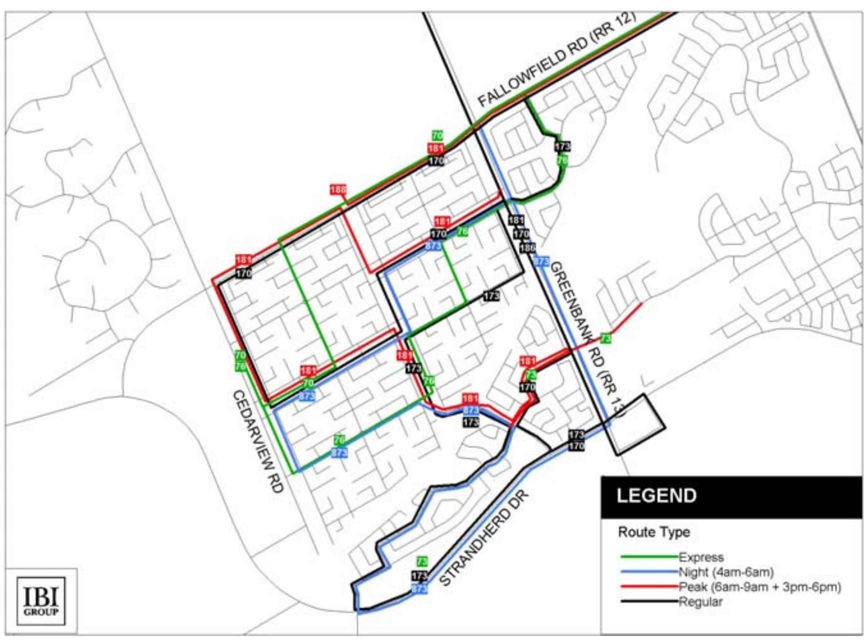


Exhibit 3-14: Transit Service in the Fused-Grid Layout



4. DEVELOPMENT OF THE LAND-USE SCENARIOS

The purpose of the scenario analysis is to explore the transportation performance as it relates to the characteristics of the three street network layout approaches. To enable meaningful comparisons, land use assumptions are held constant for all three layouts for each scenario. In addition, in all but one scenario (Scenario 2), population densities are uniformly distributed across the entire Street Network Analysis Area. The rationale for this is to remove irregularities that are not related to the development pattern itself, but reflect circumstantial conditions. Densities are not inherent to the neighbourhood street layout they can vary depending on economic and social factors. Evolution will cause density to increase or decrease while the street pattern remains unaffected, in turn affecting the transportation performance of the network. A further consideration is the desire to test the resilience of a street network to function given changes in density, without degrading the quality of life of the residents.

A total of five scenarios have been identified for testing as follows:

1. Existing Population and Employment (Uniform Density at 40.6 pop/ha gross)

2. Existing Population and Employment (Non-uniform Density based on prevailing and expected density distribution)

3. TND Population and Employment (Uniform Density at 62.2 pop/ha gross)

4. Transit Supportive Population Densities (Uniform Density at 90 pop/ha gross)

5. Increased Employment Densities (Uniform Density at 90 pop/ha gross)

The scenarios are distinguished by different population and employment levels. As discussed above, with the exception of Scenario 2, population density is distributed evenly across all traffic zones. In Scenario 2, population and employment are distributed according to existing and expected conditions to determine how irregular densities could affect transportation performance. This scenario is also required to calibrate the CORSIM Model to existing conditions.

In Scenarios 1-4, employment densities and schools are distributed according to prevailing conditions. In Scenario 5, the large employment increase renders it impractical to limit the employment to the original employment zones, therefore it is distributed to traffic zones closest to transit corridors as indicated in Section 4.1.5.

Scenarios 4 and, particularly, 5 include population densities that are extraordinary for suburban districts and are more applicable to central city areas. Based on their similarity to central districts of medium sized urban centres, these scenarios not only test the hypothetical case of extreme densification of suburban districts, but also test the hypothesis of how a central district would function should its street layout resemble each of the three tested here.

4.1.1 S1. EXISTING DENSITIES UNIFORMLY DISTRIBUTED

For the base scenario, population is generally distributed uniformly across each traffic zone for each layout. Exceptions are as follows for zones of mixed use:

- For the Conventional Suburban Layout, where the land use map is available and commercial and residential areas can be distinguished, population is distributed evenly across residential land parcels.

- The neo-traditional layout, where residential space is typically provided above all ground floor commercial space, population is distributed proportional to the total zone area instead of only residential area. Schools are contained within school specific zones and are given no population.

- Similar to the conventional layout, the Fused-grid traffic zones are designed such that schools and major commercial areas are contained in specific zones separated from residential areas. Accordingly, population was distributed only among the residential zones.

Employment sources in the study area consist of 7 commercial areas, 5 elementary schools, 1 secondary school, and 3 other institutional uses. Unlike population, it is not appropriate to re-distribute employment evenly across each traffic zone since the distinction between residential and commercial areas is an inherent characteristic of each layout. For example, the conventional suburban approach does not generally include commercial uses in residential areas. Therefore, employment was distributed to each zone based on prevailing conditions. Due to the fact that employment data is not available at a disaggregate level, some judgement was required to distribute the aggregate employment figures to the detailed traffic zones as follows:

- Home based employment, which is known, was distributed based on population

- School employment was estimated to be 20 employees per elementary schools, 40 for the secondary schools and an average of 20 for each of the institutional uses.

- Commercial (retail and office) employment was estimated by assuming employment rates of 1 employee per 100 m^2 of commercial floor area and a floor area ratio (Gross Floor Area : Land Area) of 1 : 2.5. These values were applied to known commercial areas by zone as determined from the land use map of existing conditions.

The latter two employment categories were balanced such that the combined sum across all employment types equated to known employment totals. The number of commercial, school, and other institutional uses, as well as the employment associated with each use, was maintained across each layout for the base scenario. The distribution of these employment sources was maintained as consistently as possible subject to plausible locations for such uses within each neighbourhood type.

Based on these assumptions, population and employment figures by traffic zone, as well as the distribution of employment sources, for the conventional suburban, neo-traditional grid, and fused-grid layouts are shown in Exhibit 4-1, Exhibit 4-2, and Exhibit 4-3, respectively. These represent the base scenario. Although each layout has the same population, the density varies due to commercial zones, open space and school zones.

Exhibit 4-1: S1 Conventional Layout - Distribution of Population and Employment

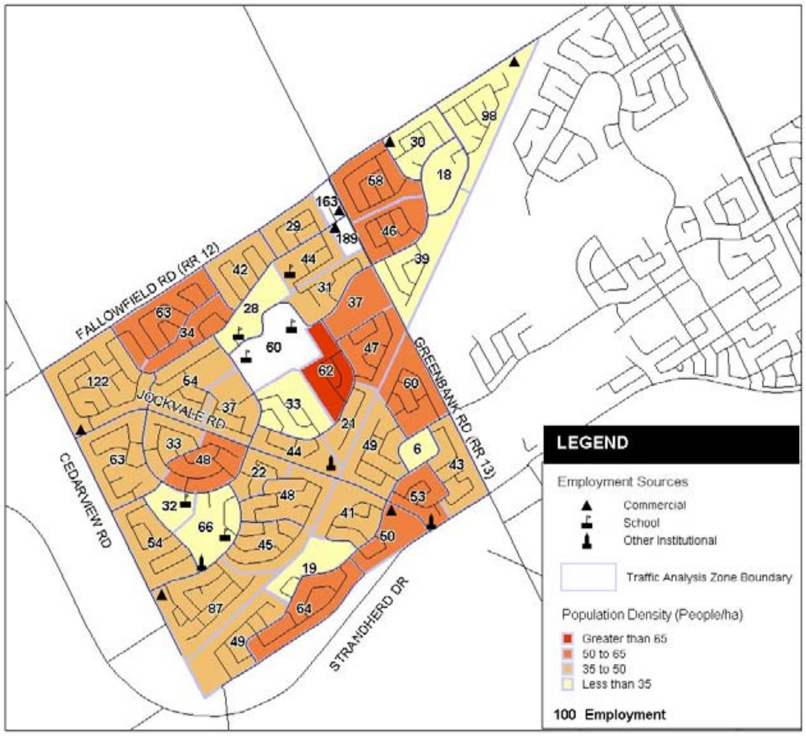


Exhibit 4-2: S1 Neo-Traditional Layout - Distribution of Population and Employment

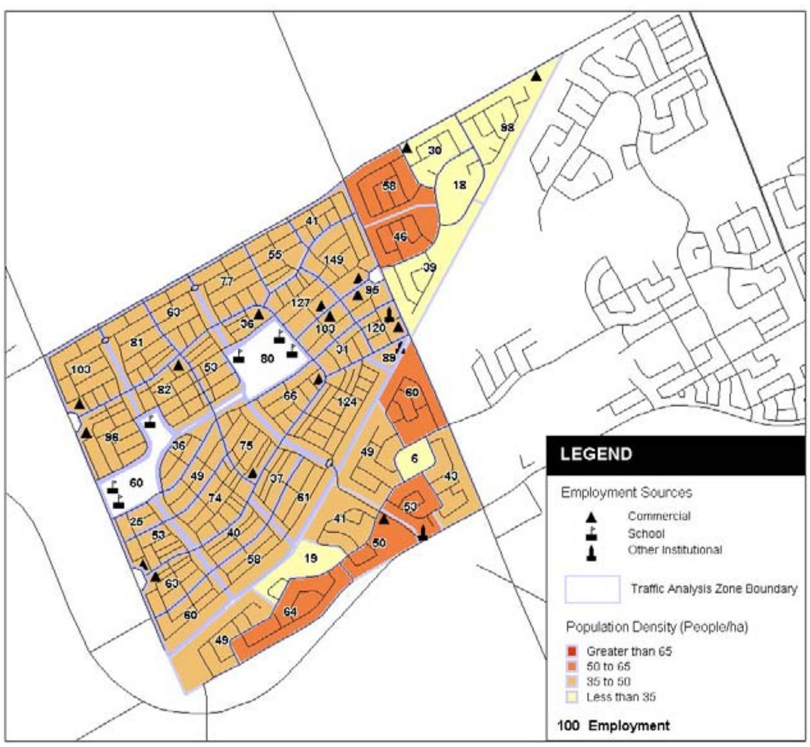
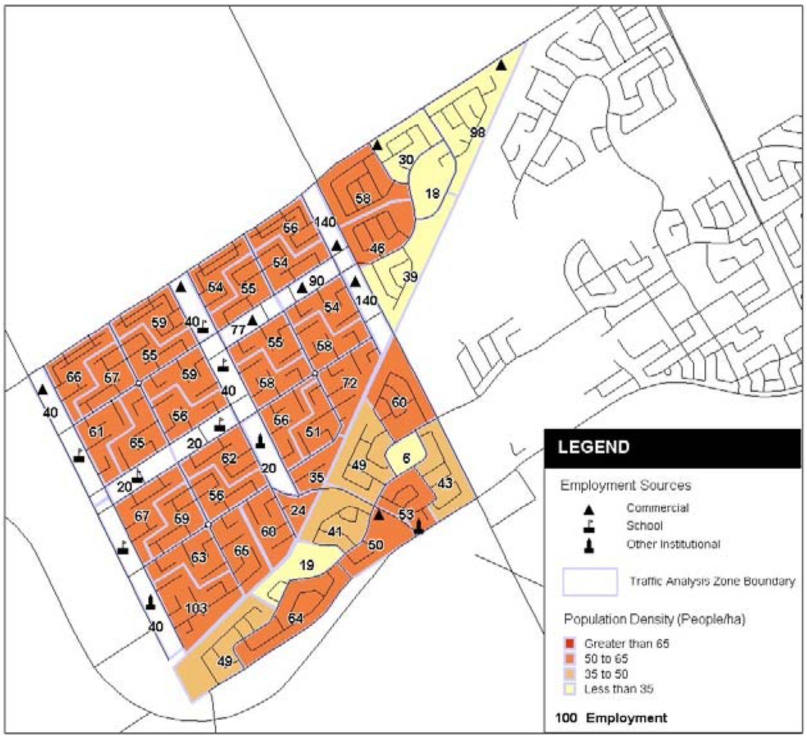


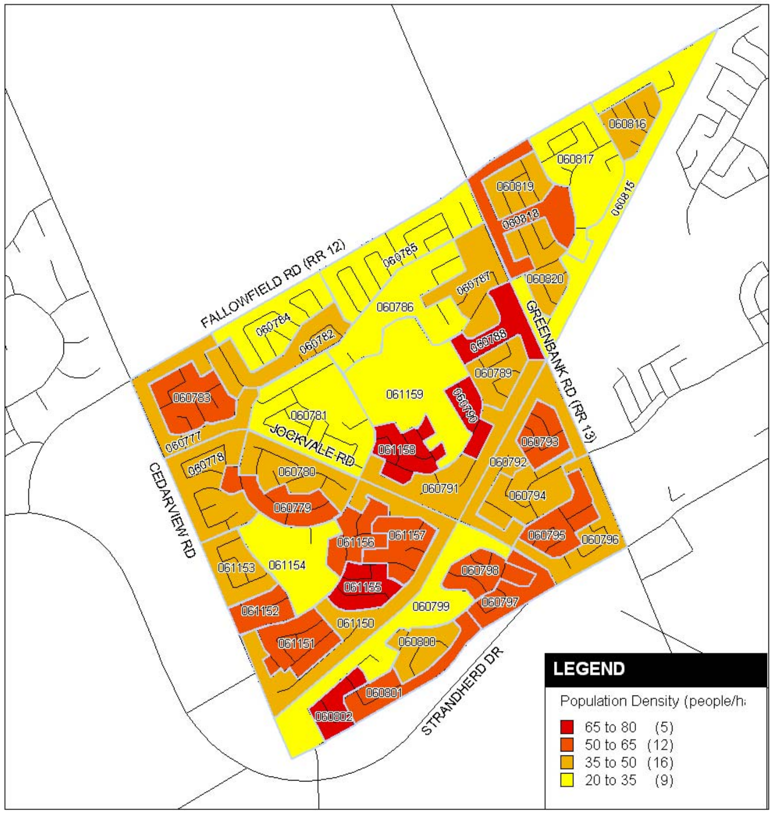
Exhibit 4-3: S1 Fused-Grid Layout - Distribution of Population and Employment



4.1.2 S2. EXISTING DENSITIES WITH THE PREVAILING DISTRIBUTION

In this scenario, population is distributed across each layout based on the current observed land-use using the dissemination zones as a starting point shown in Exhibit 4-4 below. This was fairly straightforward for the conventional layout. If a traffic zone covered half the area of a given dissemination zone, the traffic zone would be apportioned half of the population in the dissemination zone. This calculation assumes even population distribution across each dissemination zone. Professional judgement is used to reapportion population by traffic zone in the cases where even population distribution could not be assumed, such as the presence of higher-density town house developments or non-residential uses (e.g., open space, commercial, etc.). For the neo-traditional layout and fused grid layouts, further judgement was used to apportion population as close as possible to the existing distribution.

Exhibit 4-4:Population Density by Dissemination Area



4.1.3 S3. TRADITIONAL NEIGHBOURHOOD DESIGN APPROPRIATE DENSITIES

This scenario is similar to the base scenario in that it assumes uniform population densities across residential zones. However, the total population distributed to these zones is approximately 50% greater than the existing population. In this case, population is assumed to be in line with what would be expected for the TND scenario, based on previous work completed by CMHC[11]. Employment is assumed to grow at the same rate.

4.1.4 S4. TRANSIT SUPPORTIVE DENSITIES

One of the most direct ways of increasing transit usage in an urban area is to increase densities along transit corridors. Higher densities can support higher levels of transit, which in turn increases the attractiveness of transit. The objective is to accommodate increases in population without requiring additional road infrastructure or incurring significant congestion. Such an approach has been successful in the City of Vancouver (Vancouver proper) where transit trips have increased by 20% in the last decade but vehicle trips entering Vancouver are down 10%[12].

This scenario involves increasing population density and proportional increases in institutional and commercial uses to the level where frequent bus transit service could be expected and justified. Various studies have quantified what constitutes a “transit-supportive” density. The 1992 Ministry of Municipal Affairs of Ontario publication on Transit Supportive Land Use guidelines suggested that

[11] Conventional and Alternative Development Patterns, Phase 1: Infrastructure Costs, CMHC, 1997.
[12] City of Vancouver Transportation Plan Progress Report, www.city.vancouver.bc.ca/engsvcs/transport/plan/pdf/ppt681.pdf

the minimum residential density required for frequent bus service is 37 units per hectare (approximately 90 persons per hectare), adjacent to the route[13]. For this scenario, it is assumed that all bus routes will be surrounded with transit supportive densities and therefore the entire district is given a density of 90 persons per hectare. Exhibit 4-5 displays transit potential based on urban density, which is based on a variety of sources as indicated.

Exhibit 4-5: Transit Potential based on Urban Density

Density Range (Gross Density in People plus Jobs per Hectare)	Transit Potential	Type of Service
Less than 20	Low	No public transit. Requires dial-up cabs, jitneys, etc.
20 to 40	Modest	Marginal public transit. Buses every half-hour. Rush hour express buses.
40 to 80	Good	Good bus service.
80 to 120	Very Good	Excellent bus, possibly BRT/LRT.
120 to 200	BRT/LRT	High order transit.
Over 200	Subway	High order transit.

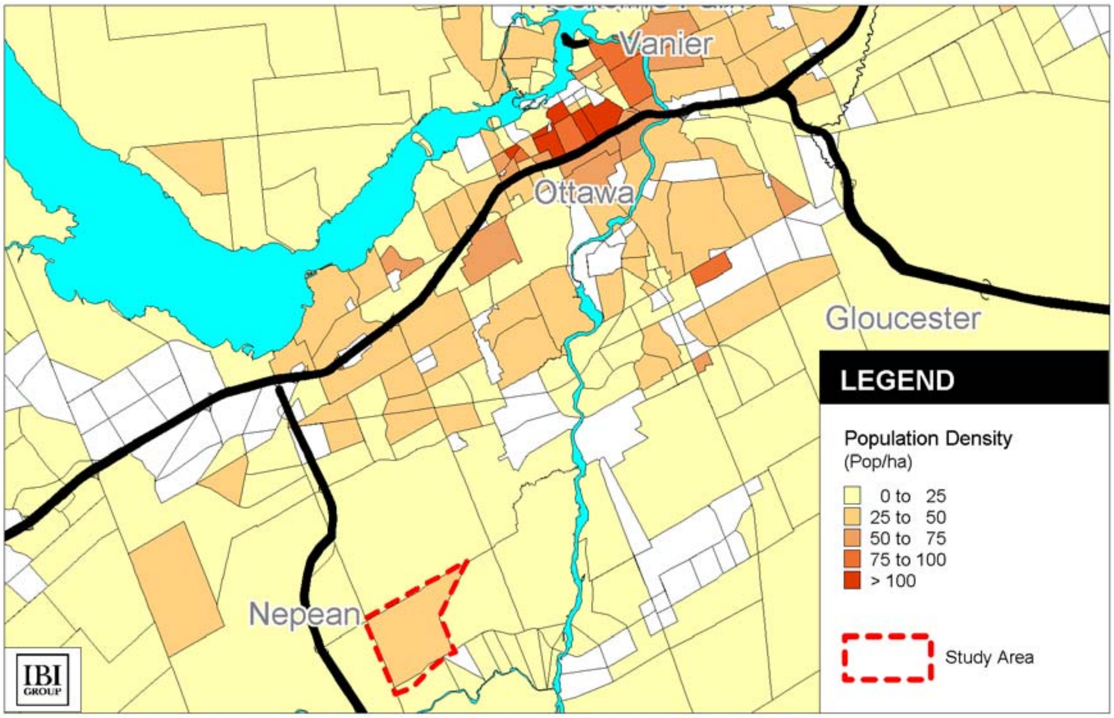
Source: ***Toronto-Related Region Futures Study***, Neptis Foundation, 2002, as compiled/derived from Revitalization Guidelines, Metro Toronto Building Ltd., 1990, ***GTA Report – House Forms and Density***, Hemson et al., 1993, ***Urban Density Study for OGTA***, Lehman & Associates with IBI Group et al., 1995, ***Public Transit and Land Use Policy***, Boris S. Pushkarev and Jeffrey Zupan, Regional Plan Association, 1977.

Exhibit 4-6 provides an illustration of the current population densities in Barhaven and the rest of the Ottawa Urban Area. In general, most zones outside the central area do not achieve transit-supportive densities, though some of these zones also have associated employment, which increases the viability of transit.

For this scenario, employment is increased in proportion to population.

[13] Transit Supportive Land Use Guidelines, Ministry of Municipal Affairs and Housing, 1992

Exhibit 4-6: Existing (2001) Residential Densities in Ottawa



4.1.5 S5. EMPLOYMENT CENTRE APPROPRIATE DENSITIES

The final scenario is built on the transit-supportive scenario by increasing employment to ten (10) times the current and 4.5 times the level of Scenario 4. The purpose of this scenario is to test how each layout would respond to commercial intensification. For preliminary testing purposes, an average density of 50 jobs per hectare is assumed, equating to a total of 16,850 jobs. The increases in employment are only distributed to commercial corridors as shown in Exhibit 4-8, Exhibit 4-9 and Exhibit 4-10. The employment centres are located along Greenbank Road to take advantage of pass-by trips and to avoid attracting large volumes into the heart of the district. The employment areas creep into the districts along Malvern Drive, as it is the street connecting Barrhaven on either side of Greenbank Road.

