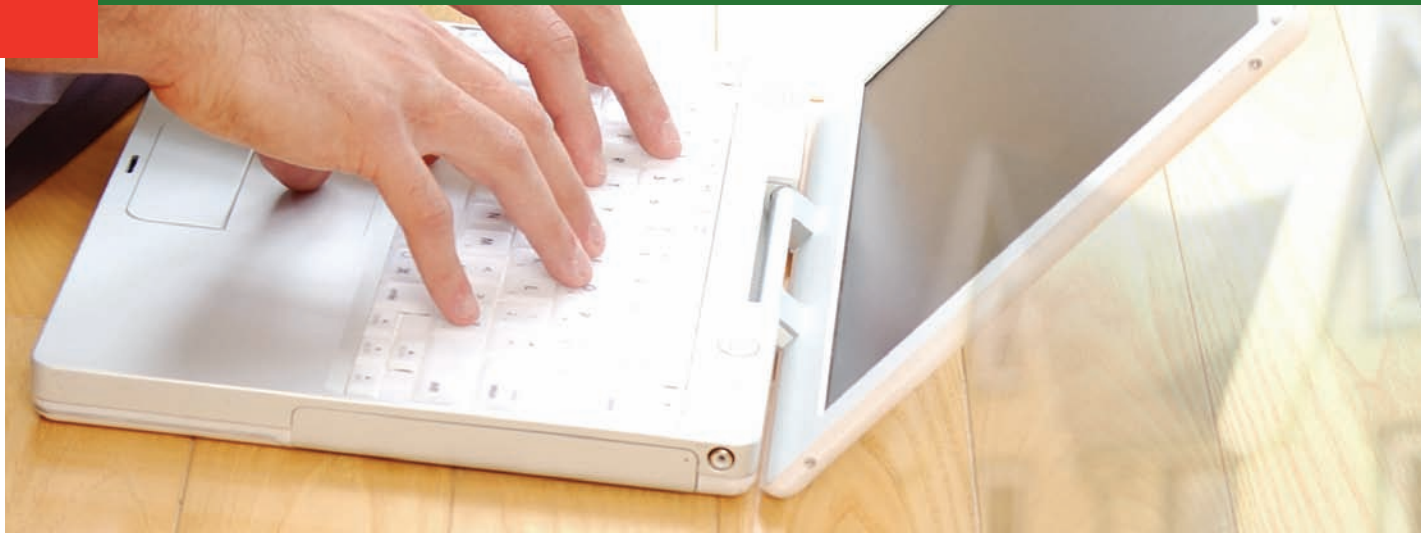


RESEARCH REPORT

External Research Program



Fused Grid Assessment:

Travel and Environmental Impacts of
Contrasting Pedestrian and Vehicular
Connectivity



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Fused Grid Assessment:

Travel and environmental impacts of contrasting pedestrian and vehicular connectivity

Final Report

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Giving Pedestrians an Edge—Using Street Layout to Influence Transportation Choice

INTRODUCTION

Transportation networks are a hotly debated topic, as municipalities and regional governments attempt to balance residents' demands for traffic control and safety with public objectives of healthy activity, compact land-use patterns or better air quality, while maintaining traffic flows. To date, research on travel behaviour and urban form has not isolated the influence of variations in street network connectivity on different travel modes. This study seeks to fill this gap by evaluating the relative effect of pedestrian versus vehicular connectivity on the choice to walk.

Attention to the potential variation in connectivity across modes comes into focus through a variety of strategies to mitigate adverse traffic impacts in existing communities (*see* Figure 1). For example, traffic calming techniques, which include a variety of techniques that slow and limit travel by cars while making walking and biking easier and safer are designed to increase the relative utility of walking and biking in comparison to driving. However, to date, evidence is limited on the performance of specific design solutions that promote non-motorized while constraining vehicle based networks within newly developing and existing communities.

Canada Mortgage and Housing Corporation (CMHC) recognized potential positive impacts of direct pedestrian movement between residential and commercial areas and between neighbouring subdivisions. This has resulted in the development of the Fused Grid street network.

The Fused Grid is a combination of patterns currently in use that presents a proposed middle ground among street network types. It opens the possibility of more optimal solutions than currently exist in planning practice.

In this study, the highest proportion of trips on foot (18%) is found in areas where a path is relatively more direct to nearby retail and recreational destinations on foot than by car. The lowest proportion (10%) of trips occur on foot in places where there is a low degree of pedestrian connectivity. By comparison, places with both high levels of pedestrian and vehicle connectivity have only about 14% mode share on foot. These results suggest that the relative connectivity of pedestrian and vehicular modes is an important predictor of the choice to walk.



Figure 1 Traffic calming techniques—street closed to cars only

The Fused Grid creates environments in which access between neighbourhoods is relatively easier on foot than by car (*see* Figure 2). The hypothesis is that a Fused Grid neighbourhood, which has greater connectivity and continuity for pedestrian travel compared to a vehicular network, will likely encourage more walking. But will it?

In both cases—transforming existing neighbourhoods and applying a new layout model—the question of influence on travel choice remains open.

The working hypothesis, that connectivity that favours pedestrians will result in more walking, was investigated using a quasi-experimental approach within a rational utility-behavioural framework.

This study¹ contributes to the understanding of how street network design influences travel behaviour. The research applied detailed, parcel-level, land-use road network and pedestrian network databases and it accounted for socio-demographic factors. It builds upon an extensive literature of urban form and travel behaviour research; contributes to the evidence base; and provides some unique methods to understand the role of mode-specific street networks in shaping travel patterns.

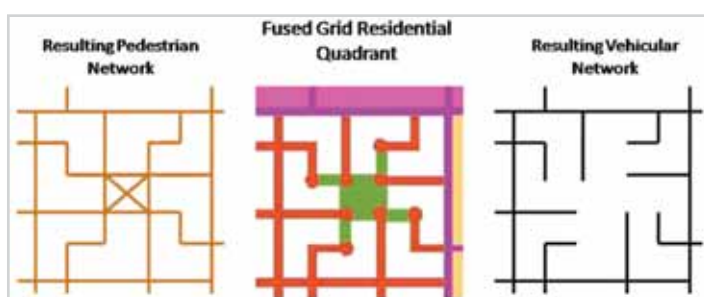


Figure 2 A Fused Grid neighbourhood: higher pedestrian connectivity than vehicular

PURPOSE OF THE STUDY

This study was prompted by the need for evidence of likely travel, environmental and health based outcomes from the Fused Grid. This innovative street network design by CMHC attempts to find a balance between the benefits of street connectivity for transportation efficiency with the use of street space to enhance neighbourhood quality of life for local residents. (see Figure 3 and 7)

Research to describe and test the relationship between the built environment and travel behaviour is needed, particularly with regard to street network design. Municipalities want to know the potential of street network design in supporting the attainment of various transportation and livability objectives.

FRAMING THE DEBATE

A review of the planning literature reveals a long-standing debate about street network design—especially about the functionality and impact of traditional, gridiron street network versus loops and cul-de-sac patterns.

It is apparent that differing street patterns could influence travel behaviour and mode choices: whether residents choose to travel by car, bicycle, foot or other means. A grid pattern, with its rectilinear network of intersections, provides more frequent street connections and more direct pathways between destinations.

A dendritic pattern of curvilinear streets and loops generally has more closed streets and indirect routing, with a design that favours more green space, larger lots and privacy. As most existing networks do not differentiate paths between modes, prior research has not been able to clarify how differences in connectivity across travel modes relate to or affect travel behaviour.

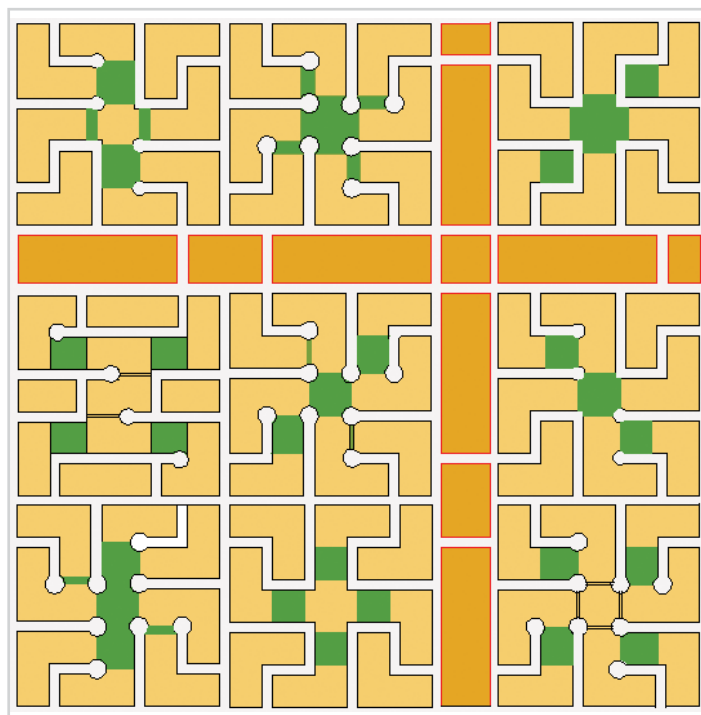


Figure 3 A Fused Grid district diagram showing residential neighbourhoods and zones of mixed use

It is important to understand which street network characteristics will best support the optimal achievement of multiple urban planning objectives. One objective, making urban areas and new neighbourhoods more conducive to walking, has become more important as a result of increased awareness of the health and environmental benefits of walking and conversely the harm of extensive driving. Yet opinion is varied on how best to achieve improved walkability.

¹ Lawrence Frank and Christopher Hawkins (2008). *Fused Grid Assessment: Travel and environmental impacts of contrasting pedestrian and vehicular connectivity*

This study investigates how kilometres travelled, number of trips taken and modes chosen differ among residents of neighbourhoods with varying degrees of vehicular and pedestrian accessibility. It focuses on how observed differences between vehicular and pedestrian access to destinations from where people live predicts travel choice.

Understanding the performance (in terms of travel patterns) of the Fused Grid was enabled by separating out pedestrian and vehicular street networks for a sub-set of households in the Puget Sound Region that completed the 1999 Puget Sound Travel Survey. This allowed the evaluation of how access (directness) to destinations on each network predicted observed travel patterns when adjusting for demographic and other urban form factors (density and land use mix).

NETWORK ROUTING AND CONNECTIVITY

Over the past 20 years, research has attempted to uncover the effects of urban form on travel behaviour^{2,3}. It shows that the built environment most strongly correlates to distance and time travelled, whereas socio-economic factors are more strongly related to other travel behaviours (e.g. car ownership, and frequency of trips).