Exhibit 4-7: Existing (2001) Employment Densities in Ottawa

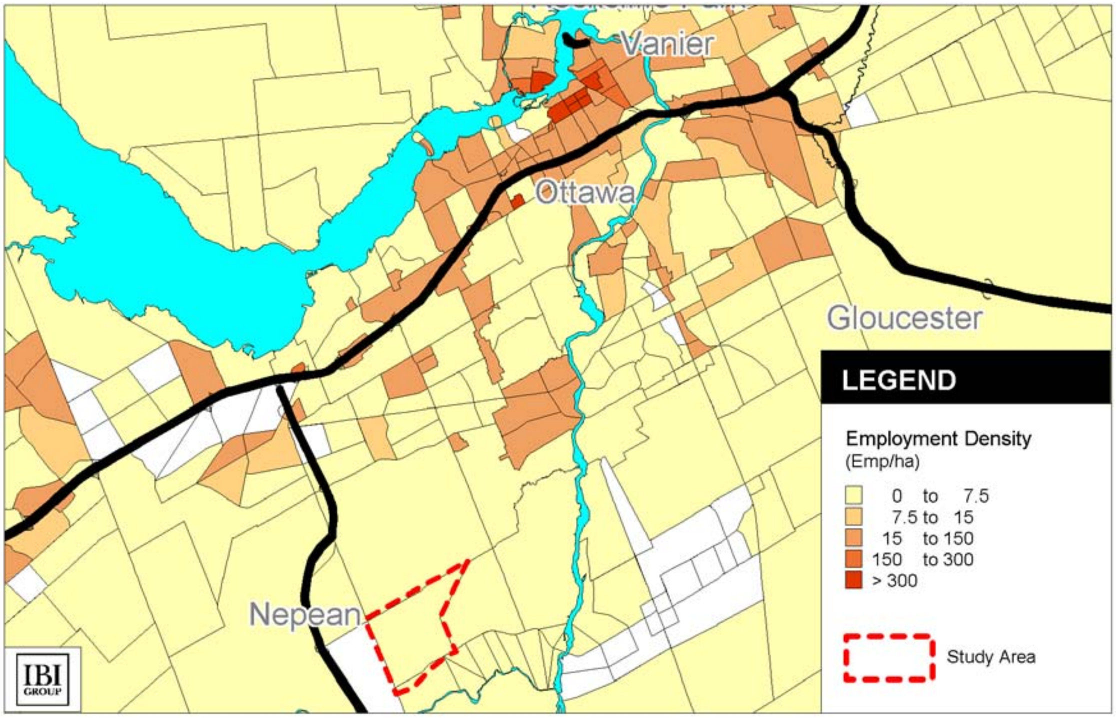


Exhibit 4-8: Conventional Layout Scenario 5 Employment Centre

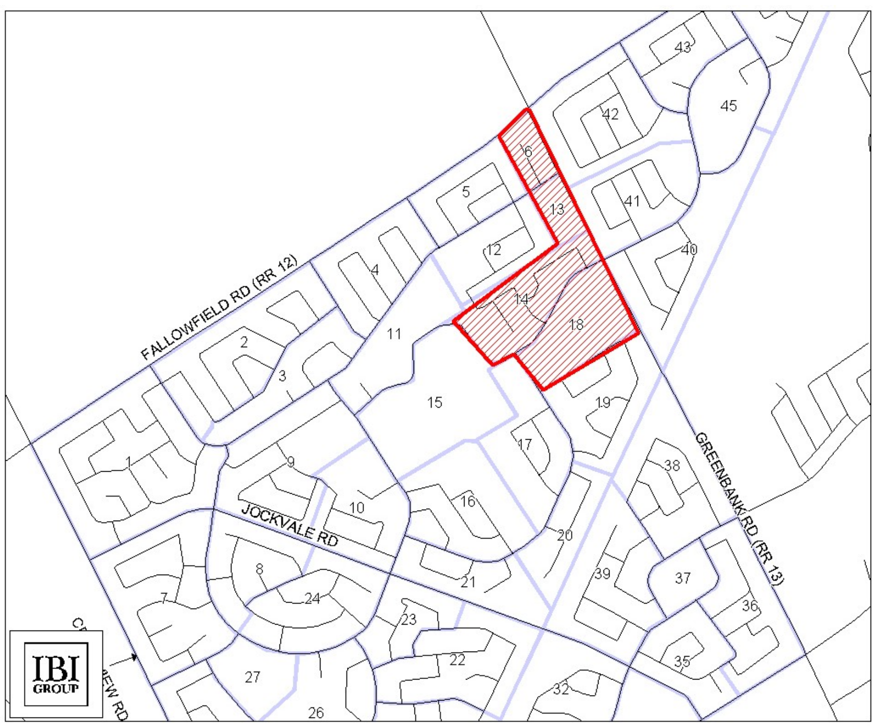
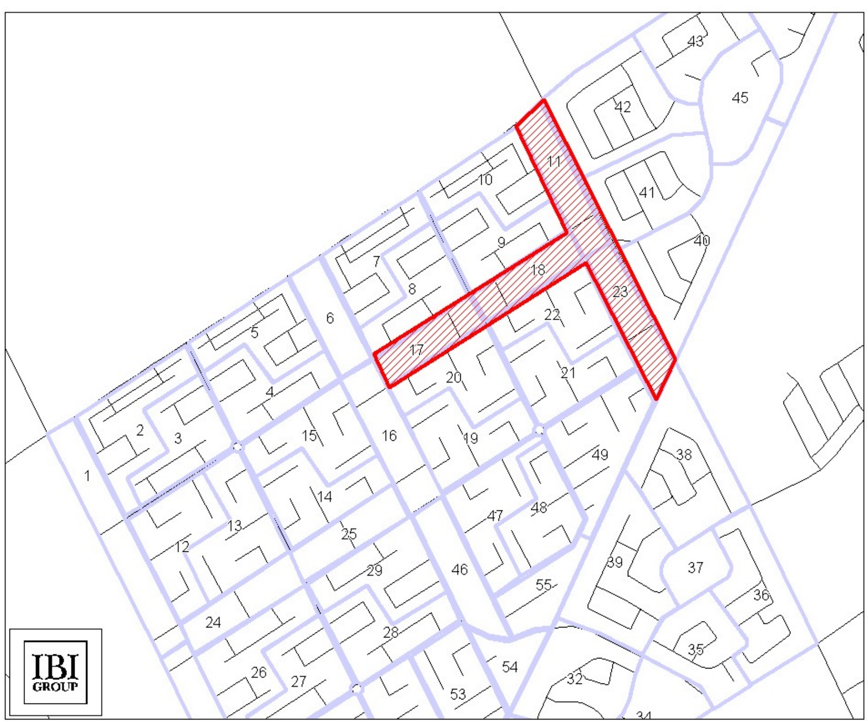


Exhibit 4-9: Neo-traditional Scenario 5 Employment Centre

Exhibit 4-10: Fused Grid Scenario 5 Employment Centre



4.1.6 SCENARIO COMPARISON

The population and employment figures are summarized in Exhibit 4-11 below.

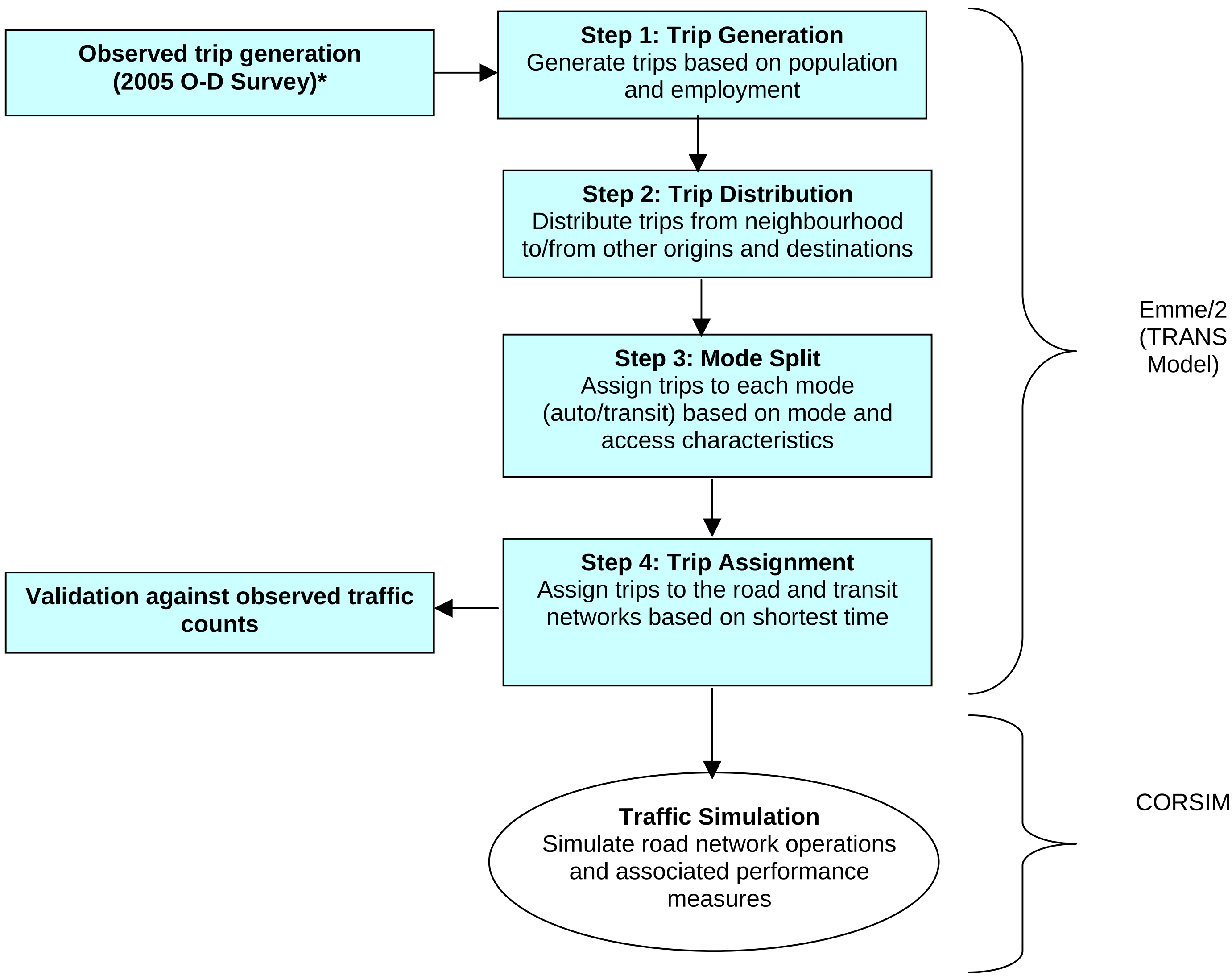
Exhibit 4-11: Scenario Descriptions

Scenario	Description	Population	Gross Population Density (Pop/ha)	Employment
1	Existing Population and Employment (Uniform Density)	13,680	40.6	1,640
2	Existing Population and Employment (Non-uniform Density based on prevailing/expected conditions)	13,680	40.6	1,640
3	TND Population (Uniform Density)	20,949	62.2	2,510
4	Transit Supportive Population Densities (Uniform Density)	30,330	90.0	3,640
5	Increased Employment Densities (Uniform Density)	30,330	90.0	16,850

5. DEVELOPMENT AND CALIBRATION OF TRANSPORTATION MODELS

Two models were used to respond to the challenges of the study. The first is the Emme/2 model given by the City of Ottawa for use in this study; it was utilized to perform the four-stage modelling procedure to determine the overall traffic volumes expected to travel to, from and within Barrhaven given the varying land-use scenarios. The second model was developed by IBI Group for this study using Corsim traffic simulation software. Corsim is a micro-simulation software, which enables a closer look at how the various layouts affect the traffic conditions in and around the neighbourhood and arrive at more accurate Levels of Service.

Exhibit 5-1: Transportation Analysis Approach



* As the 2005 O-D survey was not available in time for this study, the model development utilized the 1995 trip matrices.

5.1 Emme/2

5.1.1 DEVELOPMENT OF ZONE SYSTEMS AND CONVENTIONAL LAYOUT ORIGIN-DESITNATION MATRICES

Ottawa has a four-stage Emme/2 model, which was used as a starting point for the modelling process of this project. The existing model had one traffic zone (TZ) representing the Barrhaven neighbourhood. The first step in updating the model was to subdivide the Barrhaven traffic zone into the 45 zones defined in Section 3.2. The street network in the existing model contained all the major and minor collectors as defined in Section 3.1 and therefore did not require any updating for the purpose of generated inputs for the simulation model, except for the addition of centroid connectors to the new traffic zones.

The Neo-traditional and Fused-grid layouts' major and minor collectors were coded in Emme/2 based on the characteristics of the collector streets found in the existing model. The existing transit routes were coded as illustrated in the Section 3.3. Forty-nine (49) traffic zones were coded for the Neo-traditional layout and fifty-five (55) for the Fused-grid layout, as shown in Section 3.2.

Population and employment data, consistent with each scenario, were tabulated for the model and the four-stage model was run for the PM peak period. Origin-destination (OD) trip matrices were produced for autos and transit and the Existing (Conventional) layout OD matrix was validated against recent count data provided by the City of Ottawa at intersections inside and outside the Street Network Analysis Area. The count data available inside the Street Network Analysis Area could not be used for validating the Neo-traditional or Fused-grid layouts, nor could any count data be used to validate the model outputs for Scenarios 3 to 5; therefore, for these layouts and scenarios, the OD matrices had to be developed from the validated OD matrices of the existing layout and scenario.

5.1.2 DEVELOPMENT OF ALTERNATIVE LAYOUT ORIGIN-DESITNATION MATRICES

The existing traffic scenarios (1 and 2) were validated along screenlines surrounding the study area using a built-in emme/2 macro. A sub-area OD matrix was then developed in Emme/2 consisting of the study area traffic zones and "gates". Gates, located around the boundary of Barrhaven on major arterials, represent the outbound and inbound traffic from/to the neighbourhood (they can be seen in Exhibit 5-3 at the ends of the arterials extending away from the study area).

The Neo-traditional and Fused-grid layouts were run through the four-stage Emme/2 model to determine the generation (which is the same for each layout because the population and employment are held constant), mode split (which did not vary significantly among the three layouts, so was held constant), distribution and assignment. The result is three layouts with the same generation, the same mode split, and the same entry and exit volumes at the gates. The only variation is regarding the distribution of trips, which changes due to the "attractiveness" or travel times between OD pairs. The goal is to maintain a constant total demand applied to each layout to limit the difference in results to the differences in street layout.

The same process had to be undertaken for the alternative scenarios. In scenarios 3 to 5, which vary land use from the existing scenario, the generation and mode split differ from that of scenarios 1 and 2 but are consistent among the layouts; the Emme/2 model was used to determine the generation, mode split and distribution for each layout for each scenario. The distribution, again, varies among the layouts based on the "attractiveness" of OD pairs.

5.2 Micro-Simulation Analysis

5.2.1 SIMULATION INPUTS

Corsim is a microscopic modelling software; individual cars are modelled on the street network guided by intricate and complex car following and lane changing logic. Queuing, acceleration, the tendency for cars to stagger while driving on multilane roads and other detailed traffic characteristics are considered in microscopic traffic models that are not considered in macroscopic models. The Corsim model is bounded by the gates discussed in the previous section; roughly located on Greenbank, Strandherd, Fallowfield and Cedarview as they extend beyond the Study Area the Corsim networks for each layout are shown in Exhibit 5-3 to Exhibit 5-5.

Exhibit 5-2: Corsim Intersection Example

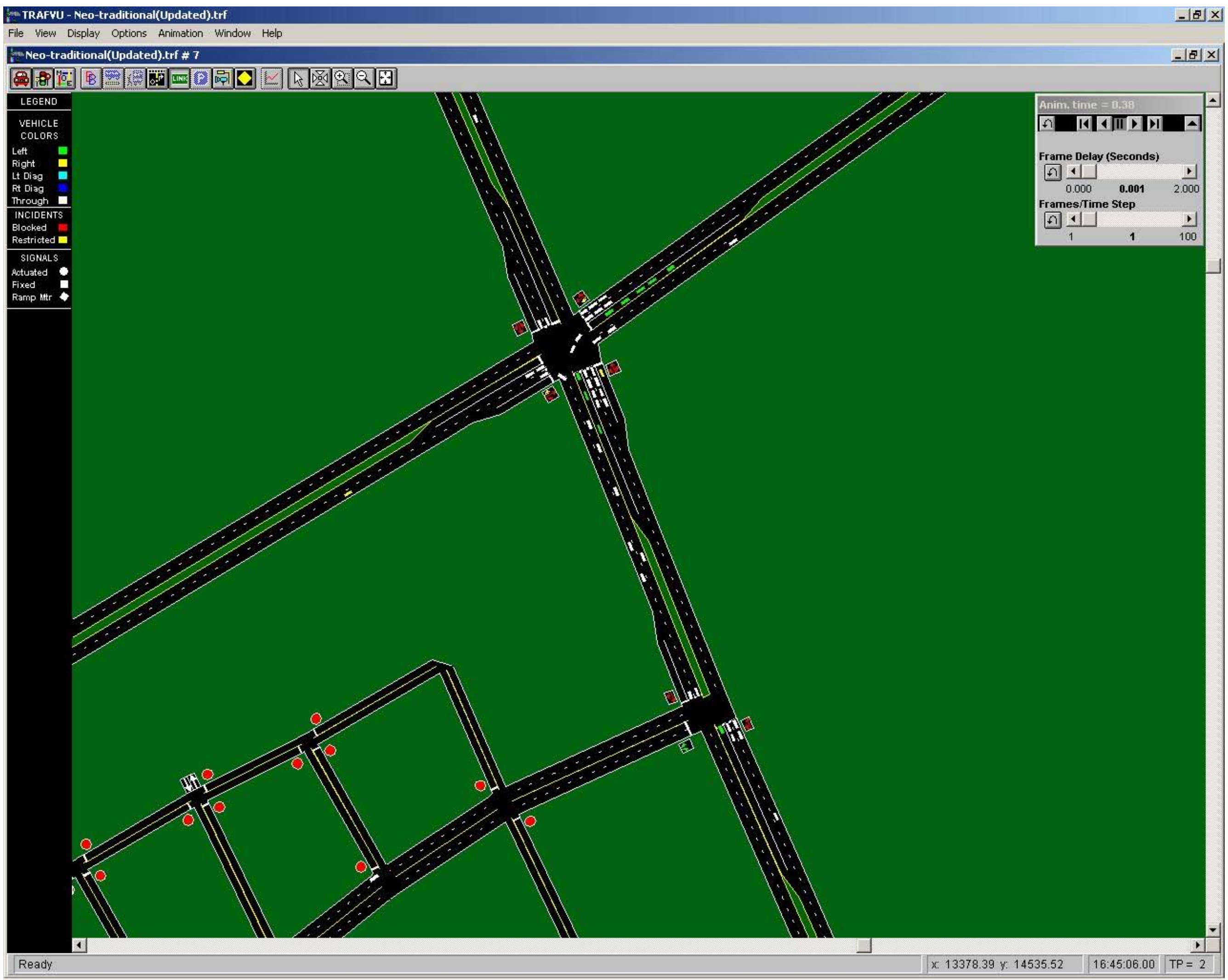
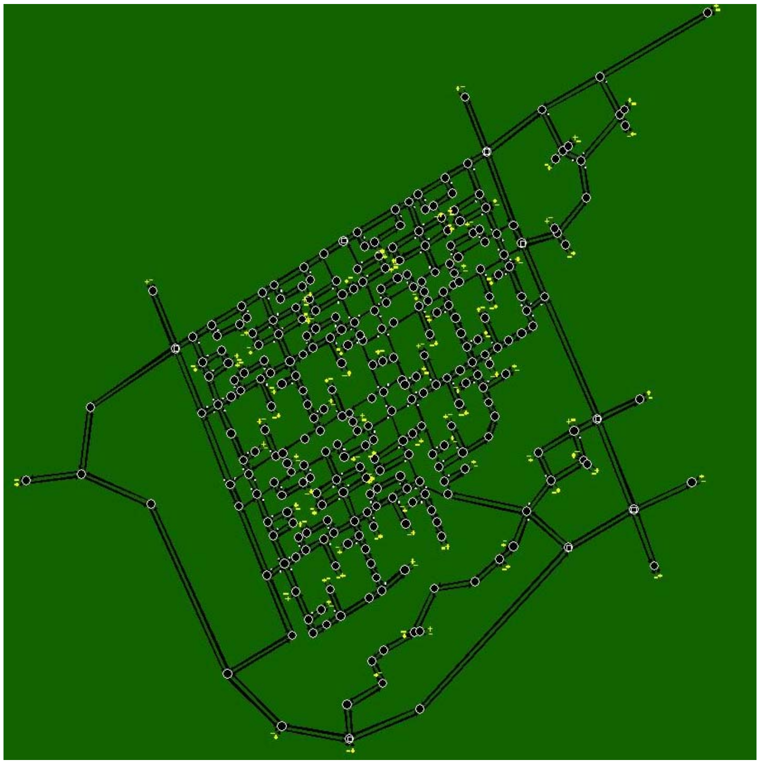


Exhibit 5-3: Corsim Network of the Conventional Layout

Exhibit 5-4: Corsim Network of the Neo-traditional Layout

Exhibit 5-5: Corsim Network of the Fused-grid Layout



The arterial street characteristics remain consistent among the three layouts, as do the streets located outside the Street Network Analysis Area. The characteristics of the streets within the Street Network Analysis Area vary slightly between existing and proposed layouts, as previously shown in Section 3.1. Exhibit 5-6 below illustrates the exact values used in the model, as opposed to the ranges that were shown in Exhibit 3-7, and the only difference among the layouts, which is the number of lanes of the major collectors.

Exhibit 5-6: Modelled Street Characteristics

Layout Design	Conventional			Neo-traditional			Fused Grid		
	Lanes	Speed km/h	Lane Width	Lanes	Speed km/h	Lane Width	Lanes	Speed km/h	Lane Width
Arterial	1-2	80	3.6m	1-2	80	3.6m	1-2	80	3.6m
Major Collector	1	60	3.6m	2	60	3.6m	2	60	3.6m
Minor Collector	1	40	4.6m	1	40	4.6m	1	40	4.6m
Local	1	40	3.6m	1	40	3.6m	1	40	3.6m

Further division between street types is introduced using intersection control. For consistency across the three layouts stop signs are placed at approaches where the street is intersecting a street of similar or higher hierarchy; that is, a minor collector has a stop sign when intersecting another minor collector, a major collector or an arterial but not when intersecting a local street. Traffic signals are placed in a pattern consistent with the existing conditions as indicated in Exhibit 3-1 to Exhibit 3-3.

The Corsim model is used to produce statistics on vehicle-miles, travel times, wait time, link speeds, and intersection level of service. The comparison and discussion or these results is contained in Section 6.