Research also has revealed that three factors—density, land-use mix and connectivity—strongly correlate with travel behaviour. These factors co-vary and so the challenge for developing a more precise understanding is to isolate connectivity from other urban design and land-use factors.

However, most of the research to date does not include detailed accounting of the pedestrian environment or network patterns when measuring connectivity. Therefore, “connectivity” usually refers to the road network only and often does not clearly specify what is actually experienced by pedestrians.

The most important difference among street network types is the kind of routing that each provides, usually evaluated with a measurement of circuitry or connectivity. Routing and connectivity strongly affect travel distance and as a result the comparative costs (in time and money) of various travel mode choices. This research focuses on empirical investigation of the outcomes from varying levels and disparities of travel network connectivity across modes.

THE SCALE FACTOR

A brief review of the evolution of street patterns (*see* Figure 4) reveals that the impacts of street network design are an issue of scale. Conventional suburban street design does address the desires for safety and livability for local residents. But in a neighbourhood and city-wide context, the results tend toward auto-dependency, traffic congestion—especially on the limited number of collector streets—and externalized costs of negative health and environmental outcomes.

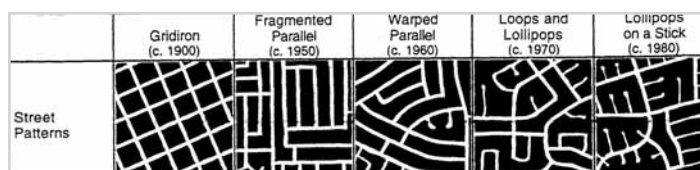


Figure 4 The evolution of street network patterns (adapted from Southworth and Owens, 1993)

Consequently, local governments are caught between competing objectives—improving connectivity for its transportation benefits, such as providing more transportation choices like walking and cycling—but retaining limited access streets for their benefits in improved safety and neighbourhood quality.

Many municipal planners have concluded that the car-oriented configurations of sparse suburban street networks are in need of retrofit and new designs are urgently needed⁴. The Fused Grid provides a potential middle ground as a means of mitigating some of the most adverse safety, environmental, and health impacts of completely auto dependent design approaches.

PREVIOUS RESEARCH AND METHOD CHOSEN

The measurement and evaluation of street networks has generally been centered on motor vehicle movement and level of service. Little attention was paid to the accessibility and mobility of pedestrians, and to a lesser degree bicyclists, which have emerged as key topics of recent research. Perhaps the most significant aspect of street designs that encourage more walking is the connectivity of the street both within neighbourhoods and to nearby destinations.

Research has descriptively (comparing different regions or areas with distinct characteristics) and experimentally investigated the relationship of urban form to travel behaviour. The evidence points to significant effects of land-use density and mix as well as neighbourhood design characteristics, particularly transit.

² Crane, Randall. 2000. The influence of urban form on travel: an interpretive review. *Journal of Planning Literature*. 15, 1: 4-23.

³ Frank, L.D., T.L. Schmid, J.F. Sallis, J. Chapman, and B.E. Saelens. 2005. Linking objectively measured physical activity with objectively measured urban form. *American Journal of Preventive Medicine*. 28(2S2): 117-125

⁴ Frumkin, Howard, Lawrence Frank, and Richard Jackson. 2004. *Urban sprawl and public health*. Washington, D.C.: Island Press

These studies have argued persuasively that variation of three main factors—density of residences or employment, mix of uses, and urban design (including transportation systems)—at a regional scale does relate to differences in travel behaviour. There have also been efforts to understand the impacts of urban design at a smaller scale.

In exploring the sub-neighbourhood scale, this research faced serious challenges: inadequacy of methods that is, not isolating one aspect of urban form from others; failure to account for residential self-selection; and other confounding factors, including urban form and non-environmental variables, that can affect travel behaviour.

In addition, travel survey data on non-motorized travel is very limited—systematic collection has only recently been done—and there is significant under-reporting on short trips, most of which are by non-motorized modes. Very localized data on the built environment is expensive and hard to collect, and protocols to clean the data to be more reliable are difficult to develop, and to date, have not been validated.

BEHAVIOURAL FRAMEWORK/THEORY AND PEDESTRIAN TRAVEL

The most robust model for explaining travel behaviour is a rational-choice framework that posits travel demand derived from the need to get to and from activities and decisions affected primarily by costs (in time and money). This framework, and related micro-economic theory of travel demand, was adopted for this research.

Walking activity in particular has been shown to be influenced consistently by distance to destinations and by the quality of the built environment. Distance, then, becomes a main cost in this analysis. Walkability has been summarized in indexes that attempt to capture the key dimensions of density, diversity and design. These factors attempt to encompass the whole of urban form, but the interest of this study is the effects of street configuration. In order to capture the effects of streets on travel behaviour, this study addresses some of the existing gaps in methods for measuring street networks.

SELECTION OF METHOD AND SCALE FOR CURRENT STUDY

The current study is unique because it includes a fully detailed assessment of pedestrian and motorized vehicle networks in the Puget Sound Region around households for which data on travel patterns and demographics was available. The unit of analysis is the person, and urban form characteristics are evaluated within a 1 kilometer distance from each person's home.

The study employs two complementary metrics of street connectivity: pedestrian and vehicular route directness and pedestrian and vehicular network density. Characteristics of each mode are directly compared, using a ratio to express relative connectivity and continuity between cars and pedestrians. Including separate measures of the distinct networks available for driving and walking, the research can more effectively and more broadly assess the effects on relative network connectivity to destinations on the choice to walk.

Analytical results were sought that would test the hypothesis that more direct pedestrian routing (relative to vehicular routing) results in higher walking mode share (increase in percentage of trips by pedestrian mode) and less automobile use (lower vehicle kilometers of travel, or VKT).

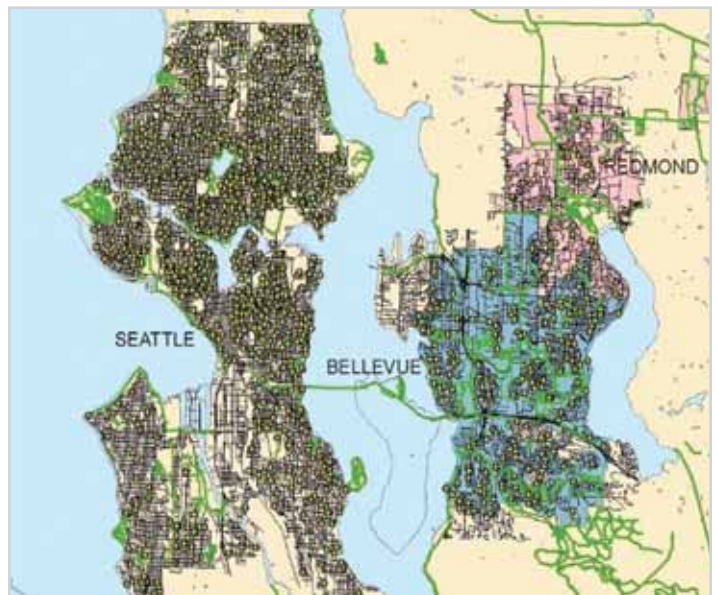


Figure 5 Map showing Seattle, Bellevue and Redmond in Washington

RESEARCH STUDY AREA

The study presents a detailed research assessment of relative vehicle and pedestrian network connectivity within three cities' Seattle, Bellevue, and Redmond, located in the central Puget Sound. The Seattle metropolitan region was chosen for the research because of extensive available urban form and travel behaviour data. The cities of Redmond (41 km² [15 sq. mi.]), Bellevue (83 km² [32 sq. mi.]), and Seattle (216 km² [83 sq. mi.]), encompass a land area of 340 km² (131 sq. mi.)

The study attempts to deconstruct the fused grid into its component parts by focusing on the relative connectivity between vehicular and non-motorized modes of travel. It evaluates the relative connectivity to the nearest retail and recreational destination between these two modes of travel for a set of households and compares this to self-reported travel patterns. The sample was drawn from three cities that possess considerable variation in their street patterns, and in the level of connectivity between vehicle and pedestrian modes of travel.

Disparities between pedestrian and vehicle networks are found in areas with steep slopes resulting in dead end streets to cars but have pathways for pedestrians. (*see* Figure 6) These are also areas where pedestrian connections have been added to cul-de-sac networks increasing the relative connectivity for pedestrian over vehicles to nearby destinations. Conversely, areas exist where pedestrian connections are restricted due to lack of sidewalk provision, even on grid networks where driving is direct. In these areas vehicle based connectivity is higher than that encountered by pedestrians.



Figure 6 Example of pedestrian only connector

Congruence between pedestrian and vehicle networks occurs in areas characterized by urban grids with sidewalks or on cul-de-sacs without sidewalks. This contrast of street connectivity is essential to the process of testing the research hypothesis.

STUDY SUMMARY AND FINDINGS

The results assess the likely performance of the Fused Grid street design on several travel outcomes of interest to urban transportation and community planning. The assessment begins to answer the question of whether new layout configurations and street standards, in addition to the retrofit programs of traffic calming, will result in the desired outcomes of increased levels of walking and decreased reliance on automobiles.

The current study concludes that there is significant relationship between local street networks configuration and travel behaviour, and that modifications to street patterns are associated with changes in levels of walking and driving for local travel.

KEY FINDINGS

This study examines two main measures: relative route directness and relative network density across walking and driving modes. Both measures have associations with odds of walking, odds of driving, distance walked, distance travelled by vehicle, and number of trips.

All else being equal, the results of this study suggest that increasing connectivity on foot relative to in-vehicle travel increases the likelihood that people will walk more and drive less. This result is consistent with the premise of the Fused Grid. (*see* Table 1)

Table 1 Disparate street connectivity and walk shares (by person to commercial)

		Pedestrian Connectivity	
Vehicular Connectivity		Low	High
	Low	Southeast and Central Bellevue; Southwest Seattle—Loop and culs-de-sac Mean walk share: 10% walking n = 985	Queen Anne, Capital Hill (Seattle)—Modified grid with connectors Mean walk share: 18% walking n = 66
	High	North and South Bellevue, North Seattle—Grid and major streets w/o sidewalks Mean walk share: 10% walking n = 59	Downtown and older Seattle neighbourhoods—Gridiron Mean walk share: 14% walking n = 966

Research Highlight

Giving Pedestrians an Edge—Using Street Layout to Influence Transportation Choice

This study's primary findings demonstrate that relative route directness is associated with increased levels of walking and decreased driving. As well, relative network density—a higher density of walking pathways than driveable streets—generates even greater increases in walking and reduction of driving.

This finding suggests that street designs that improve the directness of routes for pedestrians, relative to those enjoyed by other modes in the network, are associated with more walking. The Fused Grid street design provides a transportation network pattern that achieves a change in relative utility of walking. (see Figure 7) Certain traffic calming measures in existing neighbourhoods would achieve similar results.