5.2.2 MODEL REFINEMENT FOR SCENARIOS 4 & 5

After initial model runs of scenario 4 and 5 were observed, it was evident that the network as initially coded was insufficient to accommodate the large vehicle volumes found in both high-density scenarios. Large queues developed at the intersections of Fallowfield and Cedarview, and Fallowfield and Greenbank. To alleviate the problem, the signal timings at these intersections were adjusted; the same adjustments were made in each neighbourhood layout. The problem becomes much worse in scenario five. Congestion near the business centres in each layout spreads throughout the neighbourhood until gridlock cripples any movement within the model. More severe measures needed to be undertaken to alleviate this problem. Signal timings were changed again at Fallowfield and Greenbank; three intersections in each of the layouts were changed to roundabouts; and, all streets between the major business centres and their nearest arterial were widened to two lanes, which equates to 700, 620 and 610 more metres of road in the Conventional, Neo-traditional and Fused Grid layouts, respectively.

6. COMPARISON OF RESULTS AND DISCUSSION

The primary purpose of this study is to compare the traffic performance of different neighbourhood road layouts including district and regional roads in a real setting. After the completion of the Literature Review, gaps in previous research were discussed some of which this study set out to fill. The primary research gap addressed by this study is in **quantifying the transportation level of service impacts of different street layouts using commonly accepted transportation engineering techniques and models and assessing how and why these results vary across the street layouts**.

In addition, other research issues to be investigated include:

- The effect of street layout and land use on travel behaviour and mode choice;
- The effect of connectivity on travel distances;
- The effect of connectivity on non-local traffic penetration;
- The performance of one-way couplets; and
- The impact of the arterial connection spacing on arterial traffic level of service.

6.1 Trips by Land Use Scenario

Using the City of Ottawa's four-stage Emme/2 model and population and employment data developed for each land use scenario, origin-destination (OD) trip matrices were produced by mode. Each land use scenario is described in detail in Section 5. Population, employment, and total trips are summarized by scenario in Exhibit 6-1 for the PM peak hour.

Exhibit 6-1: PM Peak Hour Vehicle Trips by Scenario

Scenario	Description	Population	Employment	Local Trips	External Trips	Total Trips	Intra-Neighbourhood Trip Rate
1	Existing Pop & Emp with Uniform Density	13,680	1,640	2,711	3,867	6,578	6.0%
2	Existing Pop & Emp with Prevailing Density Distribution	13,680	1,640	2,711	3,867	6,578	6.0%
3	Traditional Neighbourhood Design	20,949	2,510	3,558	3,867	7,425	8.7%
4	Transit Supportive Density	30,330	3,640	5,881	2,776	8,657	12.4%
5	Downtown Employment	30,330	16,850	9,623	2,717	12,340	26.1%

Local trips refer to trips that have either origin or destination within Barrhaven and intra-neighbourhood trips are those with both origin and destination within Barrhaven. Intra-neighbourhood trips were determined through the Emme/2 trip distribution process. The intra-neighbourhood trip rate refers to the proportion of local trips that do not leave the neighbourhood. As shown, this rate increases with growing population and employment density, as the proportion of residents that also work in the neighbourhood increases. External trips refer to regional trips that have neither origin nor destination within Barrhaven. For higher density scenarios the number of external trips decrease as neighbourhood roads and arterials become more congested and non-local trips choose alternative routes away from Barrhaven.

Given that there are three street layouts and five land use scenarios, combined with four road classifications, external and local trips, etc., data analysis and display in a thorough, yet clear and understandable manner is challenging. As such, much of the detailed analysis, such as vehicle kilometres travelled and delay by road type, will be presented and compared for Scenario 1and Scenario 5. Between Scenario 1, “Existing Population and Employment with Uniform Density”, and Scenario 5, “Downtown Employment”, population is increased almost threefold, while employment is increased more than tenfold. . Scenario 5 can be regarded as illustrating the effects on Barrhaven of extreme intensification and mixing of uses. Scenario 1and Scenario 5 represent opposite extremes in terms of population and employment density and, as such, bookend the range of results across the scenarios.

6.2 Mode Split

While the transportation demand modelling and traffic simulation method employed in this study cannot predict changes in non-motorized travel, the mode split component of the Ottawa TRANS Emme/2 model does provide basic functionality to assess changes in transit mode split across street layout concepts and land use scenarios. Mode split is estimated in the TRANS model using a logit model, which is outlined below followed by a discussion of the mode split analysis.

6.2.1 TRANS MODE SPLIT MODEL

The TRANS mode split model consists of work trip and post-secondary school logit models. The general formulation of a logit model is presented below, which calculates P_{ijm}, the probability that a trip from origin zone *i* to destination zone *j* is made via mode m, as:

$$P_{ijm} = \frac{\exp(V_{ijm})}{\sum_{m' \in C_t} \exp(V_{ijm'})}$$

where:

V_{ijm} = utility of using mode *m* for a trip from zone *i* to zone *j*
= $\beta * X_{ijm}$

β = vector of utility function parameters

X_{ijm} = vector of utility function explanatory variables for zones *i*, *j* and mode *m*

C_t = choice set of available modes for a trip from zone *i* to zone *j*

Data from the 1995 National Capital Region (NCR) O-D Travel Survey was used to calibrate the work trip model for the a.m. and p.m. peak hours. Variables considered in the work trip mode choice model include the following:

- Auto In-Vehicle Time – The time spent in the vehicle driving. It is estimated based on the auto equilibrium assignment algorithm, which considers the travel time impacts of congestion;
- Auto Cost – Parking cost plus the auto operating cost;

- Transit In-Vehicle Time – Time spent on the transit vehicle;
- Transit Walk Time – Time to walk to the transit stop at the trip origin, from the stop at the destination and the time spent walking to make transfer connections;
- Transit Wait Time – The time spent at the transit stop waiting for the transit vehicle, estimated as one-half the headway of the transit route; and
- Vehicles Per Household – Categories include zero, one and two plus vehicles per household.

Since only a small proportion of Barrhaven residents are post-secondary school students, the post-secondary logit model is not expected to have a significant effect on overall mode splits; however, it is outlined briefly here. The logit model developed for a.m. peak hour post-secondary school trips is also based on disaggregate data for post-secondary travel as obtained from the 1995 NCR O-D Travel Survey. The model is similar in structure to the work trip model except that cost is not included in the formulation and walk and wait time are aggregated as out-of-vehicle travel time.

6.2.2 MODE SPLIT RESULTS

There are two key conclusions from auto and transit mode splits estimated by the Emme/2 model.

First, for each land use scenario, there are only marginal differences in transit mode split across the street layouts. This supports results from a previous CMHC study (IBI Group, 2000), which found that, although neighbourhood design (including street layout) influences travel decisions, locational and socio-economic variables have a significantly stronger relationship to auto ownership, transit mode choice, and vehicles kilometres travelled. In addition, as discussed in the literature review, if neighbourhoods do not have major transit infrastructure in place to which pedestrian friendly neighbourhoods can feed and are surrounded by conventional suburban subdivisions, then changes in travel behaviour could be limited (Friedman et al., 1994). While Barrhaven is served by relatively good bus service, the provision of higher order transit (e.g., bus rapid transit, light rail) may elicit larger differences in transit mode split across street layouts.

Secondly, the estimated mode split results support that increased density and mix of uses increases transit use. Transit mode split in the PM peak hour increased from approximately 11% to 16% between Scenario 1 and Scenario 5, an increase of 45%. It is expected that these results may somewhat underestimate transit mode split, since transit service was not increased substantially across land use scenarios. In addition, motorized trip rates were reduced for higher density scenarios to account for higher levels of non-motorized trips as well as reduced trip making due to live-work arrangements. Further study is required to assess differences in non-motorized travel across the street layouts, such as the work undertaken by Frank and Hawkins (2007). However, given the nature of the analysis, if auto trips were slightly overestimated, as expected, this only provides a stronger test of the traffic performance of each layout.

6.3 Vehicle Kilometres Travelled and Connectivity

Connectivity describes how well the transportation network connects one point to another in a community. It refers to the quantity and quality of the connections, including the number of paths between origin and destination, the directness of the paths, and the modes supported along each path (Handy et al., 2003). In the case of neighbourhood vehicle travel, connectivity influences the directness of a trip, the number of alternative routings available between two points, and the potential for non-local traffic penetration as long distance travellers may be able to use local roads to bypass congested arterials and arterial intersections.

As was discussed in the Literature Review, there are many ways to measure connectivity, but ultimately the goal of measuring connectivity is to determine how efficiently vehicles can traverse a road layout. When the number of trips is held constant for each layout, the vehicle-kilometres travelled is the actual measurement of how directly vehicles can traverse a road layout. Simulation results of VKT are shown below for local trips and non-local trips are compared to the conventional measures of connectivity, such as intersection density. VKT refers to the distance travelled by automobiles, but does no include bus travel from transit trips, as transit vehicles were not included in the traffic simulation.

Connectivity for each street layout is compared in Exhibit 6-2. Conventional suburban and fused-grid layouts have similar vehicular connectivity levels. Based on intersection density, the neo-traditional layout has approximately 75% higher level of connectivity than other layouts.

Exhibit 6-2: Neighbourhood Layout Connectivity Comparison

Street Layout	Intersection Density (Intersections/ha)	Street Density (lane-km/ha)
Conventional suburban	0.48	0.35
Neo-traditional	0.87	0.48
Fused-grid	0.51	0.36

6.3.1 LOCAL TRIPS

Total neighbourhood VKT for local trips (i.e., trips that originate or are destined for Barrhaven) and average local trip length are illustrated in Exhibit 6-3 and Exhibit 6-4, respectively. While total VKT increases with each scenario given increasing number of trips, average trip length decreases. This is indicative of the increase in internal capture within Barrhaven: as the population and employment use density is increased, more trips start and end within Barrhaven.

The exhibits also show that while VKT levels are similar for each scenario, the neo-traditional layout has the lowest VKT for all land-use scenarios, ranging from approximately 8% to 12% lower than conventional suburban and fused-grid layouts. This is a result of the higher connectivity in the neo-traditional neighbourhood, which allows for more direct trips. These results are by no means as dramatic as the 57% reduction in intra-neighbourhood VKT predicted by Kulash et al. (1990) for a high connectivity neighbourhood compared to a conventionally designed neighbourhood. However, they are more substantial than LUTAQH (*undated*) results from Portland, Oregon, which indicate a 0.5% reduction in VKT per 10% increase in intersections per square mile. By comparison, these results indicate a VKT reduction of approximately 1%-1.5% per 10% increase in intersection density; however, this VKT reduction only refers to travel within the neighbourhood (including the surrounding arterials).

Exhibit 6-3: Total Neighbourhood VKT For Local Trips

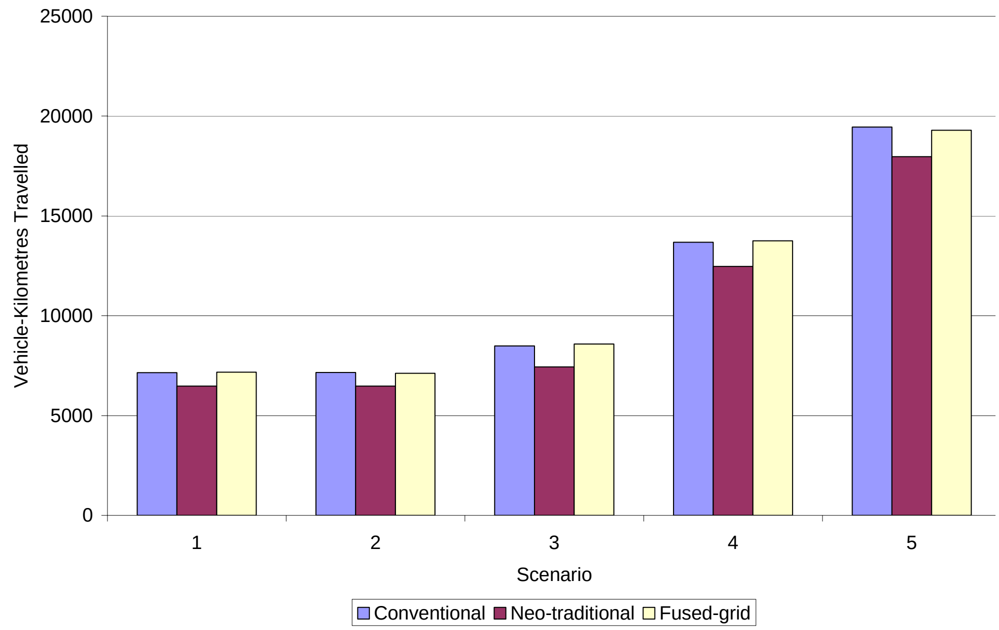
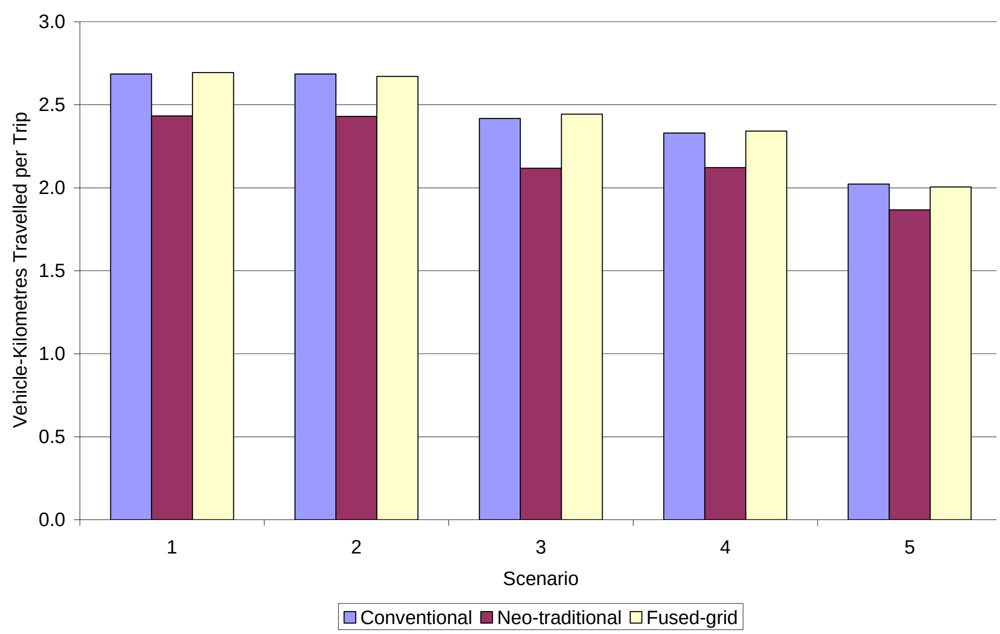


Exhibit 6-4: Average Local Trip Length



The breakdown of VKT by road type also provides instructive results with respect to the effect of each street layout on the flow of traffic into and out of the neighbourhood. The distribution of total VKT by road type for local is shown for scenarios one (1) and five (5) in Exhibit 6-5 and Exhibit 6-6, respectively, as they represent the two extremes of population and employment density. The exhibits illustrate how the popularity of each facility type changes as traffic becomes more congested.

In general, a smaller proportion of traffic uses arterials as they become more congested in the “Downtown Employment” scenario and drivers look for alternate routs. The VKT of the Fused-grid follows the hierarchy of the street types: the arterials carry the most traffic followed by the major collectors, minor collectors and finally the local roads. Since local roads are generally short with cul-de-sacs and minor collectors end at T-intersections, more traffic uses the major collectors as arterials become more congested. In the Neo-traditional layout, there is a noticeable increase in the proportion of VKT on the local roads, which are continuous and can provide alternate routings. The local roads are relied upon more than the minor collectors to move vehicles. In the Conventional layout, both the local and minor collectors are relied upon more than the major collectors. As shown in the exhibits, a greater proportion of traffic uses the local roads and minor collectors as arterials become more congested.

The analysis shows that the Fused Grid restricts the amount of traffic on local streets more effectively than the Conventional and Neo-traditional plans. Only 14% of the traffic in the Fused Grid Plan uses these roads as opposed to 24% and 17% for the Conventional and Neo-traditional plans, respectively, based on Scenario 1 results. Under the higher density scenario (Scenario 5), the proportion of traffic on lower classification streets for the Conventional and Neo-traditional Neighbourhoods increases while the Fused Grid holds constant at 14%.

These trends are not specific to Barrhaven, but are a function of the street layout. The Fused-grid layout is designed so that a resident leaves their house travels for a short distance on their local street and then onto a minor collector, major collector and out to an arterial road. In comparison, in the Neo-traditional layout, residents travel from their local street to perhaps several other local streets before exiting to a minor or major collector. In the Conventional layout, residents travel for long periods on their local streets and minor collectors (because of their curvilinity) and may not even travel on a major collector, since major collectors are sparsely distributed in Conventional layouts.

Exhibit 6-5: Scenario 1 - Total Local Trip VKT by Road Type

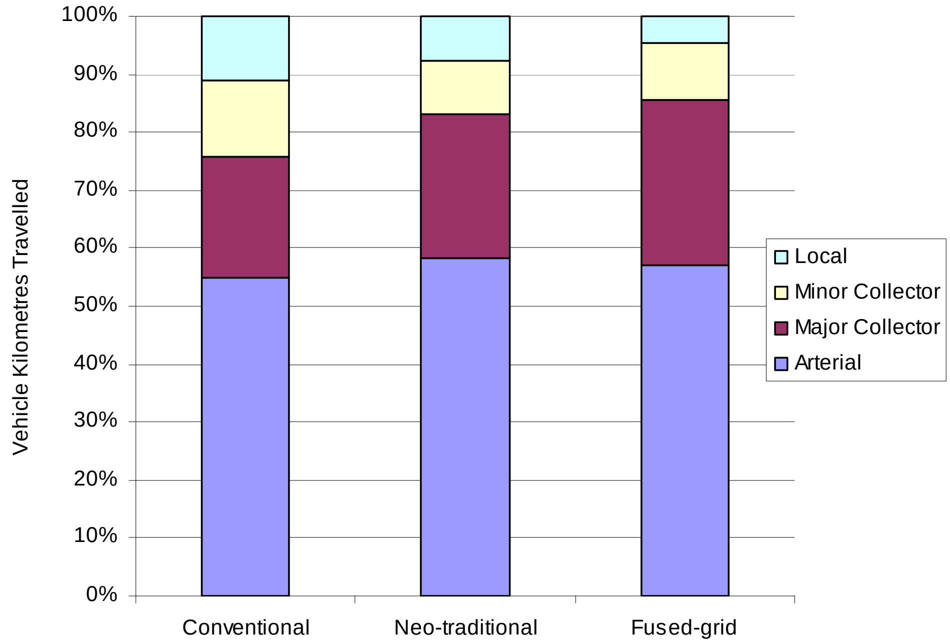
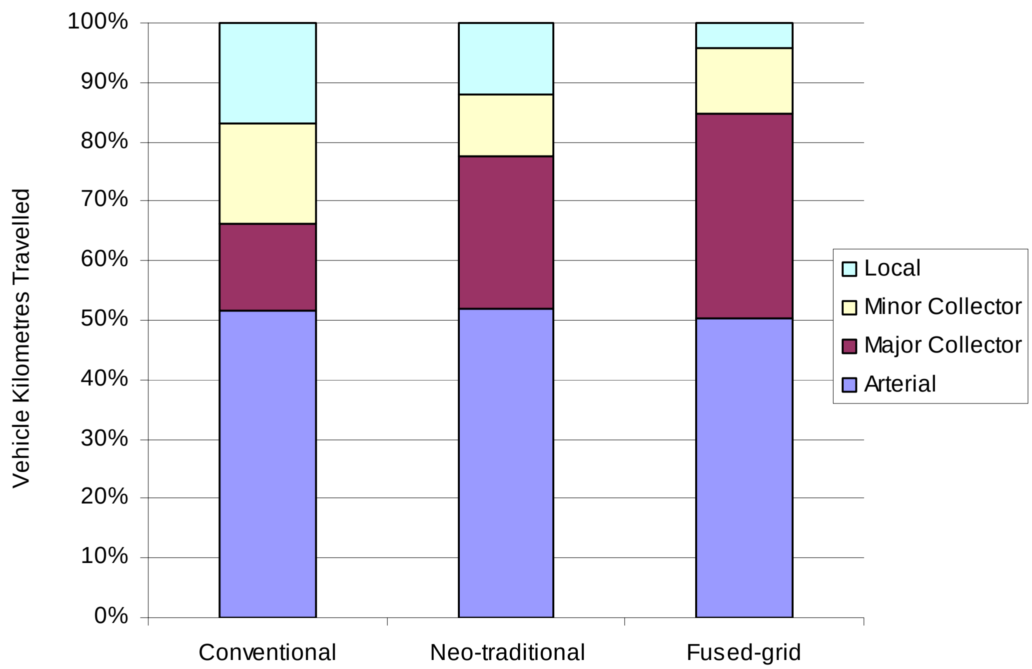


Exhibit 6-6: Scenario 5 - Total Local Trip VKT by Road Type



6.3.2 NON-LOCAL TRAFFIC INFILTRATION

Increased connections to arterials coupled with increased internal connectivity may lead to increased non-local traffic penetration as long distance travellers using the local roads to bypass congested arterials and arterial intersections. Initially discussed in Section 2.3.3, the intent of the fused grid layout is to provide quiet local streets while maintaining the connectivity of the neighbourhood and connections with arterials. On the other hand, it is expected that the Neo-traditional and Conventional layouts, provide connectivity at the expense of traffic infiltration onto local roads or vice versa.

To investigate this idea, traffic considered external to the neighbourhood (that which neither begins nor ends its trip within the neighbourhood) was tracked in the Corsim models for each layout. The analysis was undertaken for Scenario 1 and Scenario 5, to test whether the amount of non-local traffic infiltration increased as congestion increased on surrounding arterials. Non-local VKT by road type is shown for Scenario 1 and Scenario 5 in Exhibit 6-7 and Exhibit 6-8, respectively. Overall non-local traffic decreases significantly from Scenario 1 to Scenario 5, as increased local traffic causes increased congestion around the neighbourhood, which pushes non-local traffic onto other roads further away from the neighbourhood.

The results indicate that the vast majority of non-local traffic travels on the arterials (i.e., Fallowfield and Greenbank), there is some non-local through traffic on major collectors, and little to no traffic infiltration onto minor collectors or local roads for any layout or scenario. Even the neo-traditional layout, with high connectivity among its local roads, experiences very little non-local infiltration. This likely occurs for several reasons.