The study's correlation and regression analysis indicate that the relative network density measure exhibits a significant relationship with the choice to walk. This suggests that more complete pedestrian pathways to destinations increase pedestrian travel. Directness of connections relates to more walking activity but less so than the density of pedestrian facilities or the presence of retail stores nearby.

Importantly, these two street network factors—the ratio of route directness and ratio of network density—are additive in their effects. That is, designs that create improvement on both measures will generate even larger benefits on travel outcomes. The Fused Grid street design is characterized by a higher density of pedestrian pathways than vehicle pathways. Land use mix and density were held constant in this study as were demographic factors.

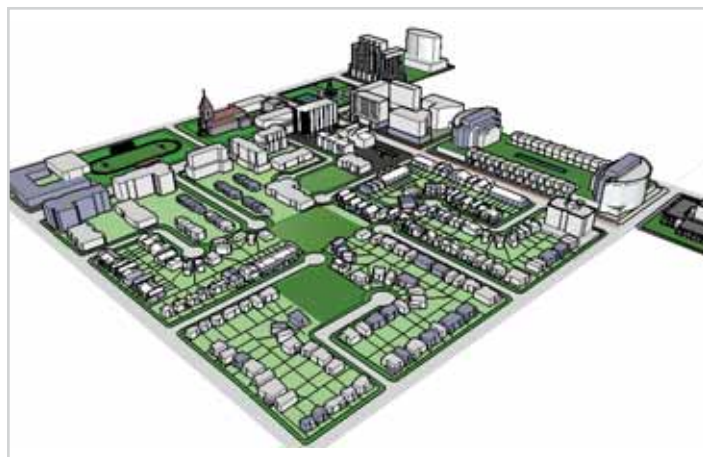


Figure 7 Axonometric of a Fused Grid Quadrant bounded by a mixed use zone. Pedestrian paths to common amenities are more direct than vehicular.

For the three Seattle neighbourhoods, the regression model demonstrated that a change from a pure small-block grid to a modified grid (that is, Fused Grid) can result in an increase in odds of a home-based trip being walked by 11.3 per cent.

The modified street pattern, like a Fused Grid, is also associated with a 25.9 per cent increase over street patterns with equivalent route directness for walking and driving, in the odds a person will meet the recommended level of physical activity through walking in their local travel. The same 10 per cent increase in relative pedestrian continuity (network density) associates with a 9.5 per cent increase in odds of walking, all other factors remaining the same.

Finally, the Fused Grid's 10 per cent increase in relative connectivity for pedestrians is associated with a 23 per cent decrease in vehicles miles of local travel, and the improved continuity is associated with increases in both number of walking trips and total distance walked for local travel.

COMMUNITY PLANNING AND DESIGN IMPLICATIONS

Both traffic calming and street layout options that offer increased directness of routing for pedestrians relative to motor vehicles can be used to help achieve increased levels of walking, reduced motor vehicle use, or both. Increasing the extent of sidewalk or other pedestrian pathways, by adding them as stand-alone projects or including a higher density of them relative to street length in plans for new neighbourhoods, is likely to be useful in achieving the same walkability outcomes.

These changes to travel network patterns are also associated with walking a sufficient amount to have a healthy level of physical activity. These kinds of measures will be particularly effective when they result in both reductions in the connectivity of the motor vehicle network (that is, street closures or other interruptions in the network for motorized vehicles) relative to the walking network and increase the pedestrian network's extent relative to the vehicular network.

Emerging evidence about environmental impacts, livability and public health are setting the stage for new street network designs based in better understanding of travel behaviour. Past designs and retrofitting of newer streets, while part of the solution, may not provide the most satisfactory results.

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Donner leur place aux piétons – Utilisation du tracé des rues pour influencer sur le mode de déplacement

INTRODUCTION

Les réseaux de transport sont un sujet chaudement débattu, à un moment où les municipalités et les gouvernements régionaux tentent d'atteindre un équilibre entre les demandes des résidents pour le contrôle et la sécurité de la circulation et les objectifs publics d'activités saines, d'utilisation compacte des terres ou de meilleure qualité de l'air, et ce, tout en maintenant un bon débit de circulation. À ce jour, les recherches sur les habitudes de déplacement et la forme urbaine n'ont pas été en mesure d'isoler l'influence que peuvent avoir les variations de la connectivité des réseaux routiers sur les différents modes de déplacement. Les auteurs de cette étude ont cherché à combler cette lacune en évaluant dans quelle mesure la connectivité des voies de circulation a une incidence sur le choix de marcher selon qu'elle est favorable aux piétons ou aux véhicules.

Une attention à la variation éventuelle de la connectivité entre les modes s'impose si l'on doit considérer diverses stratégies pour atténuer les effets défavorables de la circulation dans les collectivités existantes. Par exemple, les techniques de modération de la circulation, qui comprennent différentes stratégies visant à ralentir et à limiter le passage des véhicules tout en rendant la marche et le vélo plus faciles et plus sûrs, sont conçues pour accroître l'utilité relative de la marche et du vélo comparativement à la conduite automobile (figure 1). Toutefois, à ce jour, il est difficile de confirmer le rendement de solutions conceptuelles spécifiques susceptibles d'encourager la circulation non motorisée et, du même coup, de contraindre les réseaux véhiculaires dans les collectivités existantes ou en voie d'aménagement.

La Société canadienne d'hypothèques et de logement (SCHL) a compris que les déplacements piétonniers directs entre les secteurs résidentiels et commerciaux, et même entre les subdivisions d'un quartier, pouvaient être avantageux, ce qui a conduit à la création d'un tracé de rues appelé « ilogramme mixte ».

L'ilogramme mixte propose un compromis entre différents schémas de rues actuellement en usage. Il élargit le spectre des solutions possibles pour optimiser ce qui existe actuellement dans la pratique de l'urbanisme.

On trouve la plus forte proportion de déplacements à pied (18 %) dans les secteurs où l'accès aux destinations commerciales ou récréatives est relativement plus direct à pied qu'en voiture. À l'inverse, cette proportion est la plus faible (10 %) là où les liens pour les piétons sont les moins efficaces sur le plan de la connectivité. Par comparaison, les endroits où la connectivité est bonne à la fois pour les piétons et les véhicules moteurs n'affichent une proportion de déplacements à pied que de 14 %. Ces résultats portent à croire que la connectivité relative des liens piétonniers et véhiculaires est un important paramètre de prévision quant au choix de la marche comme mode de déplacement.



Figure 1 Techniques de modération de la circulation – rue fermée uniquement aux voitures.

L'ilogramme mixte crée des environnements dans lesquels l'accès entre les quartiers est relativement plus facile à pied qu'en voiture (figure 2). L'hypothèse de départ est qu'un quartier aménagé en ilogramme mixte, qui offre plus de connectivité et de continuité pour les déplacements des piétons, comparativement à un réseau axé sur les véhicules, encouragera probablement davantage la marche. Mais est-ce vraiment le cas?

Deux options sont possibles : transformer un quartier existant ou appliquer le modèle à un nouveau quartier. Dans les deux cas, l'influence du modèle retenu sur le choix du mode de déplacement demeure inconnue.

L'hypothèse de travail selon laquelle la connectivité favorable aux piétons incitera davantage les gens à choisir la marche a été étudiée à l'aide d'une approche quasi expérimentale dans un cadre comportemental rationnel.

Cette étude¹ explique comment la conception du réseau routier peut influencer sur les habitudes de déplacement des gens. Les chercheurs ont appliqué des bases de données détaillées, au niveau des parcelles, concernant les réseaux routiers et piétonniers, et ont tenu compte des facteurs socio-démographiques. Leur étude s'appuie sur une vaste consultation des recherches réalisées sur les formes urbaines et les comportements liés aux déplacements. Elle contribue à l'accumulation de données d'observation et elle offre des méthodes uniques pour comprendre le rôle des réseaux routiers axés sur un mode de déplacement particulier pour façonner les habitudes de déplacement.

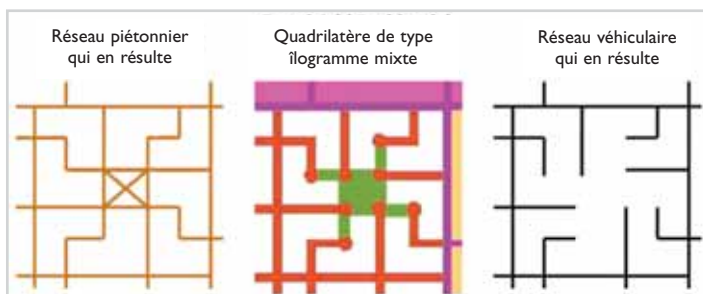


Figure 2 Le quartier de type îlogramme mixte offre plus de connectivité pour les piétons

BUT DE L'ÉTUDE

Cette étude a été entreprise dans le but d'étayer les hypothèses avancées au sujet de l'îlogramme mixte quant aux incidences possibles sur les déplacements probables, l'environnement et la santé. Ce tracé de rues novateur conçu par la SCHL vise à établir un équilibre entre un réseau routier axé sur l'efficacité du transport et un usage des rues permettant de rehausser la qualité de vie des habitants d'un quartier. (Voir figures 3 et 7)

Des recherches devant décrire et vérifier la relation entre l'environnement bâti et les comportements liés aux déplacements sont nécessaires, particulièrement en ce qui concerne la conception des réseaux routiers. Les municipalités veulent connaître le potentiel de ce concept pour les aider à réaliser divers objectifs relatifs au transport et à la qualité de vie.

POUR ENCADRER LE DÉBAT

Un examen de la documentation dans le domaine de l'urbanisme révèle un débat de longue date portant sur la conception des réseaux routiers – particulièrement en ce qui concerne la fonctionnalité et l'impact des quadrilatères traditionnels par rapport aux modèles de boucles et de culs-de-sac.

Il est évident que des tracés de rues différents pourraient influencer les gens quant à leurs modes de déplacement : automobile, bicyclette, marche ou autres moyens. Un quadrilatère, avec son réseau rectilinéaire d'intersections, offre des connexions de rues plus fréquentes et des itinéraires plus directs entre les destinations.

Un modèle dendritique de rues curvilinéaires et de boucles présente généralement plus de rues fermées et d'itinéraires indirects, selon une conception qui favorise plus d'espaces verts, des terrains plus grands et une intimité accrue. Comme la plupart des réseaux existants ne différencient pas les voies en fonction des modes de déplacement, les recherches antérieures n'ont pas permis d'établir comment les différences de connectivité entre les divers modes de déplacement sont associées aux comportements ou les influencent.