First, arterial traffic flow does not degrade to unacceptable levels of service as discussed later in Section 6.4.2. This factor, combined with frequent stop signs along local roads and minor collectors, makes these facilities less attractive than arterials to non-local traffic from a travel time perspective. However, unlike in a Corsim traffic simulation, drivers do not have perfect information. As such, it is possible that in reality more drivers would get frustrated on congested arterials and attempt to cut through a neighbourhood if the street design allowed, even if their overall travel time ended up being somewhat longer than if they had stayed on the arterial road. In addition, the lack of traffic infiltration is likely due to Barrhaven and the fact that it is not surrounded by significant activity centres. As such, there is little motivation for non-local traffic to cut through the neighbourhood to get to a destination immediately surrounding the neighbourhood. The majority of through traffic is generated by the residential areas surrounding the study area as discussed below.

Exhibit 6-7: Scenario 1 - Vehicle-Kilometres Travelled by Non-Local Traffic

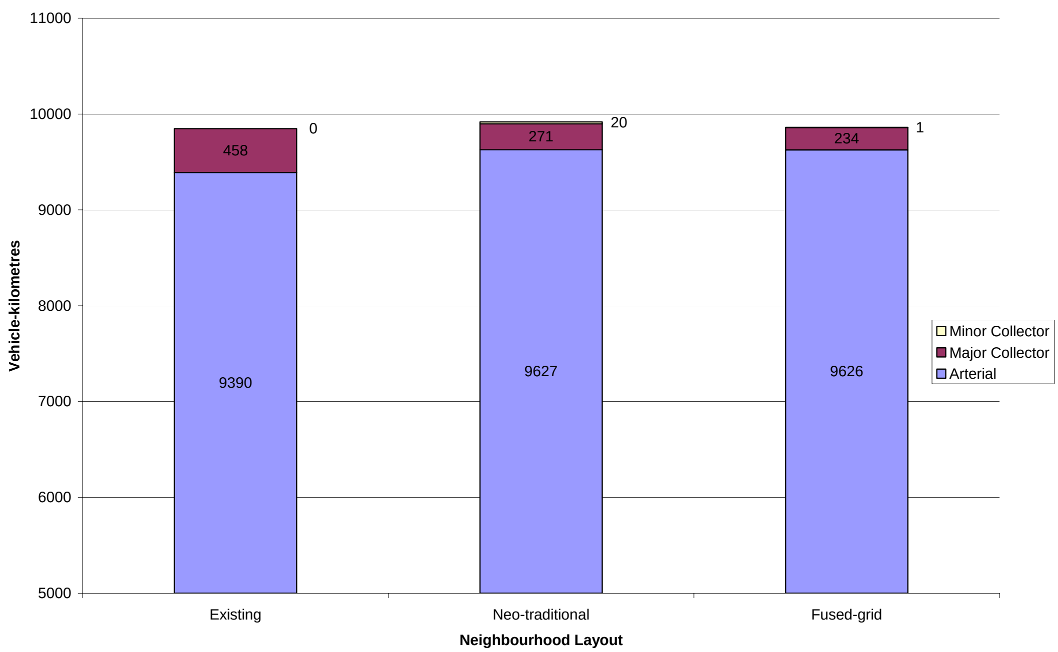
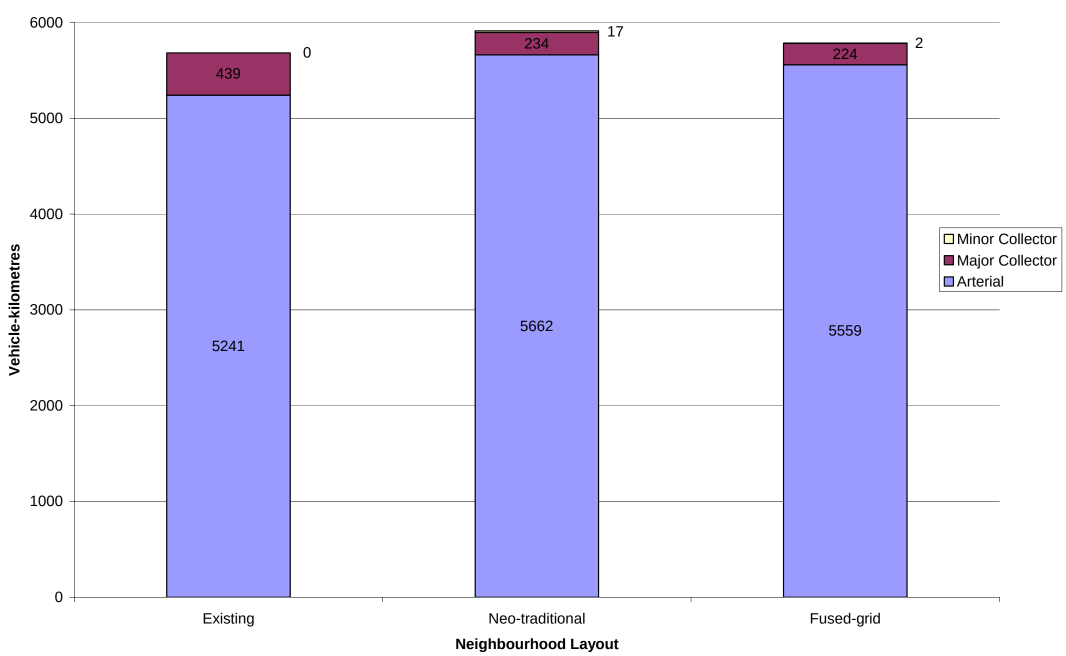


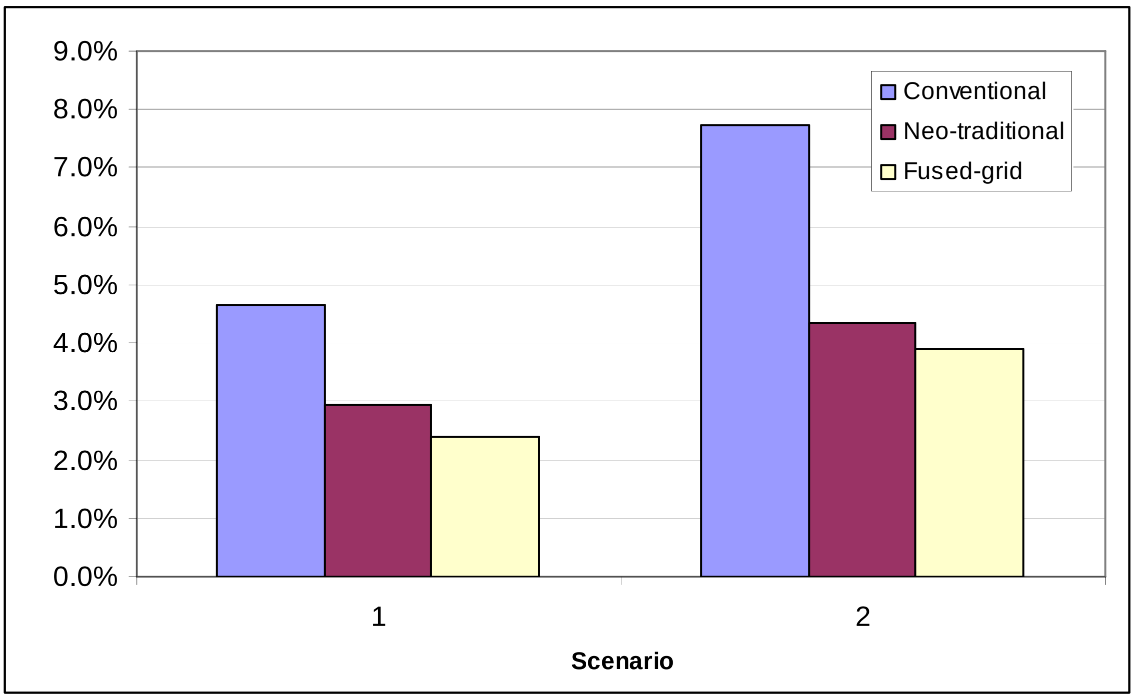
Exhibit 6-8: Scenario 5 - Vehicle-Kilometres Travelled by Non-Local Traffic



As shown in Exhibit 6-7 and Exhibit 6-8 above, a small proportion of non-local traffic (i.e., less than 10%) is though-traffic on major collectors. This type of infiltration is not necessarily undesirable given that some of the major collectors in each layout serve development outside of the study area. The proportion of non-local traffic that uses non-arterial neighbourhood facilities accounts for approximately 2% to 8% of non-local VKT, as shown in Exhibit 6-9. This proportion increases by a factor of approximately 50% to 66% between Scenario 1 and Scenario 5, which makes sense given that more non-local traffic will divert off of arterials when they become more congested, assuming alternative routes exist.

Surprisingly, the conventional suburban layout exhibits the highest rate through-movements by non-local traffic. Indeed, in Scenario 1, non-local traffic accounts for almost one quarter of total VKT on major collectors for the conventional layout, compared to approximately 15% of traffic for the neo-traditional layout, and 10% of traffic for the fused grid layout. This is because Jockvale Road is oriented diagonally and provides an efficient routing between Cedarview Road and Strandherd Raod, as well as the residential development to the south of the study area. These results indicate that at the individual neighbourhood level, the amount of traffic on major collectors is less related to general measures of connectivity (e.g., intersection density) than it is to route directness and travel time savings offered by specific facilities.

Exhibit 6-9: Proportion of Non-Local Traffic Using Non-Arterial Neighbourhood Roads



6.4 Traffic Performance

In this study, traffic performance is measured in terms of vehicle delay time: the higher the delay the poorer the performance. The first performance measure is based on the overall vehicle delay - across the entire neighbourhood and then broken down by street type. The second measure is the delay at intersections, which is commonly referred to as Level of Service. The overall results for each performance measure are shown for each land-use scenario, but a detailed discussion is undertaken for scenarios one and five, as in earlier sections.

6.4.1 DELAY

Vehicle delay time represents the travel time above free flow travel time (i.e. trip distance/average speed limit). As such, vehicle delay includes delay from traffic congestion, as well as intersection delay (due to stop signs or traffic signals). Exhibit 6-10 confirms that total delay time increases as the land-use densities increase for all layouts due to the increased number of vehicles on the street networks with the associated increases in congestion. However, this is not the case for average delay per trip, as shown in Exhibit 6-11. Delay per trip decreases slightly between Scenario 2 and Scenario 4, and increases substantially for Scenario 5. The trip delay time decreases in Scenario 3 and 4 due to the decrease in average trip length caused by the higher number of intra-district trips (those that begin and end within the district), which occurs as the population and employment density increases. Due to higher levels of congestion in Scenario 5, average trip length increases as trips disperse across the network in an attempt to find less congested routes, which is not necessarily the shortest routing. Increased average trip length in combination with increased congestion results in a significant increase in delay per trip.

Overall, these delay results indicate that the Conventional layout performs progressively worse as the density in the neighbourhood increases. The fused grid layout, consistently provides the lowest delay, up to 35% less delay in the “Downtown Employment” scenario. A closer look at delay by road type sheds light on the factors affecting the overall delay as discussed below.

Exhibit 6-10: Total Vehicle Delay Time

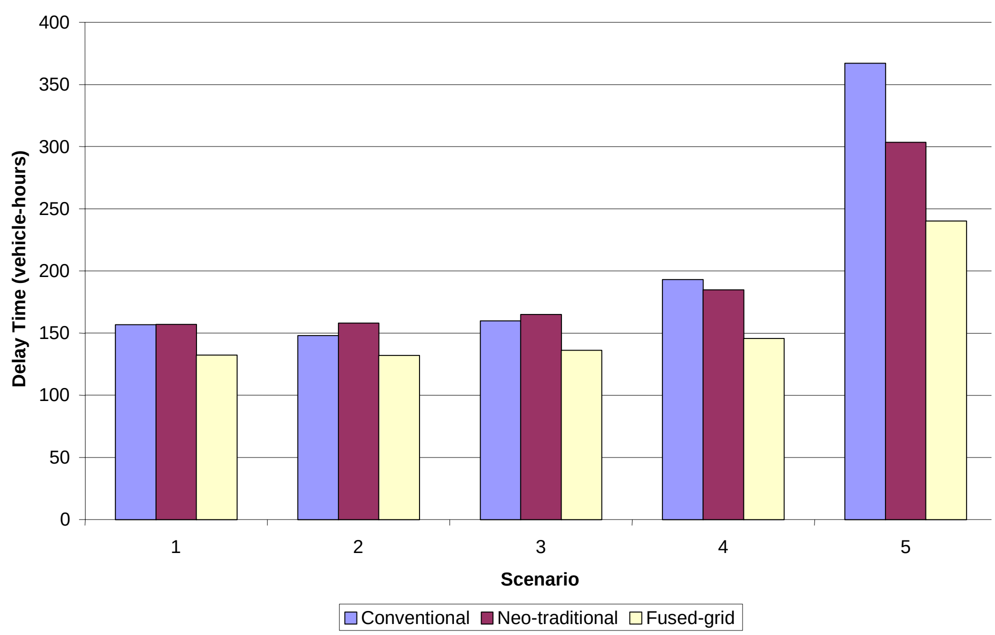
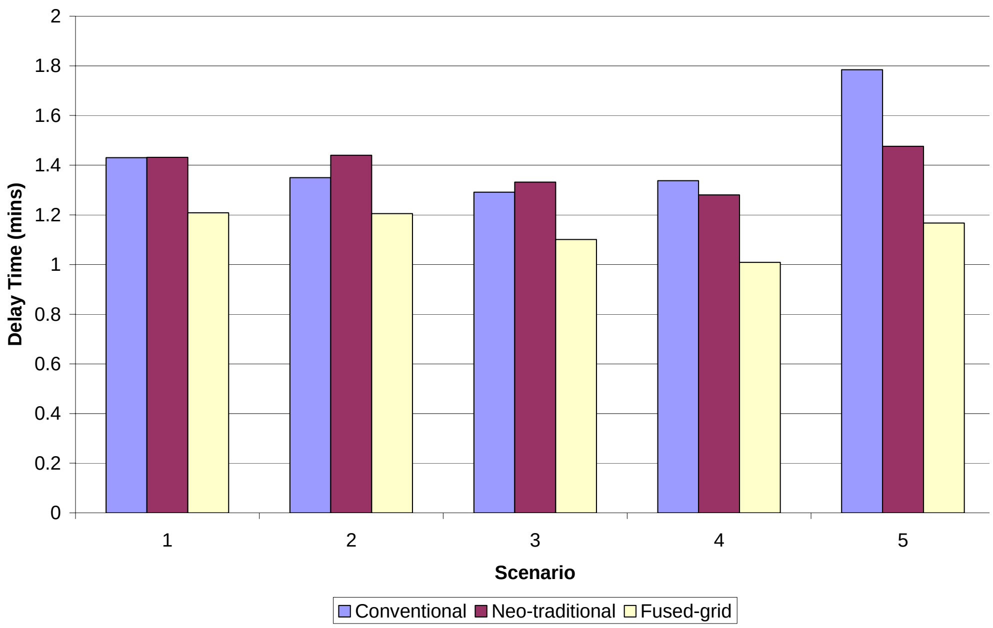


Exhibit 6-11: Average Vehicle Delay Time Per Trip



A closer look at where the majority of the delay is occurring reveals some interesting points. Exhibit 6-12 and Exhibit 6-13 show the total vehicle delay time by road type for scenarios one (1) and five (5), respectively. For scenario 1 in particular, the majority of the delay occurs on the arterial roads since a majority of the traffic volume is on the arterial roads as well as the signalized intersections. As the land-use densities increase, traffic flow on all facilities degrades, and the number of intra-Barrhaven trips increase, the delay on roads within the district begins to compose more of the total delay. In Scenario 5, the difference in delay among the three layouts by road type becomes very evident. The pattern in delay time by road type follows the pattern of the vehicle-kilometres travelled seen in Section 6.3.1.

In scenario 5, the Conventional design exhibits much delay along local streets and minor collectors. This is because the Conventional layout has few direct paths for travelling within or exiting the neighbourhood and a relatively significant proportion of travel distance must be spent on local roads and minor collectors. These facilities have many bottlenecks, which increase delay as traffic volumes grow. Indeed for traffic originating within the neighbourhood, a typical path would be from one local street to another local street that acts as an exit from the immediate area to a minor collector street, which then joins with other minor collector streets that intersects a major collector or arterial.

The Neo-traditional layout is more connected and there are fewer bottlenecks at local streets or minor collectors as there are a variety of routing options open to a driver and vehicles can more easily disperse across the network to optimize traffic flow. However, this layout is characterized by numerous stop signs on local roads and minor collectors, as shown previously in Exhibit 5-6, which negatively impact the travel time on these facilities. In addition, arterial facilities in this layout experience approximately 10% greater delay time in the conventional layout for scenario 5, despite the fact that the neo-traditional arterials experience slightly less VKT than those in the conventional layout. Arterial performance for each layout will be discussed further in the following section that deals with intersection level of service.

The use of a strongly hierarchical street system in the Fused-grid is what separates it from the other layouts. The Fused-grid exhibits the least delay, which can be attributed to the use of the hierarchical street system, as well as its connectivity. In the Fused-grid, each local street is connected directly to a minor collector and does not intersect with another local street. The movement from local street directly to minor collector, to major collector and finally to arterial is a very efficient travel path that results in lower travel delay. The efficiency of the network is evident in the lower travel time delay even though total VKT for the fused grid in scenario 5 is similar to the conventional layout. In addition to the hierarchical street system, reduced delay for the fused grid layout may also be due to arterial performance as discussed in the following section.

Exhibit 6-12: Scenario 2 Vehicle Delay Time by Road Type

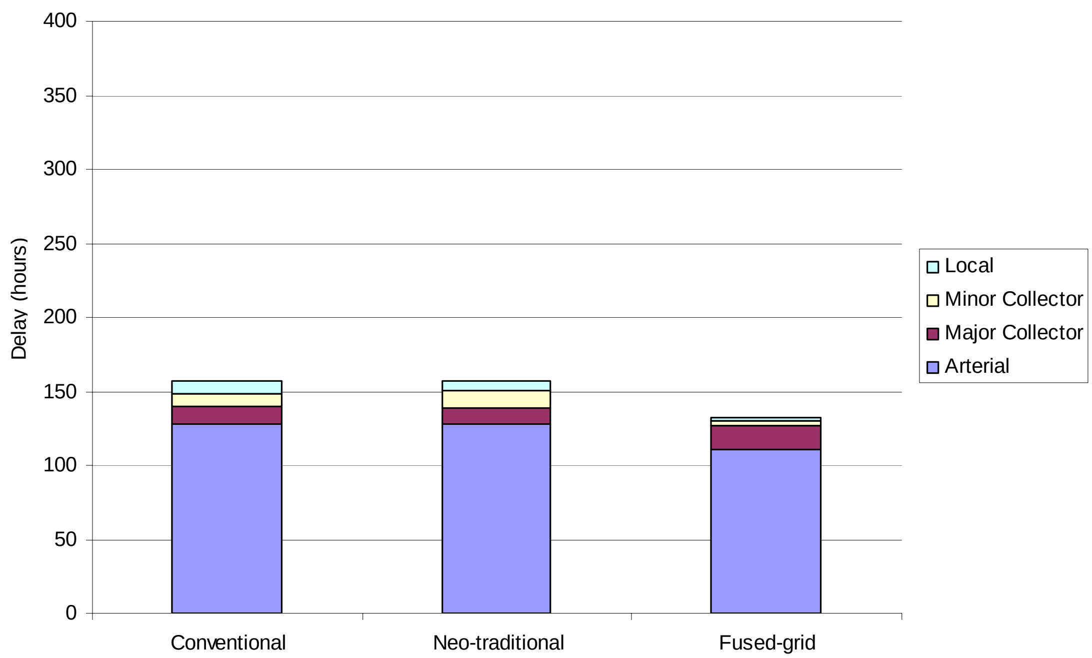
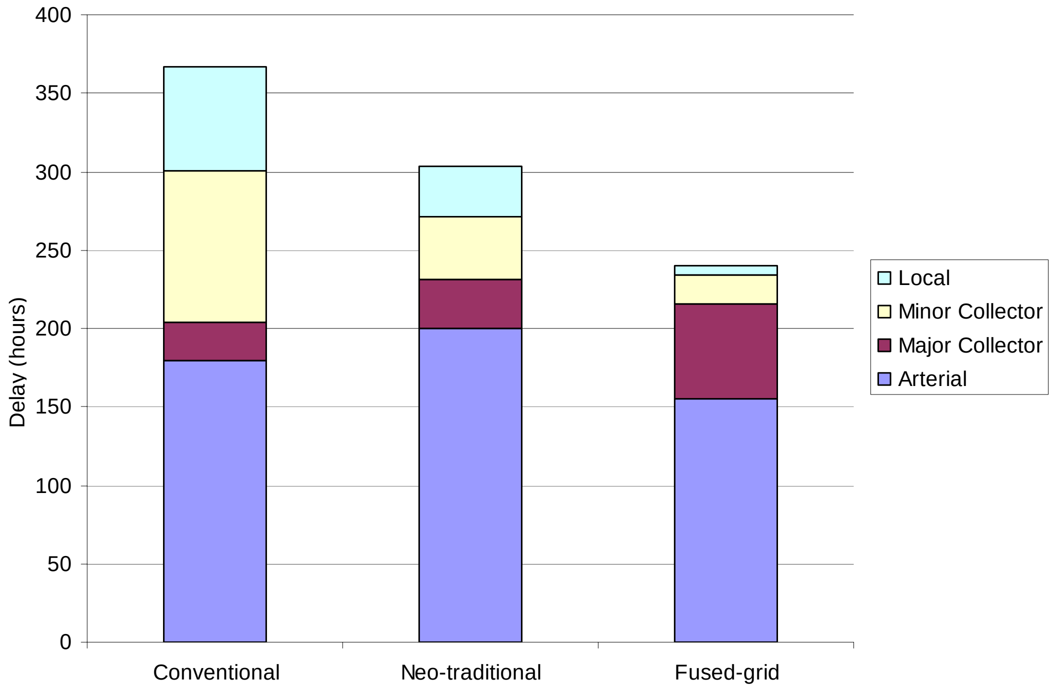


Exhibit 6-13: Scenario 5 Vehicle Delay Time by Road Type



6.4.2 INTERSECTION LEVEL OF SERVICE

Urban street networks are often graded by their intersection level of service, which is determined by approach delay. Essentially, if vehicles are delayed at an intersection for fewer than 10 seconds the intersection is said to have a Level of Service of “A”. If the average vehicle delay is greater than 80 seconds the intersection is said to have a Level of Service of “F”. Exhibit 6-14, below, shows the number of signalized intersections performing at each LOS level for each land-use scenario and neighbourhood layout. Since signalized intersections are only located along arterials, these level of service values provide an indication of arterial performance.

The Fused Grid layout demonstrated the best level of service values for all scenarios and was the only layout to have an intersections providing level of service A, although not directly evident from the table. This is likely due the design of the fused grid arterial connections in this layout, which include one-way couplets. For one-way couplets, signalized intersections were only required to allow outbound traffic along major collectors to turn left onto an arterial. A signal is not provided for left turns from arterial to major collector, rather these movements are made in gaps in traffic. Thus, one way couplets perform better from a traffic perspective because they reduce the number of turning movement timings required at a signalized intersection, allowing more time for through traffic. This result supports Calthorpe’s (2000) assertion that there are traffic flow benefits associated with couplets. In addition, it illustrates Kulash’s (1998) idea that by designing street networks that can operate with fewer signalized intersections, traffic should be able to flow more smoothly, primarily because turning movements can be made more efficiently during gaps in traffic.

Exhibit 6-14: Intersection Level of Service

Scenario	Number of Intersections at LOS Levels for each Layout								
	Conventional			Neo-traditional			Fused Grid		
	A-B	C-D	E-F	A-B	C-D	E-F	A-B	C-D	E-F
1	56%	44%	-	67%	33%	-	63%	38%	-
2	56%	44%	-	56%	44%	-	63%	38%	-
3	67%	33%	-	67%	33%	-	75%	25%	-
4	56%	33%	11%	56%	44%	-	75%	25%	-
5	44%	22%	33%	56%	33%	11%	50%	50%	-

Note: The Fused Grid layout only contains 8 signalized intersections while the others contain 9.

In terms of intersection level of service, the Conventional layout almost performs as well as the Neo-traditional layout under the lower land-use densities but does not perform as well as the Neo-traditional under the higher density scenarios due to the bottlenecking of all traffic through the few signalized intersections. However, despite the fact that the neo-traditional signalized intersections provide better level of service when compared with the conventional layout, overall arterial delay is higher for the neo-traditional layout, particularly when expressed per vehicle kilometre travelled on arterials. For neo-traditional arterials, average delay per vehicle kilometre travelled is 21% higher than for the conventional layout, and 37% higher than for the fused grid layout. Given that neo-traditional signalized intersections provide better level of service overall when compared with the conventional layout intersections, what could explain the additional delay on neo-traditional arterials?

The higher delay on neo-traditional arterials is surprising given that sources in the literature indicate that, in general, more arterial connections lead to better traffic flow on arterials (Kulash, 1998), Daisa et al., *undated*). Exhibit 6-15 presents the number of arterial connections by layout as well as the average connection spacing for the arterials Fallowfield and Greenbank. None of the arterial connection spacings approach the average spacing of 100-160 metres recommended by Daisa et al. (*undated*). As shown, there are more arterial connections in the neo-traditional layout than in the conventional layout, but not sufficient to exceed the 200 metres minimum spacing recommended by the Transportation Association of Canada (1999). Thus, the increased number of connections in this layout would be expected to improve arterial traffic flow; however, this is not the case.

If the added connections actually degrade arterial traffic flow due to increased delay from turning and accelerating vehicles at more frequent spacings, then this would also be expected to affect arterial traffic flow in the fused grid layout, which has even more arterial connections. Although, it is possible that the arterial delay reductions associated with more efficient signals at one-way couplets hide the increased delay from more arterial connections.

Exhibit 6-15: Arterial Connections by Layout

Layout	Fallowfield			Greenbank			Total Arterials		
	Connections	Segment Length (m)	Average Connection Spacing (m/connection)	Connections	Segment Length (m)	Average Connection Spacing (m/connection)	Connections	Segment Length (m)	Average Connection Spacing (m/connection)
Conventional Suburban	5	2,080	416	5	2,120	424	10	4200	420
Neo-Traditional	7	2,080	297	8	2,120	265	15	4200	280
Fused Grid	8	2,080	260	6	2,120	353	14	4200	300

Based on these results, it is unclear whether increasing the number of arterial connections actually improves arterial traffic flow. In the case of the neo-traditional layout, other factors specific to Barrhaven may be influencing the results. Further analysis of arterial traffic flow is required where the number, type, and spacing of connections are carefully controlled.

6.5 Fused Grid Alterations

Unlike the Fused Grid's arterials, minor collectors and local roads, which perform well in terms of delay, efficiency and cut-through traffic, its major collectors are typically the poorest performers among the layouts'. This is largely because the one-way streets in the Fused Grid layout create the need to double back and the city blocks between the one-way streets create discontinuity among the intersecting streets. Two alterations to the fused grid were tested for their ability to improve the performance of the Fused Grid's major collectors.

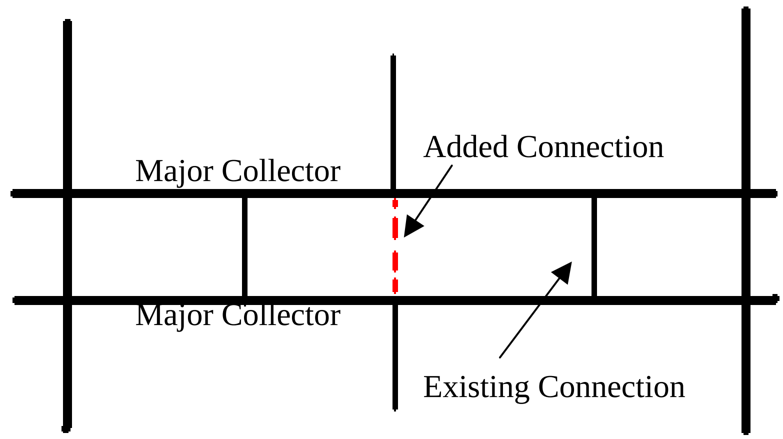
6.5.1 TWO-WAY MAJOR COLLECTORS

Changing the one-way couplet major collectors into two two-way streets increases the connectivity of the layout and leads to a decrease in the VKT on the arterial and major collector streets (See Exhibit 6-17). But, the increased connectivity attracts more non-local traffic into the network as illustrated by the amount of non-local traffic using the major and minor collectors seen in Exhibit 6-18. Also, in the initial Fused Grid design, the major collectors are two lane streets, with a total land demand four lanes wide per one-way couplet. To maintain the same number of road lane-kilometres when converting into two-way streets, each street was changed to one lane in each direction. This design proved to be sufficient for the existing conditions but when the land-use was increased to the levels associated with Scenario 5, grid lock was prevalent everywhere. The major collectors had to be increased to two lanes in each direction, doubling the lane-kilometres, to alleviate the congestion.

6.5.2 INCREASING THE NUMBER OF CONNECTING STREETS

Another way to increase the Fused-Grid's connectivity is by adding more connecting links between the major collectors. In the initial design, the minor collectors intersect one of the one-way major collectors at a "T" intersection; connecting links were added to link the minor collectors, which intersect the major collectors on either side of the city blocks, as shown in Exhibit 6-16. The result is a decrease in the VKT for the arterial and major collector streets, shown in Exhibit 6-17, but causes the VKT to increase on the minor collectors and requires more land devoted to road infrastructure.

Exhibit 6-16: Increasing the Connectivity Through Major Collector Corridors



In general, decreasing the vehicle-kilometres travelled for the Fused Grid layout can only be achieved at a cost, whether it is more non-local traffic in the neighbourhood or more road infrastructure.

Exhibit 6-17: Local VKT with Alterations to the Fused Grid

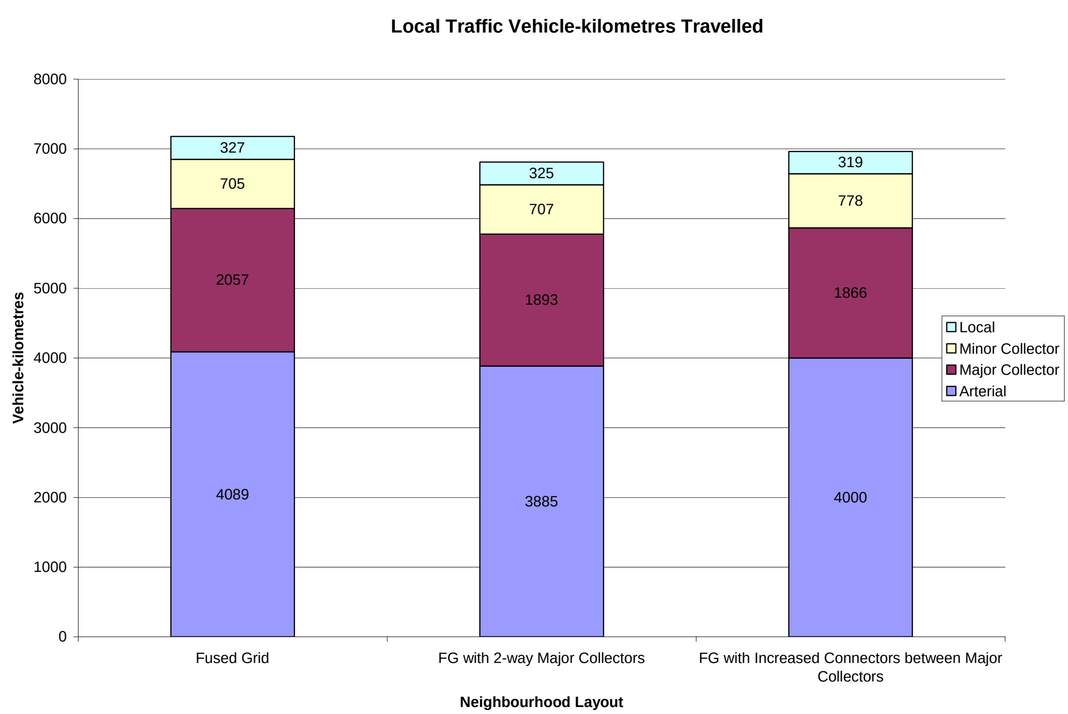
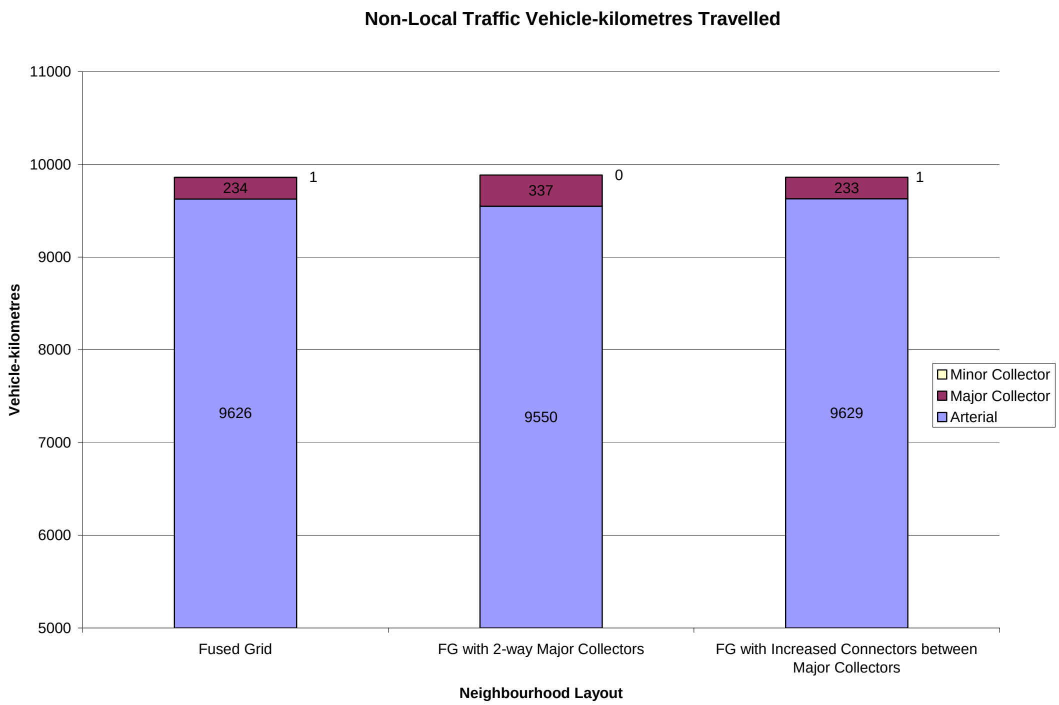


Exhibit 6-18: Non-Local VKT with Alterations to the Fused Grid



7. CONCLUSIONS

The primary purpose of this study is to compare the traffic performance of different neighbourhood layouts, including conventional suburban, neo-traditional, and fused grid street networks, for district and regional streets in a real setting. A combination of travel demand modelling and traffic simulation methods were used to quantify the transportation level of service impacts of different street layouts and assess how and why traffic performance varies across the layouts. Traffic performance was related to street network measures, such as connectivity (e.g., intersection density), and arterial connection spacing, as well as published results from similar studies.

While previous studies have assessed the traffic impacts of increasing street connectivity or commented on the traffic performance of neo-traditional networks, no known studies have specifically dealt with the traffic performance of the fused grid concept. As such, this study presents a novel contribution to the neighbourhood design and traffic literature, and may make the planning and engineering community more comfortable in applying the fused grid approach to street layout design at the neighbourhood scale. Key findings as well as implications for neighbourhood planning and policy, and study limitations and further research are summarized below.

7.1 Key Findings

All layouts exhibit acceptable traffic performance under most land use scenarios

The assessment showed that for a wide range of population and employment densities, each street layout allows for acceptable traffic flow. This is evident in the relatively low average trip delay (about 1.4 minutes on average for all trips in the district), minimal non-local traffic infiltration, and acceptable intersection level of service for Scenarios 1 to 4, which represent gross densities ranging from approximately 45 to 100 residents plus jobs per hectare. These land use characteristics are typical of most built up urban areas with the exception of Central Business Districts, which can exceed 100 residents plus jobs per hectare.

The Fused Grid layout exhibits the best traffic performance, particularly with increasing density of development

The Fused Grid layout exhibits the lowest delay and best signalized intersection level of service under all scenarios, but particularly under the high density/mixed-use land use conditions of Scenario 5, “Commercial Intensification”. With increasing density, the Fused Grid performs increasingly better in terms of total delay for local trips compared to the other layouts. These lower relative levels of delay range from 15% less delay than the poorest performing layout under existing population and employment levels, to 35% less delay for the high density/mixed use scenario. This is due to two primary factors. First, the strict hierarchical street system in the Fused Grid layout provides for efficient traffic flow into and out of the neighbourhood, as discussed above. Secondly, the Fused Grid’s intersections provide the best level of service compared to other layouts, since it includes one-way couplets for major collectors, which reduces the number of signalized intersections required and streamlines traffic signal cycle timings.

A hierarchical network layout can improve traffic performance

All three layouts are characterized by a hierarchical network structure to varying degrees. Of the three, the Fused Grid layout follows the strictest hierarchy, followed by the Conventional suburban and lastly by the Neo-traditional layout. The analysis indicates that, assuming the current land use (Scenario 2), the Fused Grid layout outperforms both the Conventional and Neo-traditional plan in terms of delay and signalized intersection level of service. In Scenario 5, under elevated traffic volumes, the relative benefits of the Fused Grid are even more evident. These results are largely due to the strict hierarchical street system in the Fused Grid layout provides for efficient traffic flow into and out of the neighbourhood.

One-way couplets improve traffic flow on arterials and deserve further consideration in neighbourhood design

The improved intersection level of service and traffic flow along arterials due to conversion of major collectors into one-way couplets for the Fused Grid layout, as discussed above, corroborates recent proposals for their use by prominent planners. However, these improvements in traffic flow must be balanced with the tendency for one-way streets to promote higher traffic speeds and more circuitous travel patterns. Cyclists and transit vehicles are particularly sensitive to the latter.

The Fused Grid reduces traffic volumes on lower classification streets

Looking at the performance of local streets and minor collectors, the analysis shows that the Fused Grid restricts the amount of traffic on them more effectively than the Conventional and Neo-traditional plans. Only 14% of the traffic in the Fused Grid Plan uses these roads as opposed to 24% and 17% for the Conventional and Neo-traditional plans, respectively, based on Scenario 1 results. Under the higher density scenario (Scenario 5), the proportion of traffic on lower classification streets for the Conventional and Neo-traditional Neighbourhoods increases while the Fused Grid holds constant at 14%.

For the street layouts considered, intersection density (i.e. connectivity) and the presence of loops and cul-de-sacs do not have a strong correlation with traffic performance

Two of the three plans, the Conventional and the Fused Grid, have considerably lower intersection density than the Neo-traditional plan (i.e., 0.48 and 0.51 intersections per hectare vs. 0.87 intersections per hectare). This is largely because the former places cul-de-sac and loop street types, which have the effect of reducing the number of intersections and generally increasing the number of T-junctions. Overall network performance, however, had poor correlation with intersection density. For example, in the highest density scenario, the performance of the Conventional layout (as measured by delay per trip) is higher than the TND whereas the Fused Grid exhibits the lowest delay. This is in contrast to literature, which suggests that level of service, particularly on arterials, should improve with increasing connectivity, as there are more available routings to motorists. This suggests that other factors, such as the spacing and number of connections to the arterial network, may be more important to traffic performance than the presence of loops and cul-de-sacs or overall connectivity.

Increased connectivity reduces average trip distances within a neighbourhood

Looking at trips that begin or end within the study neighbourhood, increased connectivity was found to reduce average trip distances. While average trip distances are similar across layouts for each scenario, Vehicle Kilometres of Travel (VKT) for local trips in the Neo-Traditional layout are approximately 10% lower than Conventional Suburban and Fused Grid layouts. This is a result of the higher connectivity in the Neo-traditional plan, which allows for more direct trips. These results suggest a VKT reduction of approximately 1.0%-1.5% per 10% increase in intersection density, which are within the range of VKT reductions suggested in the literature; however, this VKT reduction only refers to travel within the neighbourhood. Ideally, intra-neighbourhood car trips should be displaced by walking and biking in a neighbourhood that is laid out so as to favour active transportation modes.

Non-local traffic infiltration is more dependent on route directness and travel time savings offered by specific facilities than generic measures of connectivity

Traffic simulations revealed little to no non-local traffic infiltration for every layout and land use scenario. Of the non-local traffic that used non-arterial neighbourhood facilities, the vast majority of this non-local traffic was through traffic on major collectors. Despite the lower overall connectivity of the Conventional Suburban layout (45% lower intersection density than the Neo-traditional layout), this layout exhibited the highest amount of through-movements by non-local traffic. This is in part due to the fact that a single major collector in this layout is oriented diagonally and provides an efficient routing across the neighbourhood. These results indicate that, at the individual neighbourhood level, the amount of traffic on major collectors is less related to generic measures of connectivity (e.g., intersection density) than it is to route directness and travel time savings offered by specific facilities.

Modal shares are affected more by land use density and mix of uses than by the street layout in this analysis

Estimated transit mode split increased by 45% in absolute terms (i.e., 11% to 16%) between the existing and high density/mixed use land use scenarios; however, there are only marginal differences in transit mode split across the street layouts for each land use scenario. This supports results from other studies, which indicate that although neighbourhood design (including street layout) influences travel decisions, locational and socio-economic variables have a significantly stronger relationship with auto ownership, transit mode choice, and vehicles kilometres travelled. Though not quantified in this study, it is expected that differences in street layout may have a stronger influence on the propensity to walk or cycle than they do on transit use.

7.2 Study Limitations and Further Research

A variety of areas are identified for further research. These include both additional analysis that could be supplemented to the existing study as well as new research based on research gaps identified in the literature review and through the analysis.

Simulation with single traffic zone system

In the simulation conducted in this study, unique traffic zone systems were developed for each layout. This approach facilitated the process of assigning trips from each zone to the local road network as well as interpretation of results. However, with different zone systems, traffic enters and leaves the road network in slightly different ways for each layout. This may impact the comparability of results across layouts, although the effects are expected to be marginal. To address this issue, the analysis could be rerun with one, common traffic zone system.

The impact of the spacing of arterial connections on arterial traffic flow

Despite the fact that the neo-traditional signalized intersections provide better level of service when compared with the conventional layout, overall arterial delay is higher for the neo-traditional layout. For neo-traditional arterials, average delay per vehicle kilometre travelled is 21% higher than for the conventional layout, and 37% higher than for the fused grid layout. Given that neo-traditional signalized intersections provide better level of service overall when compared with the conventional layout intersections the explanation for the additional delay on neo-traditional arterials requires further study.

A potential reason may be that the neo-traditional layout has the most frequent arterial connections, averaging one arterial connection per 280 metres. It is possible that the added connections actually degrade arterial traffic flow due to increased delay from turning and accelerating vehicles at more frequent spacings; however, this hypothesis runs counter to sources in the literature, which indicate that, in general, more arterial connections lead to better traffic flow on arterials (Kulash, 1998; Daisa et al., *undated*). Thus, the simulation results do not clearly support the idea more arterial connections lead to better traffic flow on arterials. In the case of the neo-traditional layout, other factors specific to Barrhaven may be influencing the simulation results. Neighbourhood-level simulation could not answer this result. Further analysis of arterial traffic flow is required where the number, type (including one-way couplets), and spacing of connections are carefully controlled.

The impact of laneways on collector/arterial traffic flow

Similar to the recommended research on the impact of the spacing of connections on arterial traffic flow, the traffic impacts of laneways on adjoining roadways (collector/arterial) should also be considered. In the fused grid layout considered here, laneways were required along Fallowfield Rd. to serve the housing along this arterial. However, these laneways were not considered in the simulation. As part of the research proposed above, the traffic impacts of laneways, as one type of arterial or collector connection, should be considered.

The effect of connectivity on non-local traffic infiltration

Traffic simulations revealed little to no non-local traffic infiltration for every layout and land use scenario. The proportion of non-local traffic that uses non-arterial neighbourhood facilities accounts for approximately 2% to 8% of non-local VKT, and the vast majority of this non-local traffic consists of through traffic on major collectors. Even the neo-traditional layout, with high connectivity among its local roads, experiences very little non-local infiltration. This is likely because arterial traffic flow does not degrade to unacceptable levels of service, while frequent stop signs along local roads and minor collectors, makes these facilities less attractive than arterials to non-local traffic from a travel time perspective.