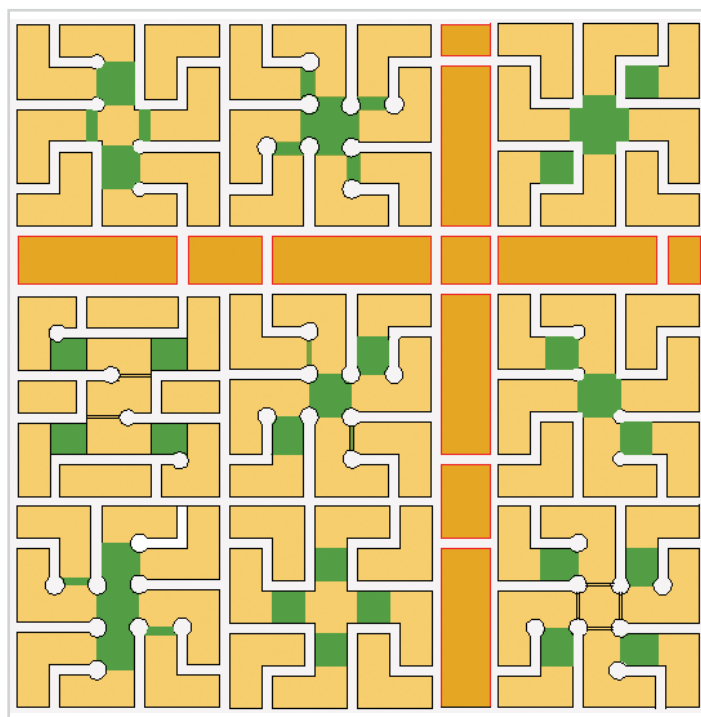


Figure 3 District aménagé en îlogramme mixte avec quartiers résidentiels et zones à usages diversifiés

¹ Lawrence Frank et Christopher Hawkins, *Fused Grid Assessment: Travel and environmental impacts of contrasting pedestrian and vehicular connectivity*, 2008

Il est important de comprendre quelles caractéristiques des tracés de rue soutiendront le mieux la réalisation optimale des multiples objectifs de l'aménagement urbain. L'un de ces objectifs, qui est de rendre les secteurs urbains et les nouveaux quartiers plus propices à la marche, a pris de l'importance dans un contexte où l'on sensibilise les gens aux bienfaits de la marche pour la santé et l'environnement et, en contrepartie, aux méfaits d'une utilisation intensive des voitures. Pourtant, les opinions varient quant à la meilleure façon de favoriser la pratique de la marche.

Cette étude examine comment les kilomètres parcourus, le nombre de déplacements et les modes de transport choisis diffèrent parmi les résidents des quartiers présentant des degrés variables d'accessibilité aux véhicules et aux piétons. Elle met l'accent sur la façon dont les différences observées entre l'utilisation d'un véhicule et la marche pour atteindre une destination à partir du domicile peuvent permettre de prédire le choix du mode de déplacement.

Pour déterminer si l'ïlogramme mixte est efficace à l'égard des habitudes de déplacement, les chercheurs ont séparé les réseaux piétonniers et véhiculaires pour un sous-ensemble de ménages dans la région de Puget Sound, ce qui a permis de réaliser la Puget Sound Regions Household Travel Survey de 1999. On a ainsi pu savoir dans quelle mesure l'accès direct aux destinations sur chaque réseau permettait de prédire les habitudes de déplacement observées en tenant compte des facteurs démographiques et d'autres facteurs liés à la forme urbaine (densité et utilisation diversifiée des terres).

ITINÉRAIRE ET CONNECTIVITÉ DES RÉSEAUX

Au cours des 20 dernières années, des chercheurs ont tenté de découvrir les effets de la forme urbaine sur les comportements liés aux déplacements^{2,3}. On a découvert qu'il existe une très forte corrélation entre l'environnement bâti et la distance et le temps de déplacement, alors que les facteurs socio-économiques sont plus fortement associés à d'autres comportements liés aux déplacements (par ex. possession d'une voiture et fréquence des déplacements).

Les recherches ont également révélé que trois facteurs – densité, utilisation des terres et connectivité – présentent une forte corrélation avec les comportements liés aux déplacements. Ces facteurs varient, et la difficulté inhérente à une compréhension plus précise du phénomène consiste à isoler la connectivité des autres facteurs propres à l'aménagement urbain et à l'utilisation des terres.

Toutefois, la plupart des recherches menées à ce jour ne tiennent pas compte de façon détaillée de l'environnement piétonnier ou des tracés des réseaux pour mesurer la connectivité. Par conséquent, l'idée de « connectivité » se rapporte habituellement au réseau routier seulement et, souvent, ne précise pas clairement ce que vivent les piétons dans les faits.

La différence la plus importante entre les types de réseaux routiers est la sorte d'itinéraire que chacun offre, un aspect qu'on évalue habituellement au moyen d'une mesure des itinéraires indirects ou de la connectivité. L'itinéraire et la connectivité agissent fortement sur la distance du déplacement et, de ce fait, sur les coûts comparatifs (temps et argent) des divers modes de déplacement choisis. L'étude dont il est ici question met l'accent sur l'étude empirique des effets obtenus à partir des niveaux et disparités divers de la connectivité des réseaux routiers entre les différents modes.

UNE QUESTION D'ÉCHELLE

Un bref examen de l'évolution des tracés de rues (figure 4) révèle que les impacts de la conception du réseau routier se ramènent à une question d'échelle. Le tracé traditionnel des rues de banlieue tient compte du désir de sécurité et de qualité de vie des résidents locaux. Mais dans le contexte des quartiers et des villes, il en résulte une tendance à la dépendance à l'égard de l'automobile, à la congestion de la circulation – particulièrement à cause du nombre limité de voies collectrices – et à une externalisation des coûts associés aux effets négatifs pour la santé et l'environnement.

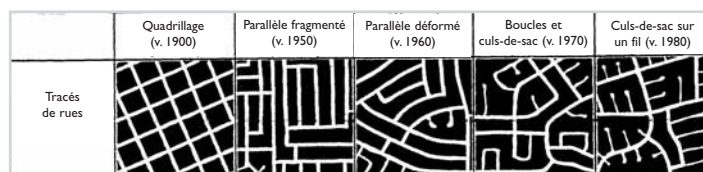


Figure 4 Évolution des tracés de rues (adapté de Southworth et Owens, 1993)

En conséquence, les administrations locales sont prises entre des objectifs conflictuels – améliorer la connectivité pour faciliter le transport, par exemple en offrant plus de choix de modes de déplacement comme la marche et le vélo – mais continuer de fermer des rues pour préserver la sécurité des quartiers et la qualité de vie des résidents.

De nombreux urbanistes municipaux ont conclu que la préférence accordée à l'automobile par les concepteurs des réseaux routiers suburbains éparpillés doit être repensée et qu'il est urgent d'adopter de nouveaux

² Crane, Randall, 2000. *The influence of urban form on travel : an interpretive review*. Journal of Planning Literature, 15, 1 : 4-23.

³ Frank, L.D., Schmid, J.F., Sallis, J., Chapman et B.E. Saelens. 2005. *Linking objectively measured physical activity with objectively measured urban form*. American Journal of Preventive Medicine. 28(2S2) : 117-125.

⁴ Frumkin, Howard, Lawrence Frank et Richard Jackson. 2004. *Urban sprawl and public health*. Washington, D.C. : Island Press.

concepts⁴. L'ïlogramme mixte pourrait s'avérer un bon compromis afin d'atténuer certains des pires impacts sur la sécurité, l'environnement et la santé des approches conceptuelles uniquement axées sur l'utilisation de l'automobile.

RECHERCHES ANTÉRIEURES ET MÉTHODE CHOISIE

La mesure et l'évaluation des réseaux routiers ont généralement été centrées sur le mouvement des véhicules motorisés et le niveau des services offerts. On a peu fait pour faciliter la mobilité des piétons et, dans une moindre mesure, des cyclistes, et rendre leurs destinations accessibles, deux aspects importants que les recherches récentes ont fait ressortir. L'élément des tracés de rues qui est sans doute le plus à même d'encourager la marche est la connectivité des rues au sein même des quartiers et vers les destinations à proximité.

Les chercheurs ont examiné de façon descriptive (en comparant différentes régions présentant des caractéristiques distinctes) et expérimentale la relation entre la forme urbaine et les comportements liés aux déplacements. Tout indique que la densité des aménagements, l'utilisation des terres ainsi que certaines caractéristiques de la conception des quartiers, notamment le transport en commun, ont des effets notables.

Ces études ont permis de soutenir de façon convaincante que la variation des trois principaux facteurs – densité de population ou d'emploi, diversification des usages et aménagements urbains (y compris les réseaux de transport) – à l'échelle régionale a effectivement une incidence sur les différents comportements liés aux déplacements. On a également cherché à comprendre les impacts des aménagements urbains à plus petite échelle.

En explorant plus loin que les seuls quartiers, les auteurs de la présente étude se sont heurtés à de sérieuses difficultés : inadéquation des méthodes, du fait qu'il n'était pas possible d'isoler un aspect de la forme urbaine par rapport aux autres, impossibilité de tenir compte des personnes qui choisissent de résider dans ce secteur pour ses caractéristiques particulières en matière de transport et d'aménagements urbains, et d'autres variables confusionnelles telles que la forme urbaine et les facteurs non liés à l'environnement, lesquelles peuvent influencer sur les comportements liés aux déplacements.

De plus, les données des enquêtes sur les déplacements non motorisés sont très limitées, car elles ne font l'objet d'une collecte systématique que depuis tout récemment, et les déplacements sur de courtes distances sont insuffisamment signalés, la plupart étant non motorisés. Les données très localisées sur l'environnement bâti sont coûteuses et difficiles à recueillir, et les protocoles pour épurer les données afin qu'elles soient plus fiables sont complexes à élaborer et, à ce jour, n'ont pas été validés.

CADRE ET THÉORIE DU COMPORTEMENT ET DÉPLACEMENTS DES PIÉTONS

Le modèle le plus robuste pour expliquer les comportements liés aux déplacements est un cadre de choix rationnel, selon lequel la demande de déplacement découle du besoin de se rendre aux activités et d'en revenir et de décisions principalement régies par des contraintes de temps et d'argent. Ce cadre et la théorie microéconomique connexe de la demande de déplacement ont été adoptés pour la présente étude.