However, unlike in a Corsim traffic simulation, drivers do not have perfect information on travel times. As such, it is possible that in reality more drivers would get frustrated on congested arterials and attempt to cut through a neighbourhood if the street design allowed, even if their overall travel time ended up being somewhat longer than if they had stayed on the arterial road. In addition, the lack of traffic infiltration is likely due to Barrhaven and the fact that it is not surrounded by significant activity centres and that regional traffic does not flow on all sides (i.e., Cedarview to the west dead-ends before Strandherd, the south side is bordered by a rail corridor rather than an arterial). As such, there are fewer opportunities and less motivation for non-local traffic to cut through the neighbourhood.

This indicates that the presence of cut-through traffic is quite specific to local conditions. Further work could investigate how cut-through traffic would change if there was increased regional traffic and additional activity centres were located around Barrhaven's perimeter. Alternatively, other locations could be modelled to see if cut-through traffic flows change with alternate local road networks and distributions of activity centres.

The effect of street layout and network connectivity on travel behaviour

Generally speaking, people will walk up to about 500 metres and bicycle up to about two kilometres, although there are wide individual differences and much variability with weather, weight to be carried, and numerous other factors. It is intended for the fused grid layout to encourage non-motorized travel and transit use by providing direct and attractive routings for pedestrians and cyclists to destinations (including transit stops). The modelling approach employed in this study did not provide the functionality to estimate non-motorized trips. In addition, the component of the travel demand model, which estimated auto and transit mode split is relatively insensitive to improvements in pedestrian access time at the local scale. Furthermore, while Barrhaven is served by relatively good bus service, the effect of higher order transit (e.g., bus rapid transit, light rail) on transit mode split was not assessed.

Further work is required in assessing changes in travel behaviour that are affected by the street layout testing more transit service scenarios, more diverse study locations, and using more sensitive modelling approaches, or actual data (e.g., Frank and Hawkins, 2007). As discussed earlier, if neighbourhoods do not have major transit infrastructure in place to which pedestrian friendly infrastructure can feed, and/or are surrounded by conventional suburban subdivisions, then changes in travel behaviour induced by the local urban form could be limited (Friedman et al., 1994).

Detailed Air Emissions Modelling

Fuel use and greenhouse gas and criteria air contaminant emissions are dependent on a variety of driving variables, including distance, speed, acceleration, and the number of stops and starts. Through a more detailed literature review and a closer assessment of such driving variables (e.g., speed profiles), a better understanding of differences in fuel use and transportation emissions between the layouts could be derived.

Pedestrian safety tradeoffs in street network design

While increasing the amount of pedestrian infrastructure and improving pedestrian route directness is associated with increased levels of walking (Frank and Hawkins, 2007), these changes may have mixed effects on pedestrian safety. According to De Nazelle (2006), the benefits of encouraging pedestrian activity may be outweighed by the health impacts of encouraging residents to expose themselves to low air quality and a high risk of traffic accidents. In addition, narrow pedestrian paths running through blocks, often used in neighbourhoods with discontinuous street networks to improve pedestrian mobility, may cross streets halfway through blocks instead of at an intersection creating a higher risk of collision at these crossings than with regular sidewalks (Frank & Hawkins, 2006). In addition, these paths tend to be segregated from more utilized land-uses and therefore there is no opportunity for passive surveillance. Thus, further studies on pedestrian safety may be warranted that take into account the types of pedestrian infrastructure as well as related characteristics (e.g., road crossing types, opportunities for passive surveillance, air quality, lighting, etc.).

Road safety evaluation by layout

Additional road safety evaluation could be conducted for each layout and land use scenario using data generated by the traffic simulation. A macro-level collision prediction model, similar to the one discussed in Lovegrove and Sayed (2006) is currently being developed for Ottawa, which can predict auto collisions based on a variety of neighbourhood variables, such as vehicle kilometres travelled and intersection density.

Optimal road layout from a transportation perspective

The approach adopted for assessing the transportation impacts of the road network layouts in this study is consistent with current transportation planning practices whereby transportation engineers are asked to “test” a given land use and transportation network to see if it functions adequately in terms of traffic level of service. If it does, then the network is considered acceptable. This process tends to preclude the option of identifying and testing alternative road network patterns that could provide the same traffic functionality and performance, but be are more efficient in terms of land

and infrastructure. The inefficiencies of some transportation networks are evident by looking at past examples such as the widely praised ‘Portland Grid’, which provides extensive connectivity but uses about 40% of its land area for roads. Further research could reverse this process and compare alternative transportation layouts in terms of traffic performance and efficiency of infrastructure, and use these insights to speculate on what might be an ideal or optimal road layout from a transportation perspective.

7.3 Implications for Neighbourhood Planning and Policy

Too often the general trend in neighbourhood design is to design to the status quo due to lack of information and confirmation that designs, other than the “tried and true”, work. The objective of this study was not to prove that the Fused Grid is superior than other layouts, but to compare it against two known and regularly used layouts; Conventional and Neo-traditional. The primary focus of the this comparison was on transportation-related impacts, including direct impacts in traffic movement as well as less direct impacts on energy use, pedestrian safety and transit-friendliness characteristics. While there are still a number of outstanding questions, it is relatively clear that “the traffic works” for the fused grid layout. Moreover, this layout appears to outperform neo-traditional and conventional suburban layouts.

With growing interest in developing more sustainable neighbourhoods that support higher densities, greater land use mix, and more travel options, transportation departments and the planning community in general should recognize the fused grid as a feasible alternative to conventional layouts. This street layout concept provides benefits regarding traffic movement, pedestrian connectivity, and the broader goals of community liveability.

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APPENDIX A – BARRHAVEN AS A REPRESENTATIVE SUBURBAN NEIGHBOURHOOD

As discussed earlier, the primary purpose of this study is to compare the traffic performance of different neighbourhood layouts including district and regional streets in a real setting. Due to the study neighbourhood approach, it is important to determine whether the results from this neighbourhood (i.e., Barrhaven) will be transferable to other neighbourhoods. To answer this question in a general sense, Barrhaven is compared with five other neighbourhoods to determine its representativeness as a conventional suburban neighbourhood from a traffic perspective.

As discussed in Section 3 and Section 4, traffic assessment will be conducted for several alternative street layouts and land use scenarios. As such, the existing conditions in Barrhaven are only a starting point for the analysis. Thus, the key characteristics influencing the representativeness of study results across all land use scenarios are Barrhaven's street layout and its relation to arterial roads. Obviously, for the 'Existing Population and Employment' land use scenario, the population and employment density and the geographic distribution of population and employment in Barrhaven will influence the transferability of results for this scenario to other neighbourhoods.

Other characteristics influencing traffic conditions in a neighbourhood include:

- Transit network,
- Active transportation network;
- Trip generation rate by time period;
- Travel patterns; and
- Transportation mode split.

These characteristics are assessed and compared for each study neighbourhood, which are introduced below.

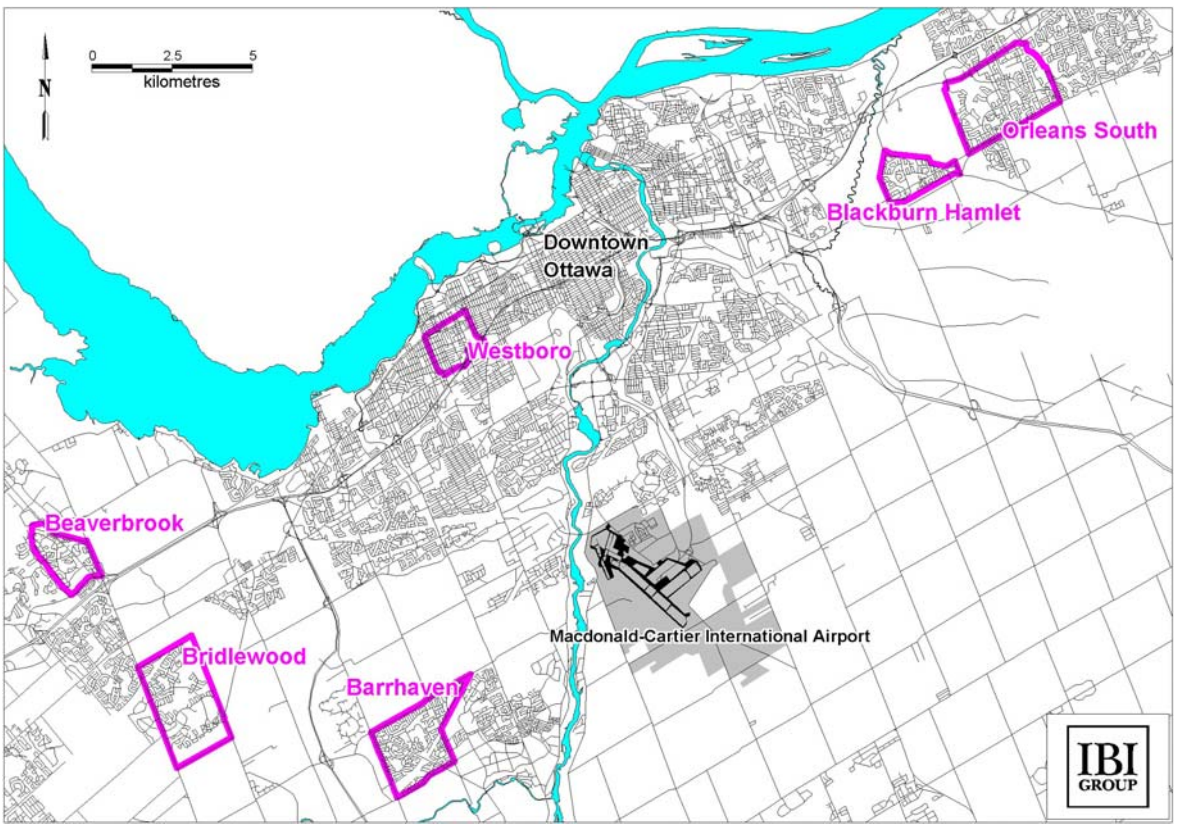
Study Neighbourhoods

Five study neighbourhoods were chosen. Four conventional suburban neighbourhoods were identified in different areas of the City to determine how travel characteristics and transportation networks vary for this neighbourhood type throughout the City and compare to Barrhaven. In addition, one older inner suburb closer to Central Business District, Westboro, was also included to provided a broader range for comparison. Exhibit A-1shows the neighbourhoods' locations. Blackburn hamlet and Orleans South are located east of downtown Ottawa, Beaverbrook and Bridlewood are located west of downtown Ottawa, and Westboro is located close to the Ottawa CBD to the west. Aerial photos of each area are provided at then end of this discussion in Exhibits A-14 to A-19.

Westboro is the oldest neighbourhood, with many of its dwellings having been constructed in the 1950s. It is included in this report as an example of an inner suburb. The majority of development in Beaverbrook and Blackburn Hamlet occurred in the 1960s. Both of these areas are smaller than Barrhaven in area, population, and employment, but they are typical of the smaller neighbourhoods surrounding Ottawa. Bridlewood and South Orleans are the newest of the neighbourhoods; having been mostly building up in the 1980s. They are approximately the same overall size as Barrhaven, although Bridlewood has lower population and employment due to differences in land use as discussed below.

All neighbourhoods, save Westboro, are located outside of the greenbelt surrounding Ottawa. Barrhaven is located 17 kilometres from downtown Ottawa; Westboro is the closest at 5 kilometres followed by Blackburn Hamlet (11km), Orleans South (14.5km), Beaverbrook (18.5km) and Bridlewood (19km). A neighbourhood's distance from the CBD is one of the major factors affecting its trip characteristics, therefore it is expected that Westboro will have different trip characteristics than the other five neighbourhoods (IBI Group, 2000).

Exhibit A-1: Neighbourhood Locations



Land Use

It should be noted that it is difficult to identify and isolate specific areas as "neighbourhoods", particularly from a transportation perspective. This is because travel behaviour depends on land use at many scales (e.g. local street scale to cross regional scale), which cannot be easily captured in the characterization of a neighbourhood. In addition, it is rarely clear what constitutes a neighbourhood and, moreover, what its distinct boundaries should be. Indeed, land uses outside of the boundary (e.g., nearby office park) may have a significant effect on travel behaviour in a given area; however, for the purposes of quantification and comparison, boundaries needed to be determined for each study area. These were typically determined based on arterial roadways and natural boundaries as well as pre-existing boundaries in available data sources (e.g. TRANS model traffic zones). To reduce the somewhat theoretical nature of the neighbourhood boundaries, the potential implications of land uses immediately outside a neighbourhood boundary will be discussed where appropriate.

The chosen neighbourhoods consist primarily of residential land uses. Other major land uses include green space and vacant land, particularly in the case of Bridlewood and Beaverbrook. While the proportion of residential land varies somewhat between neighbourhoods, the residential design of each neighbourhood appears to be similar in terms of curvilinear street layout and housing density. The exception is Westboro, which has a primarily grid-based street layout.

In each case, there is little office, commercial and industrial space in the neighbourhoods and much of the employment in these neighbourhoods is contained within residences. The neighbourhoods are somewhat more varied, however, in terms of the land uses surrounding them.

- Blackburn Hamlet is in the greenbelt and is surrounded by undeveloped land. It has little commercial land within its boundaries with one shopping centre with a land area of 2.4 hectares.

- Orleans South is primarily surrounded by other residential development. Youville Industrial Park, a small, but intensely developed industrial area is located to the immediate northwest. No land within Orleans south appears to be designated as commercial, office or industrial.

- Barrhaven is mainly surrounded by farmland, greenbelt, and other residential lands, however, there is growing retail development to the south. Within Barrhaven, there are three business centres with a total area of 8.5 hectares.

- Beaverbrook is surrounded by greenbelt to the east, residential land to the west and south, and a large commercial area, Kanata North Business Park, to the north. Two business centres are included within the neighbourhood boundary, taking up a total of 9 hectares.

- Bridlewood is mainly surrounded by farmland, greenbelt and residential lands, but a shopping centre and a sizeable commercial area, Kanata South Business Park, are located to the west. This neighbourhood only has a small plaza within its boundaries with a land area of 0.9 hectares.

- Westboro is ringed by developed areas. These areas are more mixed in terms of uses than the other neighbourhoods, but are still primarily residential. There is significant commercial development, however to the south. Within its boundaries, Westboro has 5.8 hectares of land designated as commercial, office and industrial area.

Differences in the amount of office, retail, and industrial development within and surrounding the neighbourhoods are important, since they may lead to differences in the proportion of local and short-distance trips. Westboro, with only two elementary schools contained within its boundaries, is the only neighbourhood that may have numerous non-local school trips. Commuters may be more likely to walk or cycle for these shorter trips. In addition, depending on the street layout, travellers may be more likely to use local streets for shorter-distance trips, which would have implications for the traffic performance of the neighbourhood. These factors are discussed further in Section 0, which assesses differences in the proportion of local trips and travel mode choice.

Population and Employment

Population and employment densities may affect the transferability of the results for Barrhaven because they affect the demand on the transportation network. All other factors being equal, higher density neighbourhoods will have more people per unit area making use of the streets. Gross area, population, population density, employment and employment density are shown below in Exhibit A-2. Neighbourhoods vary in area from 2-3 square kilometres for Blackburn Hamlet, Beaverbrook, and Westboro, to 5-7 square kilometres for Orleans South, Bridlewood, and Barrhaven. The gross population density (i.e., population/total area) ranges from approximately 21 people per hectare in Beaverbrook to 42 people per hectare in Barrhaven. Employee density (i.e., employees/total area) ranges from 1 employee per hectare in Bridlewood to 14 employees per hectare in Westboro.

Exhibit A-2: Neighbourhood Population and Employment

Neighbourhood	Gross Area (km^2)	Population	Gross Population Density (pph)	Households	Gross Household Density (hh/ha)	Persons Per Household	Employment	Gross Employment Density (emp/ha)	Gross Urban Density (pop+emp/ha)
Blackburn Hamlet	2.35	8,940	38	3,065	13	2.9	882	4	42
Beaverbrook	2.60	5,572	21	2,136	8	2.9	2,163	8	29
Orleans South	7.01	22,705	32	7,621	11	3.0	2,031	3	35
Bridlewood	6.59	16,494	25	5,522	8	3.0	670	1	26
Barrhaven	5.24	21,947	42	7,158	14	3.1	2,363	5	47
Westboro	2.03	7,529	37	3,210	17	2.2	2,898	14	51

Source: TRANS Travel Demand Model

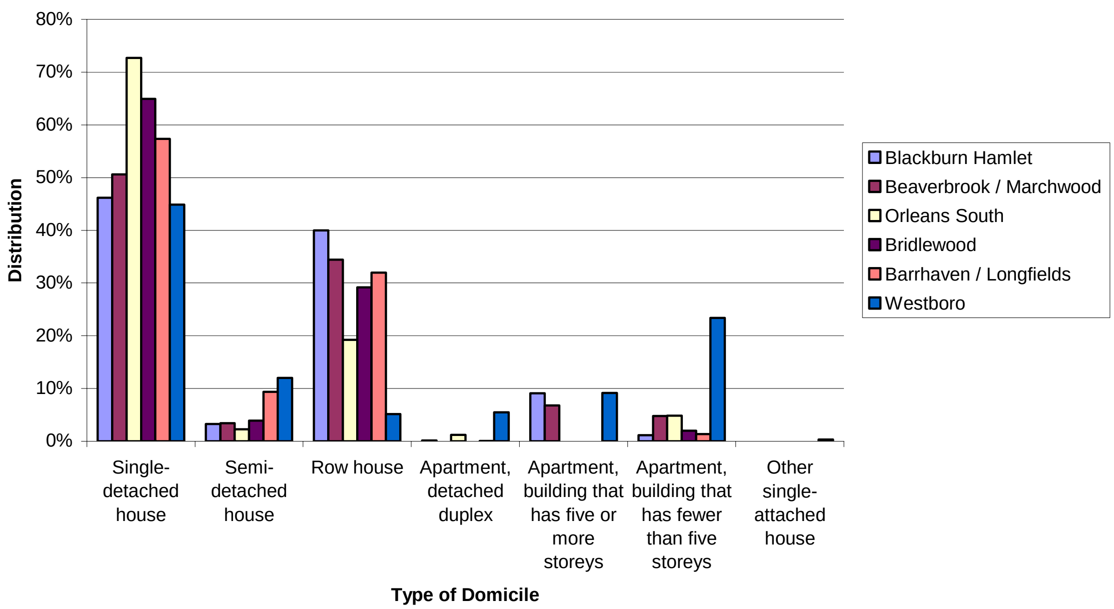
The large differences in population density are surprising given the observed similarities in residential design for each neighbourhood, except for Westboro. These gross densities, however, can be slightly misleading, because they do not give a full picture of the density of the developed area. For example, the Bridlewood neighbourhood boundary as defined by the TRANS model traffic zone includes significant amounts of farmland and undeveloped land, which is external to the developed residential area. As such, the gross population density does not provide a good comparison in this case. Removing these pieces of land from the gross area does not change the overall standings of Bridlewood: the densities increase slightly to 30 pph, 10 hh/ha, and 1 emp/ha. On the other hand, the Beaverbrook neighbourhood has many parks and undeveloped areas, but they are largely integrated into the overall residential neighbourhood. As such, the Beaverbrook's low gross population density does provide a reasonable comparison in this case. Unfortunately, net densities (e.g. population/residential area) could not be easily calculated from available data. Instead, the proportion of housing types, as seen in Exhibit A-3, and household size, as discussed in the following paragraph, are analyzed to illuminate the topic.

Another factor affecting differences in population density is household size. Differences in gross household density are less significant than gross population density, particularly for Westboro, which has a relatively low average household size of 2.2 persons per household. Westboro actually has the lowest gross household density, which would be expected based on the denser built form. The smaller average household size is because approximately 30% of units in Westboro are apartments. It is also because Westboro is an older neighbourhood with older families, many without live-in children. This demonstrates that, in many cases, as a neighbourhood ages average household size decreases, which leads to a shrinking population.

As expected, gross employment density varies widely between neighbourhoods. Westboro has the highest employment density by far, which is indicative of the greater mix of uses typically found in older, inner suburban neighbourhoods. Beaverbrook exhibits the highest employment density among conventional suburban neighbourhoods given that part of the North Kanata Business Park is included within its boundaries.

Differences in population and employment density are potentially significant to this study because they will lead to differences in auto volumes on the neighbourhood street network, all other factors being equal. This may lead to differences in traffic performance by street layout. In most cases Barrhaven's population and employment density is comparable to other neighbourhoods. The exceptions are Beaverbrook; which has more dispersed residential development and a larger amount of non-residential development and employment, and Westboro, which has a higher density of non-residential development. The effect of these differences will be further assessed in terms of road supply per capita and household trip generation in Section 0 and Section 0, respectively.

Exhibit A-3: Distribution of Housing Types by Neighbourhood



Source: Statistics Canada, 2001 Census

Road Network

The road network and supply may affect the transferability of the Barrhaven results because applying the same number of vehicles to a network having fewer roads will cause more congestion, all other factors being equal. In particular, the representativeness of Barrhaven's local street layout will affect the transferability of results for the conventional suburban layout, while the relationship between the local network and arterial roads has implications for all street layouts. .

STREET LAYOUT AND ROAD SUPPLY

Each conventional suburban neighbourhood exhibits a similar type street network characterized by:

- Hierarchical street pattern of arterials, major collectors, minor collectors, and local streets;
- Curvilinear, loop and cul-de-sac pattern of local streets;
- Long blocks; and
- Infrequent connections to the arterials by major and minor collectors.

Westboro's street network is characterized by a relatively open grid system of streets with narrower right-of-ways for local roads, although there are several cul-de-sacs and loops. The grid system of streets related to its high connectivity, defined by the number and type of intersections, as discussed in Section 2.5.

Intersection density of the local street network provides a good indicator of the street network connectivity and is compared in Exhibit A-4. As expected, Westboro has the highest intersection density, approximately twice that of many of the conventional suburban neighbourhoods. Surprisingly, Barrhaven has a relatively high intersection density compared to other conventional suburban neighbourhoods. This can be partly explained by the higher amount of developed space in Barrhaven, which also accounts for its higher residential density. However, the higher intersection density also indicates that Barrhaven exhibits higher than average connectivity for a conventional suburban neighbourhood. As such, Barrhaven's street network may provide more direct pathways between points than other conventional suburban neighbourhoods, which would be associated with more even distribution of traffic and better traffic performance. This will be further discussed in Section 0.