Il a été démontré que le recours à la marche à pied dépend généralement de la distance à parcourir pour atteindre la destination et de la qualité de l'environnement bâti. Ainsi, la distance devient une contrainte principale dans cette analyse. Le potentiel piétonnier a été résumé dans des indices qui tentent de saisir les dimensions clés de la densité, de la diversité et de la conception. Ces facteurs tentent d'englober l'ensemble de la forme urbaine, mais l'intérêt de cette étude réside dans les effets de la configuration des voies de circulation. Afin de déterminer quels effets peuvent avoir les rues sur les comportements liés aux déplacements, cette étude examine certaines des lacunes des méthodes utilisées pour mesurer les réseaux routiers.

SÉLECTION DE LA MÉTHODE ET ÉCHELLE DE L'ÉTUDE EN COURS

La présente étude est unique parce qu'elle comprend une évaluation très détaillée des réseaux piétonniers et véhiculaires dans la région de Puget Sound en regard des ménages pour lesquels les données sur les habitudes de déplacement et la démographie étaient disponibles. L'unité d'analyse est la personne, et les caractéristiques de la forme urbaine sont évaluées à une distance de moins d'un kilomètre de la maison de chaque personne.

L'étude emploie deux mesures complémentaires de la connectivité des rues : l'accès direct aux destinations pour les piétons et les automobilistes, et la densité des réseaux piétonniers et véhiculaires. Les caractéristiques de chaque mode sont comparées directement, à l'aide d'un ratio pour exprimer la connectivité et la continuité relatives entre les véhicules et les piétons. En incluant des mesures séparées pour les réseaux distincts disponibles pour la conduite automobile et la marche, la recherche peut évaluer plus efficacement et de façon plus générale les effets de la connectivité relative des réseaux, par rapport aux destinations, sur le choix de marcher.

On a tenté d'obtenir des résultats analytiques susceptibles de confirmer l'hypothèse selon laquelle l'itinéraire piétonnier plus direct (par rapport à celui des véhicules) donne lieu à une plus grande proportion de marcheurs (augmentation du pourcentage de déplacements des piétons) et à un moins grand nombre d'automobilistes (moins de kilomètres parcourus en voiture).

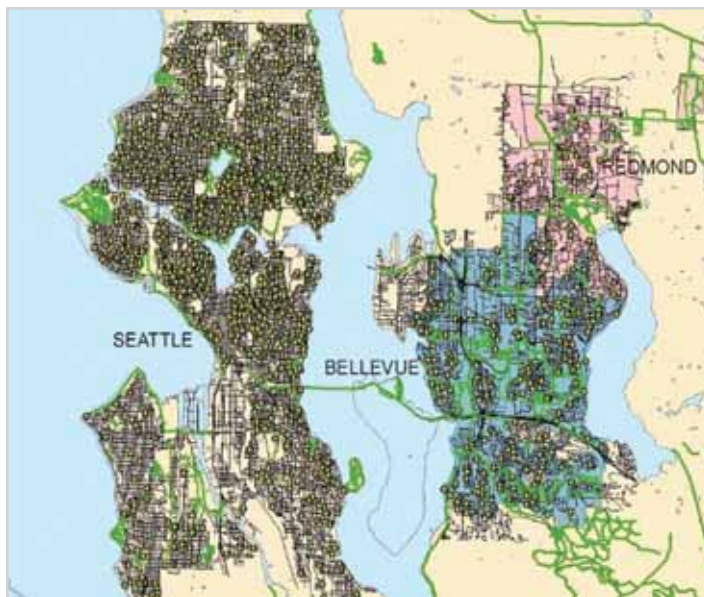


Figure 5 Carte montrant Seattle, Bellevue et Redmond dans l'État de Washington

ZONE DE L'ÉTUDE

L'étude présente une évaluation détaillée de la connectivité relative des réseaux véhiculaires et piétonniers dans trois villes situées dans la région de Puget Sound : Seattle, Bellevue et Redmond. La région métropolitaine de Seattle a été choisie pour la recherche en raison de l'important éventail de formes urbaines et du grand nombre de données disponibles sur les comportements liés aux déplacements. Les villes de Redmond (41 km²), Bellevue (83 km²) et Seattle (216 km²) couvrent une superficie de 340 km².

Les auteurs de l'étude tentent de décomposer l'ilogramme mixte en ses parties constituantes en mettant l'accent sur la connectivité relative entre les modes de déplacement motorisés et non motorisés. Ils évaluent la connectivité relative par rapport à la destination de magasinage et de loisirs la plus proche entre ces deux modes de déplacement pour un ensemble de ménages et la compare aux habitudes de déplacement autodéclarées. L'échantillon a été tiré de ces trois villes dont les tracés de rues et la connectivité entre les modes de déplacement véhiculaires et piétonniers varient considérablement.

Les disparités entre les réseaux piétonniers et véhiculaires se trouvent dans les secteurs où il y a des pentes escarpées, donnant lieu à des impasses pour les voitures, mais offrant des sentiers aux piétons (figure 6). Il y a également des secteurs où des liens piétonniers ont été ajoutés aux culs-de-sac pour ainsi augmenter la connectivité relative pour les piétons par rapport aux véhicules pour les destinations voisines. Par contre, il existe aussi des secteurs où les liens piétonniers sont limités à cause de l'absence de trottoirs, même sur les tracés du réseau où la conduite automobile est directe. Dans ces secteurs, la connectivité pour les véhicules est supérieure à celle dont bénéficient les piétons.



Figure 6 Exemple de lien accessible uniquement aux piétons

La concordance des réseaux piétonniers et véhiculaires se produit dans les secteurs caractérisés par des quadrilatères urbains dotés de trottoirs ou dans les culs-de-sac sans trottoirs. Ce contraste de la connectivité est essentiel au processus de vérification de l'hypothèse de la recherche.

SOMMAIRE ET CONSTATATIONS DE L'ÉTUDE

L'étude permet d'évaluer le rendement probable de l'ilogramme mixte pour plusieurs éléments d'intérêt en matière de transport urbain et d'urbanisme. L'évaluation se veut une amorce de réponse à la question de savoir si les nouveaux concepts et les nouvelles normes pour les tracés de rues, en plus des programmes de réaménagement des rues pour y modérer la circulation, permettront d'inciter les résidents à marcher davantage et à diminuer leur utilisation de l'automobile.

L'étude dont il est ici question conclut qu'il y a une relation significative entre la configuration des réseaux routiers locaux et les comportements liés aux déplacements, et que les modifications aux tracés de rues sont associées à des changements en ce qui concerne le nombre de personnes qui marchent au lieu de recourir à l'automobile pour effectuer des déplacements sur de courtes distances.

PRINCIPALES CONCLUSIONS

Les chercheurs ont examiné deux mesures principales : l'accès relativement direct aux destinations et la densité relative des réseaux piétonniers et véhiculaires. Les deux mesures sont associées aux probabilités que les gens marchent, aux probabilités qu'ils utilisent leur automobile, à la distance marchée, à la distance parcourue par un véhicule et au nombre de déplacements.

Tableau 1 Connectivité disparate des rues et parts de marche (par personne vers les commerces)

		Pedestrian Connectivity	
Connectivité favorable aux véhicules	Faible	Faible	Élevée
		Sud-est et centre de Bellevue; Sud-ouest de Seattle - boucles et culs-de-sac Part de marche en moyenne : 10 % n = 985	Queen Anne, Capital Hill (Seattle) – Quadrilatère modifié avec voies collectrices Part de marche en moyenne : 18 % n = 66
	Élevée	Faible	Élevée
		Nord et sud de Bellevue, Nord de Seattle – Quadrilatère et rues principales sans trottoirs Part de marche en moyenne : 10 % n = 59	Centre-ville et vieux quartiers de Seattle – Quadrillage Part de marche en moyenne : 14 % n = 966

Tous les autres éléments étant égaux, les résultats de cette étude indiquent qu'une connectivité plus favorable aux piétons qu'aux véhicules augmentera la probabilité que les gens marchent au lieu de prendre leur voiture. Ce résultat va dans le même sens que l'hypothèse de départ formulée au sujet de l'îlogramme mixte. (tableau 1)

Les principales conclusions de cette étude démontrent qu'un accès relativement direct des itinéraires est associé à une proportion accrue de marcheurs et à une diminution de l'utilisation de l'automobile. De plus, la densité relative des réseaux – une densité supérieure des sentiers piétonniers par rapport aux rues autorisant la circulation automobile – génère encore plus d'augmentation de la marche et diminue d'autant le recours à l'automobile.

Cette conclusion indique que les tracés de rues qui rendent les itinéraires plus directs pour les piétons, par rapport à ceux des autres modes de déplacement du réseau, sont associés à un accroissement de la marche. L'îlogramme mixte procure un réseau de transport plus favorable aux piétons que ceux offerts par les tracés de rues traditionnels (figure 7). Certaines mesures de modération de la circulation dans les quartiers existants donneraient des résultats semblables.

L'analyse de corrélation et de régression de l'étude indique que les gens choisissent de marcher dans la mesure où la densité relative du réseau y est favorable. Cela suggère que des sentiers piétonniers plus étendus menant aux destinations habituelles augmentent la fréquence des déplacements piétonniers. Des liens directs augmentent aussi le nombre de piétons, mais dans une moindre mesure que la densité des installations piétonnières ou la présence de magasins à proximité.

Aspect important, ces deux facteurs du réseau routier – le caractère direct des itinéraires et la densité du réseau – s'additionnent quant à leurs effets, c'est-à-dire que les aménagements qui améliorent les deux facteurs produiront encore plus d'avantages quant aux déplacements. Le tracé des rues fondé sur l'îlogramme mixte est caractérisé par une densité supérieure des sentiers piétonniers par rapport aux voies pour les véhicules. L'utilisation des terres et la densité ont été maintenues constantes dans cette étude, tout comme les facteurs démographiques.

Pour les trois quartiers de Seattle, le modèle de régression démontre que le fait de passer d'un quadrilatère formé de petits îlots à l'îlogramme mixte peut donner lieu à une augmentation de 11,3 % de la probabilité que les gens marchent.

Un tracé de rues modifié, comme celui de l'îlogramme mixte, est également associé à une augmentation de 25,9 % par rapport aux tracés offrant un accès aux destinations aussi direct pour les piétons que pour les automobilistes. Par la même occasion, le fait de marcher pour se rendre aux destinations locales permet aux résidents de faire suffisamment d'activité physique pour atteindre les niveaux recommandés. La même augmentation de 10 % de la continuité piétonnière relative (densité du réseau) est associée à une augmentation de 9,5 % de la probabilité que les gens marchent, tous les autres facteurs demeurant les mêmes.

Enfin, l'augmentation de 10 % de la connectivité relative des voies piétonnières que permet l'îlogramme mixte est associée à une diminution de 23 % du nombre de milles parcourus avec un véhicule pour les déplacements locaux, et cette connectivité améliorée entraîne un accroissement du nombre de déplacements à pied et de la distance totale marchée pour les déplacements locaux.

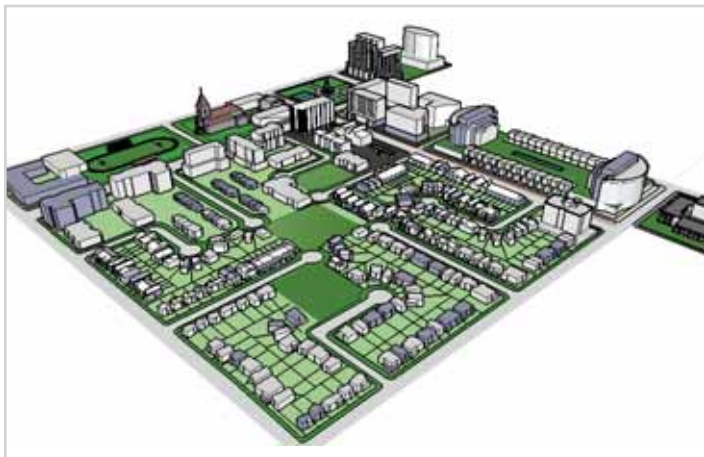


Figure 7 Représentation axonométrique d'un quadrant d'îlogramme bordé par une zone à usage diversifié. Les sentiers pédestres menant aux commodités courantes sont plus directs que ceux créés pour les véhicules moteurs.

RÉPERCUSSIONS SUR L'URBANISME ET L'AMÉNAGEMENT

Les normes de modération de la circulation et de conception des rues qui offrent des itinéraires plus directs pour les piétons par rapport aux véhicules moteurs peuvent servir à accroître la marche, à réduire l'utilisation des véhicules, ou les deux. Le fait d'augmenter le nombre de trottoirs ou d'autres voies piétonnières en les ajoutant dans le cadre d'initiatives ponctuelles ou en prévoyant une plus grande densité de trottoirs et de sentiers piétonniers par rapport à la longueur des rues au moment d'élaborer les plans des nouveaux quartiers sera probablement utile pour atteindre les mêmes résultats quant à la pratique de la marche.

Ces changements aux tracés des réseaux de déplacement sont également associés à un niveau d'activité physique suffisant, grâce à la marche, pour qu'il soit bon pour la santé. Ces types de mesures seront particulièrement efficaces lorsqu'ils pourront donner lieu à une réduction de la connectivité du réseau pour les véhicules moteurs (c'est-à-dire par la fermeture de rues et d'autres interruptions dans le réseau pour les véhicules moteurs) par rapport au réseau piétonnier, et à une augmentation du réseau piétonnier par rapport au réseau véhiculaire.

De nouvelles observations relatives aux impacts environnementaux, à la qualité de vie et à la santé publique mettent la table pour la création de nouveaux réseaux routiers fondés sur une meilleure compréhension des comportements liés aux déplacements. Les anciens concepts et le réaménagement des rues récentes, bien que faisant partie de la solution, pourraient ne pas offrir les résultats les plus satisfaisants.

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EXECUTIVE SUMMARY

This research study aims to provide improved understanding of the influence that street networks have on travel behavior. The report assesses variations in residential street network design and how a neighborhood's street network design affects the travel patterns of its residents. How does people's travel, measured in miles traveled, number of trips taken, and modes chosen, differ among neighborhoods with different street network types?

To date, the research on travel behavior and urban form has not isolated the influence of variation in street network connectivity across different travel modes. However, this remains a critical concern of new neighborhood design proposals. The more recent adoption of tools such as traffic calming also attempt to mitigate traffic impacts and influence mode choice. These techniques aim to reduce motor vehicle impacts while enhancing and encouraging walking or other non-motorized transportation

This research investigated the association of street network connectivity differences across travel modes with travel behaviour: mode choice, distance traveled and number of trips. A street network like the Fused Grid, with greater connectivity and continuity for the pedestrian mode of travel vis-à-vis the vehicular network, will likely encourage more walking. This hypothesis was investigated using a quasi-experimental approach within a rational utility behavioural framework.

The scope of this study is primarily descriptive, and assesses differing street network types for their association with individual travel behavior (and associated outcomes). It builds on the extensive literature of urban form and travel behaviour research to offer improved understanding of the nature of the relationship.

Purpose of Current Research Study

This study was prompted by the need for evidence as to likely outcomes from application of the Fused Grid. This innovation in street design attempts to find a balance between the benefits of street connectivity for transportation efficiency with the use of street space to enhance neighbourhood quality of life for local residents.

Research to describe and test the relationship between the built environment and travel behavior is needed, particularly with regard to street design. Municipalities should be aware of the potential that street network design has to assist in attaining various transportation and livability objectives. Investigating the relationship of travel behavior to various street network configurations, especially the Fused Grid design, is the goal of the present research.

Framing the Debate

A review of the planning literature reveals a long-standing debate about street design – especially about the functionality and impact of traditional gridiron street network versus loops and culs-de-sac pattern. It is apparent that differing street patterns influence travel behaviour and mode choices: whether residents choose to travel by car, bicycle, foot or other means.

A grid pattern provides more frequent street connections, with a rectilinear grain of network intersections. A dendritic pattern of curvilinear streets and loops generally has more closed streets and indirect routing, with a design that favours more green space, larger lots and privacy. A vigorous debate continues over which overall pattern provides greater benefits locally and across a given region.

However, studies to date have used measures that do not distinguish well between the functional network available to each distinct mode of travel. In particular, prior research has not been able to clarify how differences in connectivity across travel modes relates to or affects travel behaviour.

Further, it is important to understand which street network characteristics will best support the optimal achievement of *multiple* urban planning goals. Transportation networks are a hotly debated topic, as municipalities and regional governments attempt to balance resident demands for traffic control and safety with public objectives of healthy activity, compact land use patterns or better air quality, all while maintaining traffic flows.

A major concern in planning today is making urban areas and new neighborhoods more conducive to walking activity. Yet opinion is varied on how best to achieve improved walkability. In many neighbourhoods, the introduction of traffic calming is a common response, but is often a costly afterthought, with uncertain results in areas where new streets built to current standards are so wide as to induce high speeds.

The research finds that street design has been affected by available or predominant transportation technologies, development costs and economics, cultural preferences and ideologies of healthful form and safety, institutional arrangements, and most recently by concern about quality of life and the environment. Emerging evidence about environmental impacts, livability, and public health are setting the stage for new street network designs based in better understanding of travel behaviour. Past designs and retrofitting of newer streets, while part of the solution, may not provide the most satisfactory results.

One proposed answer to these challenges is the Fused Grid street network design: an interrupted or modified gridiron pattern. A need for evidence about the potential benefits of the Fused Grid, and related interventions like traffic calming, prompted this inquiry into residential street design history, methods for evaluating, and ultimately measurement and analysis of, street network configurations.

CMHC and the Fused Grid

Residential street design is one element of ensuring healthier communities by design.

The Canada Mortgage Housing Corporation works to create better community design by assisting the local governments who set standards for street construction. These practitioners, from the federal to the local level of government, are understandably interested in how various street designs might perform on key transportation dimensions such as levels of walking and vehicle miles traveled.

The CMHC is promoting study of the potential of wider adoption of the Fused Grid street pattern. This variation on the traditional pattern presents a proposed middle ground among street network types, and suggests the possibility of more optimal solutions than currently exist in most municipal street standards.

Network Routing and Connectivity

The design of individual streets, and their overall configuration in street networks influences their use by people. Some dimensions influential to mode choice and other travel behavior outcomes are: width of vehicular area (lanes), streetscape (extent and quality), access points, speed limit/design speed, surface quality, crossings/intersection design, and network type.

Over the past twenty years, a wide array of research has attempted to uncover the effects of urban form on travel behavior. The research shows the built environment is most strongly related to distance and time traveled, whereas socioeconomic factors are more strongly related to other travel behaviors (i.e. frequency of trips).

The measurable factors of the built environment are generally categorized into three main areas: residential or employment density, land use mix, and connectivity. Each of these built environment factors, often referred to as density, diversity and design, has been shown to have a significant relationship with some aspect of travel behavior. This research recognizes that these factors co-vary and so the challenge for developing evidence is to isolate connectivity from other urban design and land use factors.

The key categories of urban form measurement that affect travel behavior, and the access people are seeking to an urban area's activities, are connectivity and proximity. The focus of this research is on understanding the factor of connectivity, that is, the extent to which travel routes are linked together to form an interconnected system of routes that facilitates movement. Moreover, we are interested in the differential connectivity across modes, a characteristic of the Fused Grid street design which affords pedestrians relatively direct routing to the locally disconnected vehicle network.

The salient difference among street network types is the kind of routing that it provides, usually evaluated with a measurement of its circuitry or connectivity. Routing and connectivity strongly affect travel distance and thus the comparative costs (in time and money) of various travel mode choices.

In most studies to date, the effects of various street designs are modeled for their effects on traffic flow. This research study focuses on empirical investigation of the outcomes from varying levels and disparities of travel network connectivity and continuity in terms of walking and driving behaviour.

This study's core hypothesis is that street network designs that enhance connectivity for pedestrians relative to vehicles result in increased share of travel by walking.

Review of History and Evolution of Residential Street Design

Residential streets are a basic feature of urban communities. Streets and systems of roadways are a fundamental part of planning for development and urbanization. This critical function holds true throughout the history of urbanization.

Streets provide connection among the various locations of human activity within a given area. In modern cities, streets have evolved to provide multiple roles. A residential street design must function well for a variety of municipal objectives. Chief among these are vehicle movements (traffic flow), pedestrian and overall traffic safety, air and water quality, community health, municipal services and neighborhood impact or livability.

Over the last hundred years, specialized and hierarchical street patterns have evolved along with rapid conversion to an automobile-focused transportation system throughout North America. In general, two dominant forms have emerged in most North American cities: a grid pattern, and the cul-de-sac/loop pattern.

The rectilinear grid street network is common in many small and large North American cities. Often expanding from highly urbanized central district or along streetcar lines, the small block grid network also accommodated the prevalence of pedestrian travel, horse and buggy and early automobile use. A tight grid of proximate and connected streets provided easy access for town dwellers, commercial and social exchange. However, rapid urban growth soon revealed problems with grid networks. Poor function (congestion) and sanitation problems were evident with many pedestrians, horses and cars competing for street space. Related aesthetic, safety and social concerns soon prompted innovations in street designs, including traffic lights and street surfacing. As well, pure gridiron streets often leave little open space or remain insensitive to variations in topography or the environment.