Exhibit A-4: Non-arterial Intersection Density

Neighbourhood	Intersection Density (non-arterial intersections /km^2)
Blackburn Hamlet	24.3
Beaverbrook	35.0
Orleans South	29.8
Bridlewood	26.4
Barrhaven	49.6
Westboro	59.6

Road supply per household, when compared with auto trip rates per household can provide an indication of existing traffic conditions. This is because the quotient of these two variables (i.e. auto trips/hh ÷ road metres/hh) provides a measure of auto density on the road network (autos/road metres). The road supply for each neighbourhood is shown below in Exhibit A-5 and the household trip rates are discussed in Section 0.These similarities and differences in street layout translate roughly into the amount of road supplied per household. The length of roadways in each neighbourhood was determined using a GIS street network map.Road widths or the number of lanes were not available so supply results cannot be presented in terms of lane-kilometres. Exhibit A-5 displays the road supply per household and per hectare. Barrhaven's road supply rate, 8.8 metres per household is similar to most other conventional suburban neighbourhoods.

Beaverbrook, which has a uniquely dispersed residential form, as discussed earlier, has the highest road supply per capita; the industrial park is located at the exterior edge of the neighbourhood and is well serviced by an arterial, therefore the non-local traffic it generates stays out of the neighbourhood. Westboro, with the highest household density and the open grid system of streets has the lowest road supply per household.

Exhibit A-5: Road Availability

Neighbourhood	Road Availability	
	(m/hh)	(m/ha)
Blackburn Hamlet	8.7	113
Beaverbrook	11.5	92
Orleans South	9.8	108
Bridlewood	8.5	68
Barrhaven	8.8	123
Westboro	8.0	136

Source: StreetPro GIS Map

Beaverbrook's high road-availability means that it is likely that its roads are underutilized and there is little congestion within the neighbourhood. The other five neighbourhoods have similar road availability. There is nothing to suggest that the results from the upcoming Barrhaven study are not representative of the other neighbourhoods with respect to road supply, except for Beaverbrook, which should be less congested.

ARTERIAL ROADS

While the conventional suburban neighbourhoods have similar type street networks, there is some variation in how they relate to arterial roads. Barrhaven is surrounded by arterial roads on all sides. Blackburn Hamlet, on the other hand is developed around two intersecting arterial roads. Beaverbrook and Bridlewood in Kanata are only served by one or two adjacent arterials, because parks, golf courses, or farmland surround the rest of these neighbourhoods. Orleans south is bordered by arterial roads to the north and south and two other arterial/collector roads transverse the neighbourhood in an 'X' pattern. These differences in arterial road layout will have implications for the volume of traffic on arterials.

Arterials serving neighbourhoods will fewer such facilities will likely experience higher traffic levels. This will affect the level of service at intersections (traffic signals) between arterials and neighbourhood streets, which may encourage more travel on local streets or potentially even cut through traffic. This will also influence how local traffic accesses the arterials, which affects the distance that a driver must travel to exit the neighbourhood.

Traffic on arterials will also be affected by other users not originating or destined to the neighbourhood. This will particularly be the case for the arterials serving Westboro and Orleans South, since these neighbourhoods are located between the city centre and significant amounts of residential development. The differences in arterial road layout between neighbourhoods and the effect of external development on arterial road demand highlights the need to carefully assess traffic conditions on arterial roads in determining the traffic performance of different neighbourhood street layouts. Independent of layout, increased non-local traffic on the arterials will lead to poorer intersection performance and more cut-through traffic. The effect of arterial supply and configuration with respect to the local street layout is a key area for further investigation.

Transit Service and Rapid Transit Network

The availability of transit within a neighbourhood has an affect on the neighbourhood's transportation mode split, which in turn affects the number of vehicles on the roads, particularly during the peak periods. Ottawa has a well-developed public transit system, which includes light rail, bus rapid transit, as well as express, peak-period and local bus routes. The rapid transit network is regional and is therefore consistent among the neighbourhoods; proximity to the rapid transit has a strong effect on transit mode split and the greatest potential to affect the transferability of results.

As it is, there are not significant differences in the mixed-traffic bus service provided to each neighbourhood. Since OC Transpo, the public transit operator in Ottawa, has a service standard of providing service within 400 metres of all residents, all neighbourhoods are reasonably served by transit. Over 99% of residents in all 6 neighbourhoods are within 400 metres from a bus route.

Exhibit A-6 displays the nearest rapid transit station to each neighbourhood and indicates the approximate distance to the station using the road network from the closest point in the neighbourhood. This table also shows the number of express bus routes serving the neighbourhood, since these routes provide a high level of service, which can also affect transit mode split.

Barrhaven is currently served by Fallowfield rapid transit station at the north-eastern edge, and Strandherd station at the south-eastern edge. This rapid transit station is accessible by foot for some Barrhaven residents, but most patrons likely access this station by feeder buses or by vehicle (park-and-ride or kiss-and-ride). Similar rapid transit service can be observed at Orleans South and Beaverbrook, both of which are served by two rapid transit stations, the closest of which is approximately 2/3 kilometres using the road network from the closest point in the neighbourhood. The closest Westboro residents are also within 1/3 kilometres from a rapid transit station. Bridlewood and Blackburn Hamlet, on the other hand, are both farther than 2 kilometres from the nearest rapid transit station, making rapid transit less attractive to residents of these neighbourhoods, all other factors being equal. However, these differences may be mitigated by other factors, such as proximity to the CBD and other destinations, reliability and frequency of mixed-traffic transit routes, and auto ownership. Transit mode split by neighbourhood is assessed in Section 0.

Exhibit A-6: Rapid Transit and Express Bus Service by Neighbourhood

Neighbourhood	Nearest Rapid Transit Station (distance to station)	Express Routes	Trip Frequency
Blackburn Hamlet	Blair (4 km)	2	7 AM 7 PM
Beaverbrook	Eagleson (2/3 km) Terry Fox (3 km)	2	10 AM 9 PM
Orleans South	Jeanne d'Arc (2/3 km) Place d'Orleans :(1 1/3 km)	4	13 AM 12 PM
Bridlewood	Eagleson (2 ¾ km)	2	11 AM 16 PM
Barrhaven	Fallowfield (1/3 km) Strandherd (1/3 km)	2	11 AM 13 PM
Westboro	Westboro (1/3 km)	0	N/A

Active Transportation Network

Differences in the provision of active transportation infrastructure may also affect mode splits, which would influence the amount of vehicle travel. Apart from sidewalks and streets, pedestrians and cyclists tend to use recreational trails and stick to cycling friendly streets. Each neighbourhood has access to cycling friendly streets and multi-use pathways. It is expected that differences in walking and cycling activity will be more related to the proximity of employment and other destinations.

Trip Generation

Trip generation rates add transportation context to the population data discussed earlier. Neighbourhoods with higher trip rates demand more from the transportation infrastructure and are more likely to experience congestion if combined with a high automobile modal split. Exhibit A-7 below shows the total trips originating in the neighbourhoods for all day and a.m. peak period time periods.

Peak period trips are especially important from a traffic perspective. This table indicates that there is little difference in the daily and a.m. peak period trips per resident. However, this table does not consider a.m. peak period trips attracted into the neighbourhood by employment, schools, and other attractors. Since there is relatively small amount of employment in each neighbourhood compared to residential population, save Westboro, and since the neighbourhoods are assumed to have similar school provision levels, a relatively small number of incoming trips is expected and the rate of incoming trips is not expected to vary significantly between neighbourhoods.

While peak period trip rates are similar, differences in trip distribution and mode splits, in particular, may still lead to different traffic conditions in the neighbourhoods. Trip distribution and mode split are assessed in the following sections.

Exhibit A-7: Trip Generation Rates by Neighbourhood

Neighbourhood	Daily Trip Rate		AM Peak Period Trip Rate	
	(Trips/Household)	(Trips/Person)	(Trips/Household)	(Trips/Person)
Blackburn Hamlet	3.20	1.10	1.78	0.61
Beaverbrook	3.45	1.19	2.07	0.71
Orleans South	3.52	1.17	2.11	0.70
Bridlewood	3.15	1.05	1.87	0.62
Barrhaven	3.44	1.11	1.94	0.63
Westboro	2.77	1.26	1.43	0.65

Source: 1995 TRANS Survey

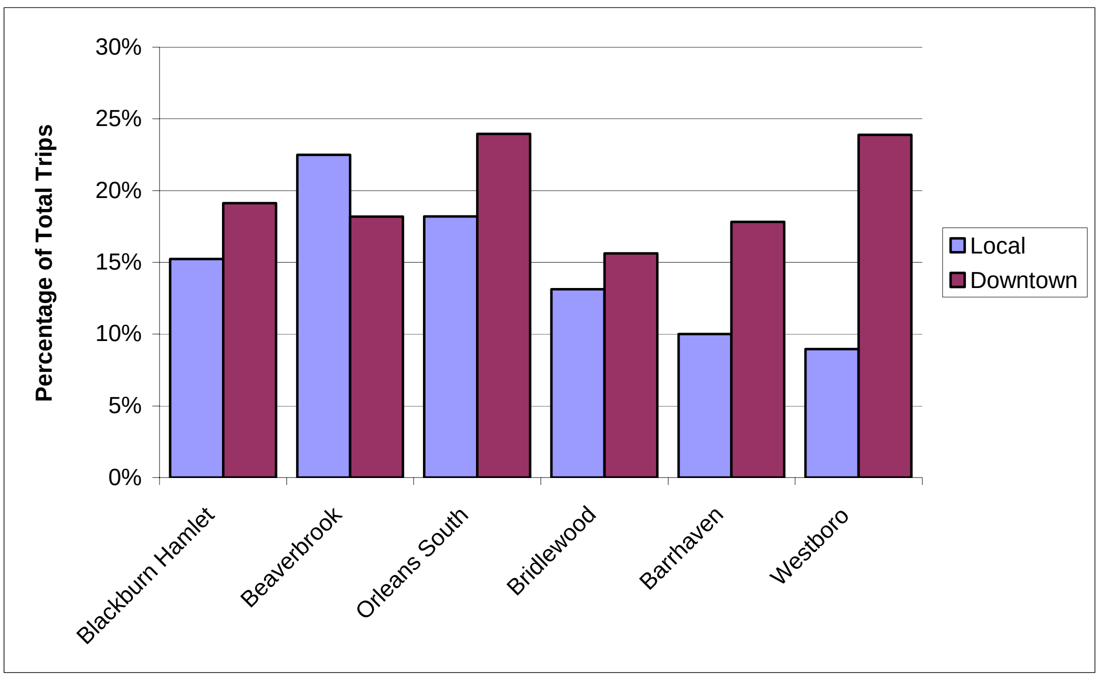
Trip Distribution

Travel patterns, in and of themselves, do not necessarily provide much of an indication of traffic conditions in a neighbourhood. Traffic conditions may be influenced when differences in travel patterns lead to differences in modal splits. This could be the case if one neighbourhood has lower auto mode splits due to a higher proportion of short-distance to downtown trips. However, the distribution of trips also provides a sense of how trip makers may respond to changes in the street layout. For example, more intra-neighbourhood trips (i.e. trips with origin and destination in the same neighbourhood) may be made using local roads instead of arterials with an increase in street connectivity.

In addition, the amount of short-distance trips is a good indicator of the availability of nearby employment and services, and provides an indication of the number of trips that are short enough to be candidates for a modal switch to walking or cycling.

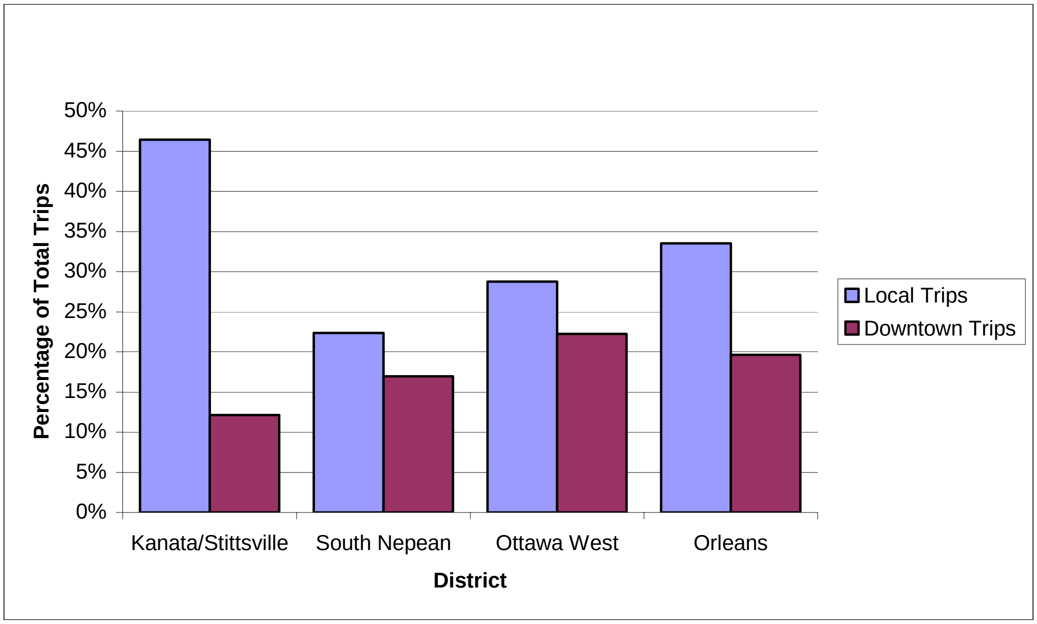
displays the proportion of a.m. peak period trips originating in each neighbourhood destined to other locations in the neighbourhood or to the downtown. Exhibit A-9 displays similar results for the district level.

Exhibit A-8: Distribution of AM Peak Period Trips Originating in Each Neighbourhood



Source: 1995 TRANS Survey

Exhibit A-9: Distribution of AM Peak Period Trips Originating in Each District



Source: City of Ottawa

The a.m. peak period trip distributions shown above provide a picture of how travel patterns vary across the neighbourhoods and larger districts in Ottawa. Barrhaven is at the low end in terms of the proportion of intra-neighbourhood trips. In fact, if you consider that Westboro is located very close to the downtown and therefore even downtown trips are short distance trips, Barrhaven has the lowest proportion of local trips. Barrhaven is the neighbourhood that would most benefit from increased employment within its boundaries.

As such, the travel patterns displayed in Exhibit A-9 by district provide a better indication of availability of nearby employment, schools, and services. Kanata/Stittsville exhibits the highest proportion of intra-district trips by far, which is likely due to the large concentration of employment in Kanata. However, since Kanata/Stittsville is a large, auto-oriented area, this high proportion of intra-district trips does not necessarily translate into higher levels of active transportation. Improved active transportation infrastructure and route directness is needed to translate the short auto trips into pedestrian and cycling trips. Given the radial orientation of the public transit system, the proportion of downtown trips may be an indication of transit use. In such a case, the proportion of South Nepean (which includes Barrhaven) trips destined downtown falls strategically between Kanata/Stittsville and Orleans values.

Since the effect of changes to the connectivity of the pedestrian/bicycle network on cycling and walking activity is also of interest to this study, the distribution of trips by distance is assessed. The distribution of auto trips by trip length, as shown in Exhibit A-10 provides some insight on the potential for shifting to walking and cycling modes. Shorter auto trips have the potential to be changed to walking or cycling trips given a safe and convenient active-transportation route exists.

Exhibit A-10: Distribution of PM Peak Period Auto Trips by Distance [1]

Destination Neighbourhood	Distribution of PM Auto Trip Distances			
	< 2 km	2 to 5 km	5 to 10 km	> 10 km
Blackburn Hamlet	6.2%	6.0%	43.4%	44.3%
Beaverbrook	6.9%	27.4%	21.3%	44.3%
Orleans South	11.4%	21.3%	19.0%	48.4%
Bridlewood	10.4%	15.4%	33.0%	41.3%
Barrhaven	13.0%	4.9%	13.5%	68.7%
Westboro	6.2%	22.0%	40.0%	31.8%

(1) PM Peak Period results are shown here corresponding to the time period used for the EMME/2 model. This differs from the AM peak period results previously referenced, which were based on observed data and Statistics Canada journey to work data.

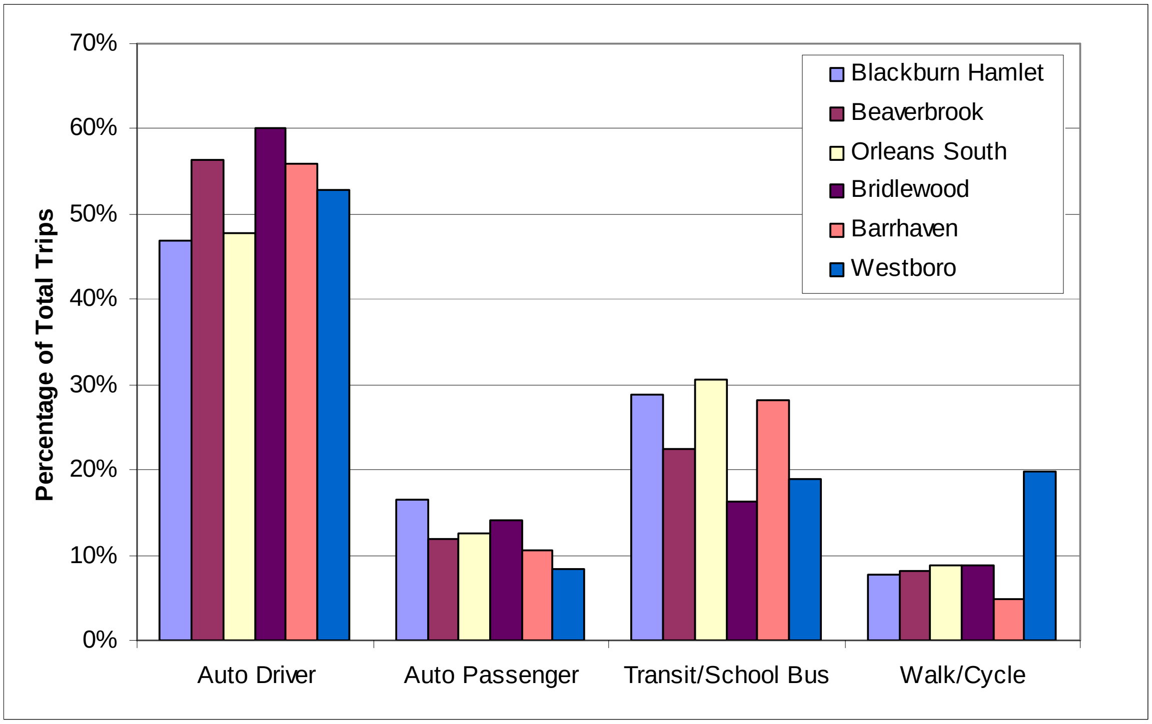
Barrhaven, Orleans South and Bridlewood are the most poised to gain from the increased active-transportation infrastructure proposed in the Fused-grid layout due to their higher percentages in trips less than two (2) kilometres in length. As shown earlier in Exhibit A-4, Barrhaven has about 85% of the intersection density of Westboro and is about two (2) kilometres across, a convienent biking distance of about 8 minutes. However, most of the shopping is beyond walking distance for over 50% of the residents. Consequently, changes to the connectivity level alone are not expected to influence a large portion of the 13% of the trips under two (2) kilometres.

Transportation Mode Split

People choose their mode of transportation based on numerous individual and trip characteristics including cost, travel time, and convenience. As such, except for perhaps short-distance trips, transportation mode split is not highly influenced by the local street layout, but by more regional factors, such as trip distance, transit service, parking costs, etc. Thus, it is possible that residents similarly designed conventional suburban neighbourhoods could exhibit significantly different travel behaviour.

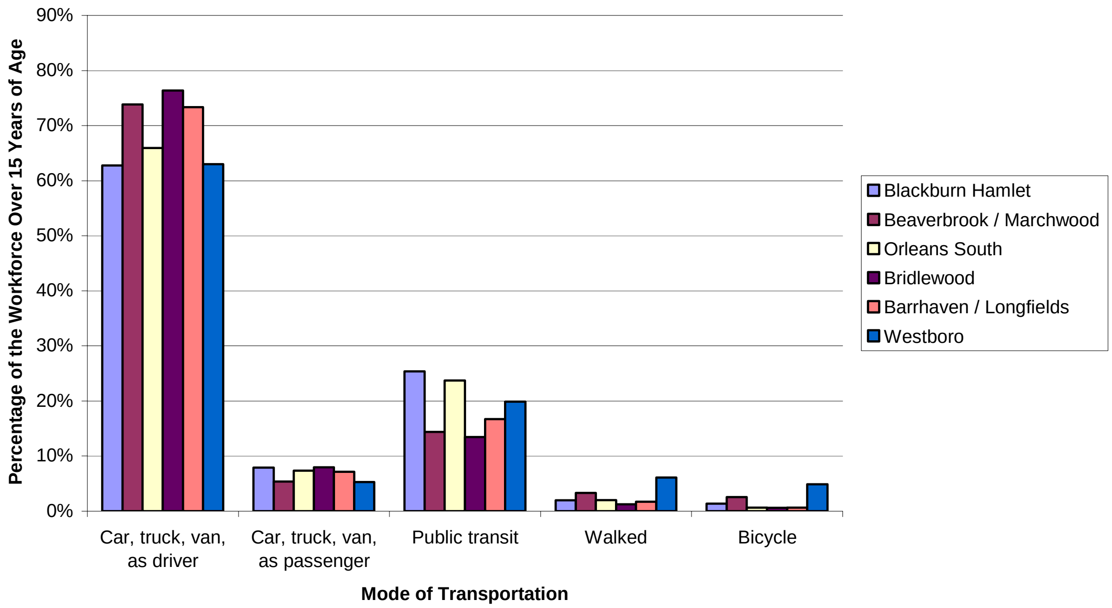
The proportion of trips made by the auto driver mode is particularly important to traffic conditions as this determines the proportion of trips that result in a vehicle on the road network. Exhibit A-12 and Exhibit A-13 display mode split data by neighbourhood. Exhibit A-12 displays by the proportion of AM peak period trips by mode for all trip purposes, as recorded in the 1995 TRANS survey. Exhibit A-13 displays mode split data for the journey to work as recorded in the 2001 Census. Despite the different data sources and time periods, the two sets of results are highly comparable. As expected the results for all trips purposes in Exhibit A-12 are more weighted towards auto passenger, transit/school bus, and walk/cycle trips given the inclusion of school trips.