In response, new and influential street forms emerged, often designed for new residential areas: wide, curving and discontinuous street designs that emphasized ample landscaping, park-like settings, and open-air environments – in direct contrast to crowded urban streets. This 'Garden City' ideal of wide, curving, landscaped streets with large suburban lots appeared to provide safety, security and greenspace. Such developments provided residents with large yards and privacy while being within driving distance of urban employment.

The grid pattern gradually lost favour with municipal planners and developers. Crucially, the loop and cul-de-sac street network design increases buildable area – less land devoted to streets enables more saleable lots to fit into their subdivision – and reduced infrastructure costs. Curvilinear street configurations were the preferred form of circulation for most new municipal districts; these rapidly growing cities encouraged the spread of low-density, residential-only districts.

However, the size and number of suburban developments revealed new problems, particularly as auto use grew and sprawling communities sprouted ever further from urban centres and workplace destinations. For example, a typical suburban network tends to funnel large volumes of traffic onto collectors and major streets in an effort to keep through-traffic away from residential areas. This often has the effect of isolating residential neighborhoods from potential destinations that might generate walking activity or more efficiently serve local needs.

In the 1960's, Jane Jacobs and other critics decried the monotony and single use character of suburban development. More recently, 'New Urbanist' proponents noted that vast sprawling suburbs with few or no continuous through streets and dispersed functions lead to heavy automobile dependency for residents, heavy reliance on car use for all social and commercial activities, as well as decreased pedestrian and social interaction. Others have pointed to significant impacts on social and health outcomes, related to low physical activity of suburban residents.

In summary, the impacts of street network design are an issue of scale. Conventional suburban street design does address the desires for safety and livability for local residents. But in a neighborhood and city-wide context, the results tend toward auto-dependency, heavy traffic congestion – especially on the limited number of collector streets – and externalized costs of negative health and environmental outcomes.

In response, local governments are caught between competing objectives – improving connectivity for its transportation benefits – such as providing more transportation choices like walking and cycling - but retaining closed streets for their benefits in improved safety and neighbourhood quality. Many municipal planners have concluded that the automobile-dependent designs of sparse suburban street networks are in need of retrofit and correction and new street designs are urgently needed.

The modified Fused Grid provides potential middle-ground as a means of solving these design challenges.

Review of Methods Literature

The measurement and evaluation of street networks has generally been focused on motor vehicle movement and level of service over the past century. Accessibility and mobility of pedestrians, and to a lesser degree bicyclists, have emerged as key topics of recent research. Perhaps the most significant aspect of street design to encourage more walking is the connectivity of the street both internally and to nearby destinations.

Various research has descriptively (comparing different regions or areas with distinct characteristics) and experimentally investigated the relationship of urban form to travel behavior. The evidence points to significant effects of land use density and mix as well as neighborhood design characteristics, particularly transit. These studies have argued persuasively that variation of three main factors - density of residences or employment, mix of uses, and urban design (including transportation systems) – at a regional scale does relate to differences in travel behavior. Efforts to understand the impacts of urban design at a smaller scale have also been undertaken.

This research has been challenged for a number of reasons: inadequacy of methods, i.e. not isolating one aspect of urban form from others; failure to account for residential self-selection; and other confounding factors including urban form and non-environmental variables, that can affect travel behavior. Another concern is the covariation of urban form characteristics in one location or area. For instance, higher density, mixture of uses and continuity of sidewalks occur together in many former streetcar suburbs or grid pattern neighbourhoods. There are difficulties in disentangling the effect of any one factor in influencing travel behaviour. In addition, researchers have argued that built environment variations are really just more contributors to the cost of travel, which should be regarded as the most direct influence on individuals' travel decision making.

Finally, travel survey data on non-motorized travel is very limited – systematic collection has only recently been done – and there is significant underreporting on short trips, most of which are by non-motorized modes. Very localized data on the built environment is expensive and hard to collect and thus generally unavailable.

Behavioral Framework/Theory & Pedestrian Travel

The most robust model for explaining travel behavior is a rational choice framework that posits travel demand derived from the need to get to and from activities and decisions affected primarily by costs (in time and money). The rational choice framework, and related microeconomic theory of travel demand, form the basic theoretical framework for this research.

Walking activity in particular has been shown to be influenced consistently by distance to destinations and the quality of the built environment. Distance, then, becomes a main cost in this analysis. Walkability has been summarized in indices that attempt to capture the key dimensions of density, diversity and design. These factors attempt to encompass the whole of urban form, but the interest of this study is the effects of street configuration. In order to capture streets affects on travel behavior, this study must address some of the existing gaps in methods for measuring street networks.

Selection of Method and Scale for Current Study

After decades of research about the effects of the transportation system on travel behavior, and which if any interventions will support desirable transportation outcomes contributing to overall quality of life, appropriate solutions are still being sought.

The relationship between various aspects of urban form, and more specifically street networks, and those travel outcomes is poorly understood or has undergone limited empirical investigation. Most research of street networks has not distinguished between motorized and non-motorized modes, though the networks for different modes may have varying degrees of connectivity.

The other influential urban form variables and design features should be accounted and controlled for. This study picks up where others leave off, in attempting to answer the question of how the greater connectivity of a modified version of the pure gridiron street network will function for transportation.

The present study considers configuration of residential street network as a factor that shapes travel behavior. Because the unit of analysis is household travel behavior, the appropriate scale of study is the sub-neighborhood level – urban form characteristics in the immediate vicinity of residences.

The characterizing of street networks is a difficult task, but recent work provides systematic analysis for categorizing types of street patterns. The concept of street network connectivity in this present study encompasses dimensions that have been described as connectivity and continuity.

For these measurements of street configuration, the study uses two complementary metrics: route directness and network density. It measures these values on each mode for the street network adjacent to the travel survey households, and then compares each mode directly, using a ratio to express relative connectivity and continuity. By including consideration and separate measures of the distinct networks available to distinct modes, the research can more effectively assess the effects on mode choice and travel behavior more broadly.

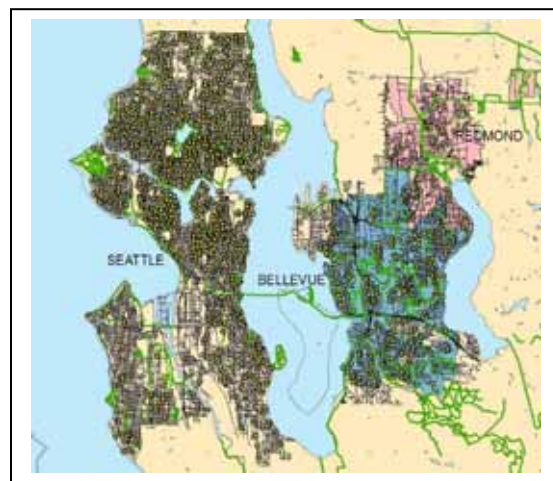
The Fused Grid Assessment – Overview

The report conveys results of analysis of street patterns in relation to travel and of the assessment of the Fused Grid street pattern. The research followed a process of conducting descriptive statistics followed by exploration of relationships among personal, urban form and travel variables using correlation and regression statistics. The main areas of interest in this research concern the influences of street network pattern on walking and driving travel behaviour.

Analytical results were sought to gather information relevant to testing an hypothesis that more direct pedestrian routing (relative to vehicular routing) results in higher walking mode share (increase in % of trips by pedestrian mode) and less automobile use (lower vehicle miles of travel, or VMT). The descriptive assessment reveals possible relationships between urban form and travel behaviour.

Research Study Area

This report presents a detailed research assessment– framed around detailed descriptive and regression analysis – from three neighbourhood areas in Seattle area in Washington State. The Seattle, Washington metropolitan region was chosen as the area for conducting research because of extensive available urban form and travel behavior data. The cities of Bellevue (83 km²), Redmond (41 km²) and Seattle (216 km²), encompass a land area of 340 square kilometers.



These three cities feature neighborhood street patterns that contain a range of connectivity and continuity types. Topographical conditions and intentional transportation facility designs or

retrofits in these three cities create the sort of street pattern that modifies standard types and exhibits characteristics of the Fused Grid in various parts of the study region – added pedestrian connections or restrictions for one mode or the other create disparities between the utility of the network for driving and walking.

This contrast of street connectivity is essential to the process of testing the research hypothesis. The variation in street design in the study area, though having limited actual disparity between modes' network connectivities across the region, runs from traditional gridiron to conventional post-World War II dendritic patterns ending in culs-de-sacs.

The City of Seattle and its suburbs were largely constructed within the past century, limiting variability in street design during its development, but more recent retrofits with traffic calming, pathway development, and other modifications have resulted in patterns that seek to overcome the flaws in the original street construction.

Study Summary and Findings

This review discusses relevant methods for analyzing the Fused Grid and other street network configurations. In studies to date, the main gap has been measuring connectivity across different modes of travel among various urban forms and street networks.

In the present study, types of street network connectivity are quantified, then combined with others, and matched to individual travel behavior in a GIS, and statistically analyzed. The results provide assessment of the likely performance of the Fused Grid street design on several travel outcomes of interest to urban transportation and community planning.

The assessment begins to answer the question of whether new designs and street standards, in addition to the retrofit programs of traffic calming, will result in the desired outcomes of increased levels of walking and decreased reliance on automobiles. The current study concludes that there is significant relationship between the urban form of local street networks and travel behaviour, and that modifications to street patterns are associated with changes in levels of walking and driving for local travel.

Key findings

This study examines two main measures: relative route directness and relative network density across walking and driving modes. Both measures have associations with odds of walking, odds of driving, distance walked, distance traveled by vehicle, and number of trips.

This study's primary findings demonstrate that relative route directness is associated with increased levels of walking and decreased driving. As well, relative network density – a higher density of walking pathways than driveable streets – generates even greater increase in walking and reduction of driving.

This finding implies that street designs which improve the directness of routes for pedestrians, relative to those enjoyed by other modes in the network, are associated with more walking. The Fused Grid street design provides a transportation network pattern that achieves a change in relative utility of walking. Certain traffic calming measures would achieve similar results.

The study's correlation and regression analysis indicate that network density measure exhibits a stronger relationship to the travel behaviour. This suggests that more pathways increases pedestrian trips, regardless of how well footpaths may connect to specific destinations. Street patterns with direct connections are associated with more walking activity, but are somewhat less influential (smaller correlation coefficient) than the relative density of walking facilities, or that of the presence of nearby retail stores in a neighbourhood.

Importantly, these two street network factors – the ratio of route directness and ratio of network density – are additive in their effects. That is, designs that create improvement on both measures will generate even larger benefits on travel outcomes. The Fused Grid street design is characterized by a higher density of pedestrian pathways than vehicle pathways. Other factors in urban form and demographics held constant, this kind of street network would be associated with more walking and less driving.