Exhibit A-11: AM Peak Period Mode Split (All Trip Purposes)



Source: 1995 TRANS Survey

Exhibit A-12: Journey to Work Mode Split

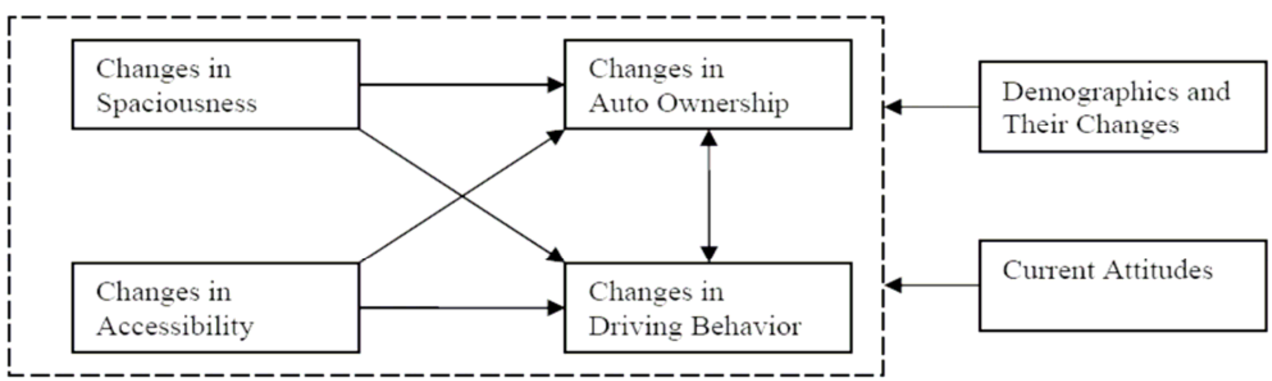


Source: Statistics Canada, 2001 Census

Auto driver mode split in the a.m. peak ranges from 47% in Blackburn Hamlet to 60% in Bridlewood. Barrhaven's auto driver mode split of 56% is similar to that of Bridlewood and Beaverbrook, while Blackburn Hamlet and Orleans South have somewhat lower values below the 50% mark. This difference and the higher transit mode split in Blackburn Hamlet and Orleans South can be partly explained by the greater proportion of residents in these neighbourhoods that commute downtown combined with good rapid transit service connections downtown and the somewhat more central locations of these neighbourhoods in comparison to the other conventional suburban neighbourhoods.

Westboro's AM peak period auto driver mode split of approximately 53% falls in between the conventional suburban results, though its journey to work driver mode split is the lowest. This is likely at least partially due to socio-economic factors, rather than the factors list in the previous sentence, as illustrated in the conceptual model of driving presented in Exhibit A-13. Demographics including age and income have an external influence on auto ownership and driving behaviour. Westboro has the highest proportion of residents older than 65 (14% vs. ~5%-10% in other study neighbourhoods) and older people are less mobile and more likely to drive to their destinations, elders are also the people that may be retired and therefore not included in the journey to work data. In addition, residents of Westboro likely have higher incomes, which is associated with higher auto ownership.

Exhibit A-13: Conceptual Structural Model of Driving (Cao et al., 2007)



Summary of the Comparative Neighbourhood Analysis

Overall, this analysis has demonstrated that Barrhaven characterizes conventional suburban neighbourhood in many ways: street layout and road density, employment density, transit service and connectivity to the rapid transit network, the availability of cycling and multipurpose paths, trip generation rates, travel patterns, and transportation mode split. It does however, differ in tis connectivity and residential density which parallel westboro's. However, the analysis also revealed that, since the neighbourhoods considered are primarily residential, with the exception of Westboro, population density is a key factor affecting neighbourhood peak traffic conditions. Thus, even though Barrhaven residents exhibit similar travel behaviour to most other conventional and traditional suburban neighbourhoods, Barrhaven's higher population density is expected to create somewhat more congested conditions during the peak periods. However, this may be offset by the higher connectivity of Barrhaven's local street network, which allows traffic to more evenly distribute itself across the network. Given that the density of the districts in on of the factors that is varied purposefully, the analysis will provide additional insights into the relationships between road supply, intersection density and traffic performance.

Because of its density and stepwise increases of it in the study, the Barrhaven study area will provide a conservative test of traffic performance of different street layouts. Thus if traffic conditions are acceptable for each layout, including the Fused-grid, in Barrhaven, they will likely work for other conventional suburban neighbourhoods. In addition, since Barrhaven residents exhibit similar travel behaviour to most other conventional and traditional suburban neighbourhoods, any changes in resident travel behaviour (e.g., increased walking) inferred through this study will likely be applicable to other conventional suburban neighbourhoods.

Exhibit A-14: Blackburn Hamlet Satellite Image

Exhibit A-15: Beaverbrook Satellite Image

Exhibit A-16: Orleans South Satellite Image

Exhibit A-17: Bridlewood Satellite Image

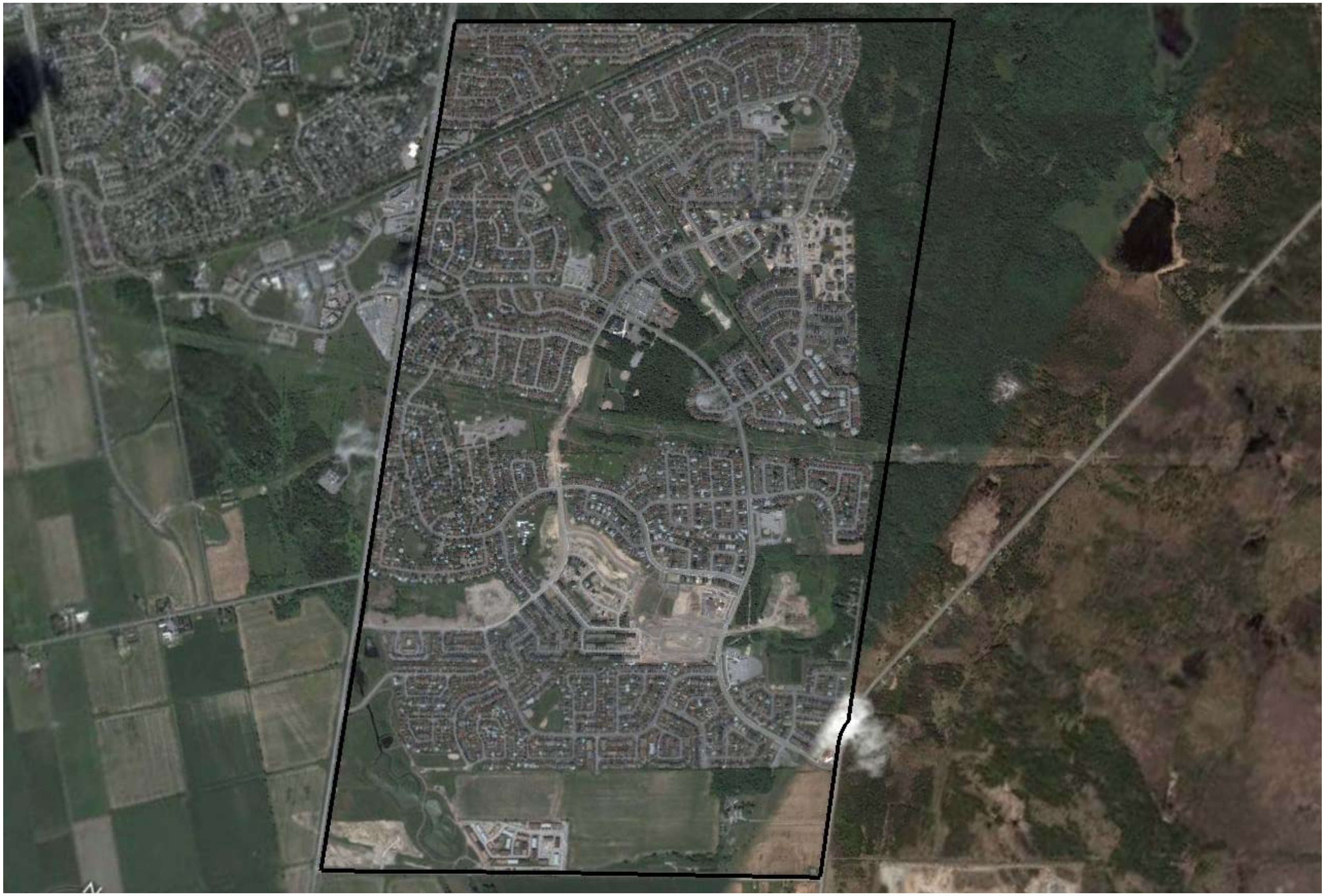


Exhibit A-18: Barrhaven Satellite Image

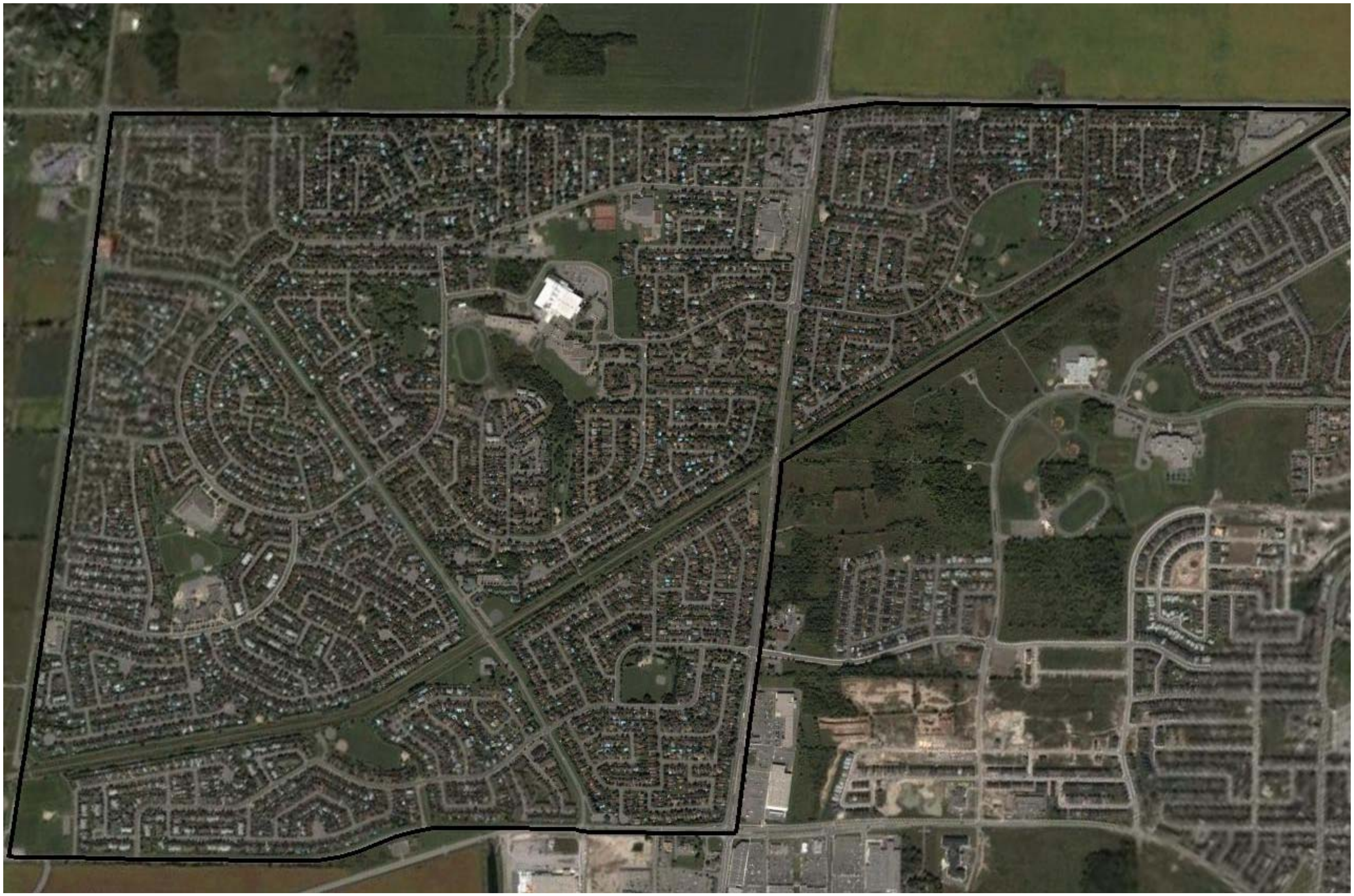
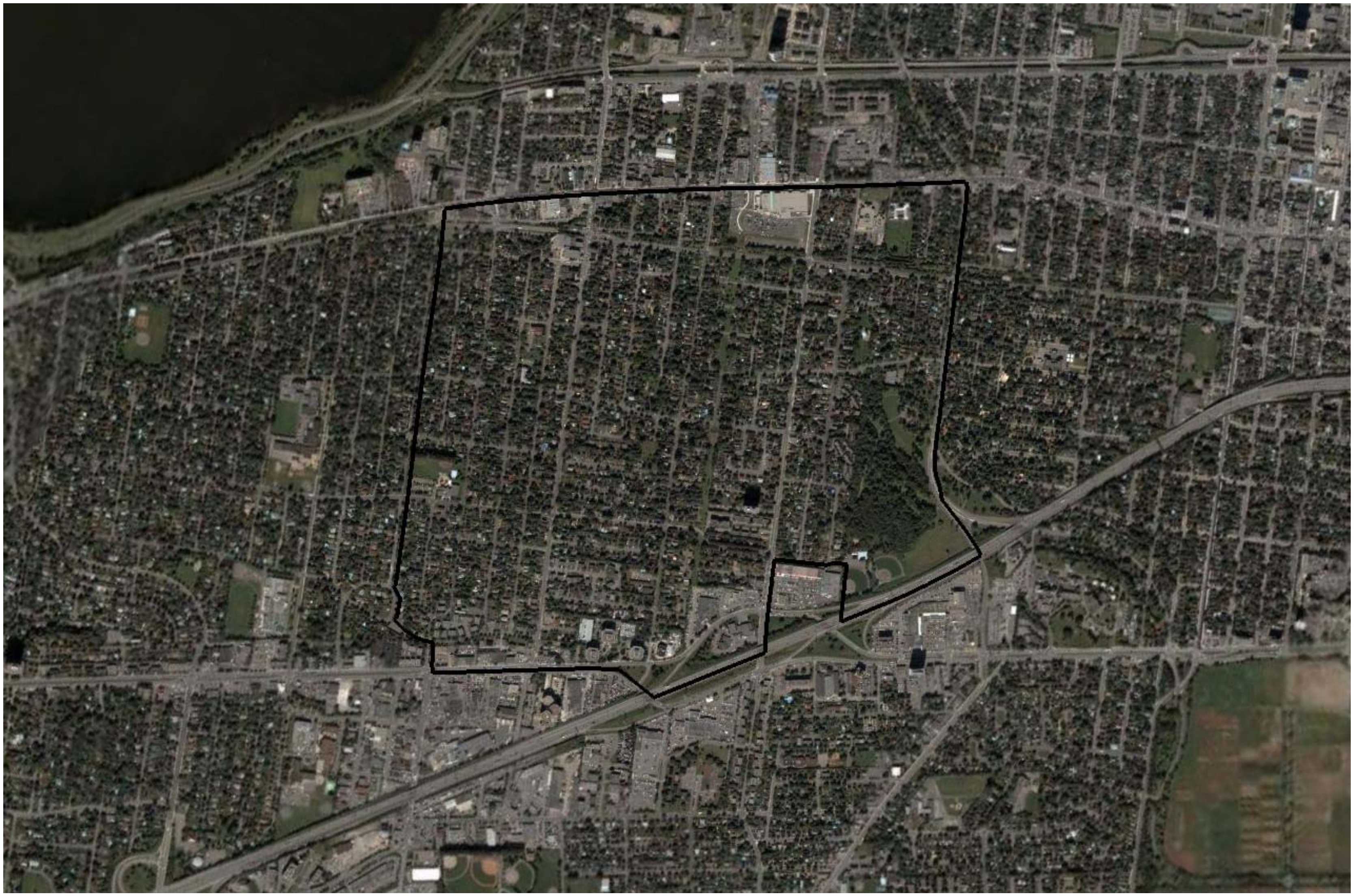


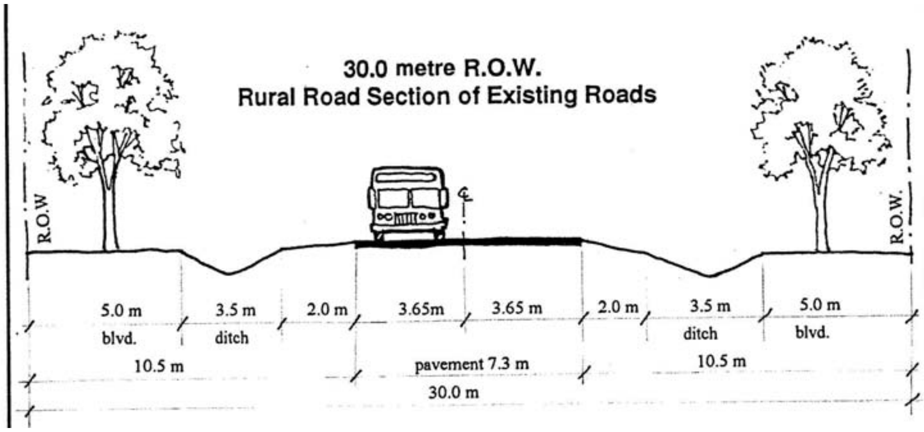
Exhibit A-19: Westboro Satellite Image



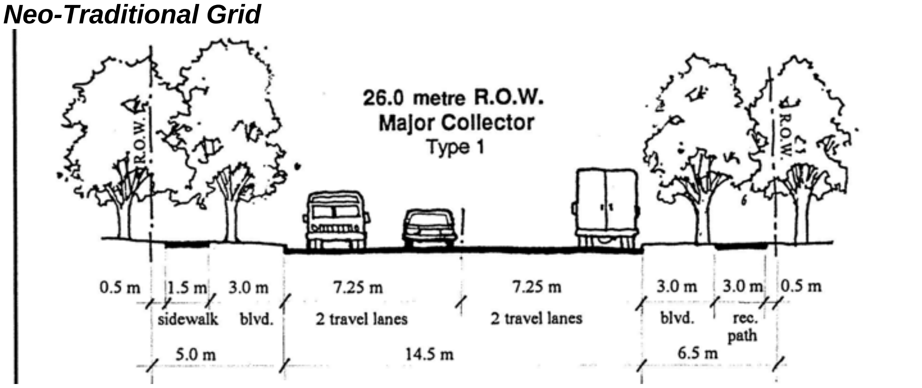
APPENDIX B – EXAMPLES OF TYPICAL CONVENTIONAL AND NEO-TRADITIONAL STREET CROSS SECTIONS

Exhibit B-1: Major Collector Cross-Sections

Conventional Suburban



Neo-Traditional Grid



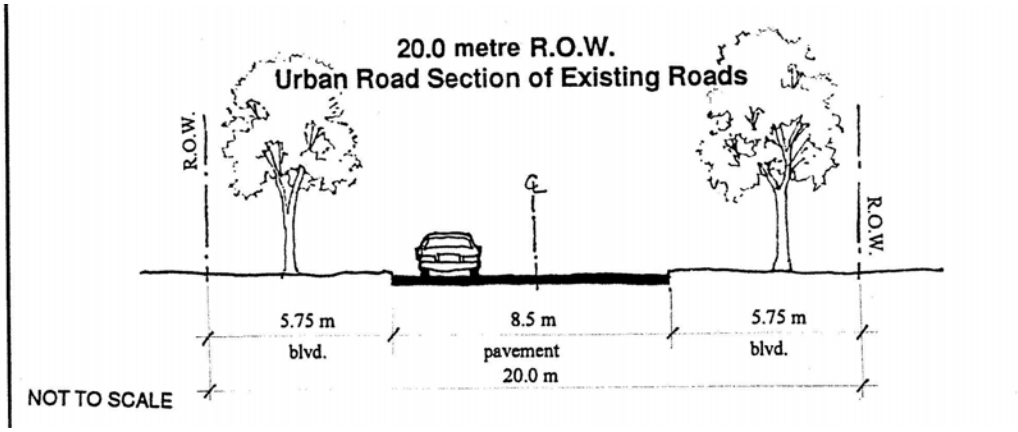
Source: CMHC (1997) *Conventional and Alternative Development Patterns Phase 1: Infrastructure Costs*. Ottawa, Canada.

*Conventional suburban **arterials** range from 1-2 lanes with extra lanes around intersections and do not allow on-street parking.*

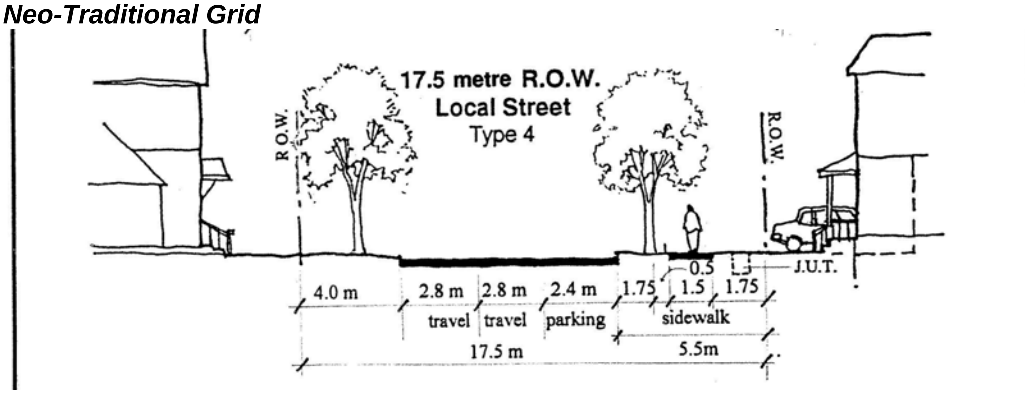
*Conventional suburban **major collectors** are narrow, two-lane roads that do not allow on-street parking.*

Exhibit B-2: Local Street Cross-Sections

Conventional Suburban



Neo-Traditional Grid



Source: CMHC (1997) *Conventional and Alternative Development Patterns Phase 1: Infrastructure Costs*. Ottawa, Canada.

*Conventional suburban **minor collectors** are wide, two-lane roads that allow on-street parking and connect to arterials in some cases.*

*Conventional suburban **local streets** are wide, two-lane roads that allow on-street parking and have low speed limits.*

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