For this study region (three Seattle neighbourhoods), the regression model demonstrated that a change from a pure small-block grid to a modified grid (i.e. Fused Grid) can result in an increase in odds of a home-based trip being walked by 11.3%. The modified street pattern like a Fused Grid is also associated with a 25.9% increase, over street patterns with equivalent route directness for walking and driving, in the odds a person will meet the recommended level of physical activity through walking in their local travel. The same 10% increase in relative pedestrian continuity (network density) associates with a 9.5% increase in odds of walking, all other factors remaining the same.

Finally, the Fused Grid's 10% increase in relative connectivity for pedestrians is associated with a 23% decrease in vehicles miles of local travel, and the improved continuity is associated with increases in both number of walking trips and total distance walked for local travel.

Community planning and design implications

Both traffic calming and street design standards that offer increased directness of routing for pedestrians relative to motor vehicles can be used to help achieve increased levels of walking, reduced motor vehicle use, or both.

Increasing the extent of sidewalk or other pedestrian pathways, by adding them as stand-alone projects or including a higher density of them relative to street length in plans for new neighbourhoods, is likely to be useful in achieving the same walkability outcomes.

These changes to travel network patterns are also associated with walking a sufficient amount to have a healthy level of physical activity.

These kinds of measures will be particularly effective when they result in both reduction in the connectivity of the motor vehicle network (i.e. street closures or other interruptions in the network for motorized vehicles) relative to the walking network and increase the pedestrian network's extent relative to the vehicular network.

Further Study and Caveats

The research final report will summarize and discuss the results concerning the central hypothesis that the Fused Grid network type encourages more walking mode share while reducing motor vehicle travel demand. A continuum of street network connectivity types, and the likely travel behaviour of changing connectivity along this gradient, will be discussed.

Future research should build on this effort to measure separate modes' networks as a means of improving the understanding of the relationship between urban form and travel behaviour. The distinct utility provided to separate modes of travel by the built environment appears to be a key factor in mode choice and other behaviours.

Though the Seattle metropolitan region offers a good range of street types that correspond to the patterns in many North American urban areas, other regions, perhaps with different eras of urban form, could be measured and analyzed using these same techniques. This, and matching current urban form with new travel and quality of life outcome variables (perceived safety, feelings of neighborhood attachment, etc.) can provide a richer understanding of the influence of residential street design and make these results more generalizable.

There are some caveats or limitations in this research. The study is cross-sectional and involves correlation and regression, which can describe and contribute to understanding certain aspects of the relationship between built environment and travel behaviour, but cannot be used as a basis for asserting causation between these factors and travel.

The results can be useful for predicting some likely responses in behaviour and associated outcomes (air pollutants, etc.), but not specifying exact outcomes, from changes in urban form (street network design). The results likewise should be considered an indication about the specific geographic area of study, and caution should be exercised in generalizing from them.

A longitudinal study would be needed to investigate causal questions, and as noted above further research would be necessary to establish a more generalizable theory for these relationships.

Overview & Purpose

This report assesses the Fused Grid by investigating residential street network design and its relationships with local travel patterns and transportation outcomes. Specifically, this study examines how the configuration of street networks (e.g., gridiron or loop/culs-de-sac) is linked to travel behavior outcomes, such as number of local trips taken and mode share. Due to trends across North America in vehicle miles traveled and physical inactivity, planners and policymakers want to understand which aspects of urban form have the most influence on travel behavior and mode choice. If travel behaviour is associated with street design, what kind of street pattern is most likely to produce outcomes that reduce reliance on automobile transportation and increase active mobility like walking?

The current study evaluated how contrasting levels of street network connectivity afforded by different modes impacts travel choice. The Fused Grid increases connectivity and route directness for non-motorized relative to vehicular travel. As demonstrated in Figure 1, the connectivity of the roadway network is a primary factor in shaping travel distance. By separating out the relative levels of connectivity across modes of travel it is possible to address underlying theoretical dimensions and the mechanisms by which the Fused Grid might impact behavior. From a micro-economic compensatory modeling framework, the Fused Grid increases the relative utility of walking over driving and should therefore increase the probability of choosing a walk trip. Subsequent components of this study will lay out a research design to assess the relative benefits of the Fused Grid followed with results from the execution of this approach.



Figure 1 – Route Distance and Network Design

In order to isolate the impact of connectivity across modes of travel, it is necessary to hold constant other demographic and urban form factors that also impact travel behavior, including the level of land use mix and residential density. In future studies it will also be important to separate out the impact of neighborhood selection and street network design on behavior and environmental and health related outcomes. Proposed solutions such as the Fused Grid residential street design offer considerable potential to address adverse environmental and health related outcomes of disconnected culs-de-sac network designs while retaining some of their transportation benefits.

Framing the Debate

The notion that street design affects how people travel is intuitively obvious - that is, one would expect a finer-grained street pattern to encourage more walk trips due to improved accessibility, and a wide range of research has tested and concluded that there is indeed an empirical association. However, studies to date have used measures that do not distinguish well between the functional network available to each distinct mode of travel. In particular, prior research has not been able to clarify how differences in connectivity across travel modes relates to or affects travel behaviour. These are critical questions. Without evidence on which to base changes to street design standards, convention may continue to hold sway despite less certain outcomes or problematic impacts to livability and environmental quality. Proposed solutions, such as the Fused Grid residential street design, should be based on objective analysis to discover whether and to what extent street network design matters to transportation system performance and travel behaviour at the neighbourhood scale.

Further, it is important to understand which residential street network characteristics will best support the optimal achievement of *multiple* urban planning goals. Transportation networks are a hotly debated topic, as municipalities and regional governments attempt to balance resident demands for traffic control and safety with public objectives of healthy activity, compact land use patterns or better air quality, all while maintaining traffic flows. A prevalent concern in planning is making urban areas and new neighborhoods more conducive to walking activity for its community benefits. Opinion is varied on how best to achieve improved walkability.

The challenge to improve walkability is considerable. Streets in many neighbourhoods, particularly those with both loops/culs-de-sac and gridiron streets, are built to current standards are so wide as to induce high speeds. As a result, many of these neighbourhoods install traffic calming or related measures to slow down traffic – a costly afterthought for municipalities. Suburban street networks also tend to funnel large volumes of traffic onto collectors and major streets in an effort to keep through-traffic away from residential areas. The unintended result is the isolation of residential neighborhoods from potential *destinations* that might generate walking activity.

Organization of this report

This quasi-experimental study will not only describe how travel behavior (total vehicle and pedestrian distance traveled, mode choice, and number of trips) is affected by street network design but will also seek to explain the strength of the relationship and set the stage for further analysis, which would allow the testing of a variety of other outcomes likely to result from particular street designs.

This report begins with a discussion of the historical context and a literature review of the analytical methods (Part I - Task 1 summary). Part II discusses the development of a methodological framework and the necessary data to conduct the analysis (Part II - Task 2 and 3 summaries). The report continues with a descriptive assessment (Part III – Task 4) and summary of results from analysis using inferential statistics. (Part IV. – Task 5). It concludes with discussion and recommendations (Part V. – Task 5).

Part I. Introduction and Literature Review

1.0 Introduction

Residential streets are basic features of urban communities built in the past century. These local street networks have been designed and built mainly by the private developers in accordance with local government standards for new development. The standards arise from a history of street design in which more specialized and hierarchical street patterns have evolved, driven in the last hundred years by rapid conversion to an automobile-focused transportation system throughout North America. Increasing awareness of the impacts to the environment and quality of life from automobile dependence (Newman & Kenworthy, 1989) has led to proposed design interventions. Key recommendations or studies in this effort to tame traffic, however, have either

- 1) reinforced some of the street network characteristics that contribute to auto-dependence, or
- 2) fallen back, without solid evidence, on past urban forms.

In recent years local communities and municipalities have been searching for street configurations that will provide optimal community health and solutions to increasing traffic impacts or diminished walkability, but durable solutions have proven difficult to identify and implement.

The Fused Grid street network design is a proposed answer to these challenges. It prompts this inquiry into the history of residential street design and methods for evaluating street network configurations. The research finds that street design has been affected by available or predominant transportation technologies, cultural preferences and ideologies of healthful form and safety, institutional arrangements.

More recently, concerns about quality of life and the environment are high on the public agenda. Emerging evidence about environmental impacts, livability, and public health have set the stage for new street network designs based in better understanding of travel behaviour. Past designs and retrofitting of newer streets, while part of the solution, may not provide the most satisfactory results.

1.1 Context: Streets, Residential Street History, and the Built Environment

Streets and systems of roadways are a fundamental part of planning for development and urbanization. This has been true since the earliest urban settlements in human history, and these transportation networks have increasing importance in the present, hyper-mobile urban areas of North America. Since they provide critical functions of access and circulation for human settlements, streets constitute the bulk of public land in urban areas, as much as 1/4 to 1/3 of all land. Streets provide connection among the various locations of human activity within a given area.

As part of the public domain, streets are governed more directly and managed more easily by public agencies than other land; therefore, streets are features of the built environment where interventions that assist in the achievement of public goals, especially those related to access, mobility and public health, are more readily and immediately implemented by these agencies.

How streets, and their overall configuration in street networks, are designed influences their use by people. Some dimensions influential to mode choice and other travel behavior outcomes are: width of vehicular area (lanes), streetscape (extent and quality), access points, speed limit/design speed, surface quality, crossings/intersection design, and network type (Ewing, 1996; Metro Regional Services, 1997; Burden, 1999). For example, a wider street with more lanes of traffic provides greater capacity for vehicular movement yet poorer accessibility and safety for pedestrians. Beyond travel, streets can serve a variety of other public purposes described further below. They are central features not only to travel function but urban quality of life in a broader sense.

The key categories of urban form measurement that affect travel behavior, and the access people are seeking to an urban area's activities, are connectivity and proximity (Frank, 2000; Frumkin, Frank & Jackson, 2004). Connectivity, alongside other street design features, is considered to be the main transportation design element of the built environment's influence on travel behavior. It is also a main characteristic distinguishing different types of street network. Proximity, how close destinations are from the point of departure (called an 'origin' in transportation planning) is the other key environmental dimension affecting travel behavior but derives more from land use attributes of density and mix (or diversity) of uses (Cervero & Kockelman, 1997).

This research recognizes that these factors co-vary. A fine-grained street network with high connectivity is hypothesized to increase walking activity and yet it also usually occurs where density is highest, meaning high proximity to activities. The challenge, then, is to isolate connectivity from other urban design and land use factors. Greater access can be achieved through either means, high mobility through a connected network, or high proximity through more density and mixing of uses. The former means of improving access is difficult, not to mention highly resource-intensive, to implement for all modes at once.

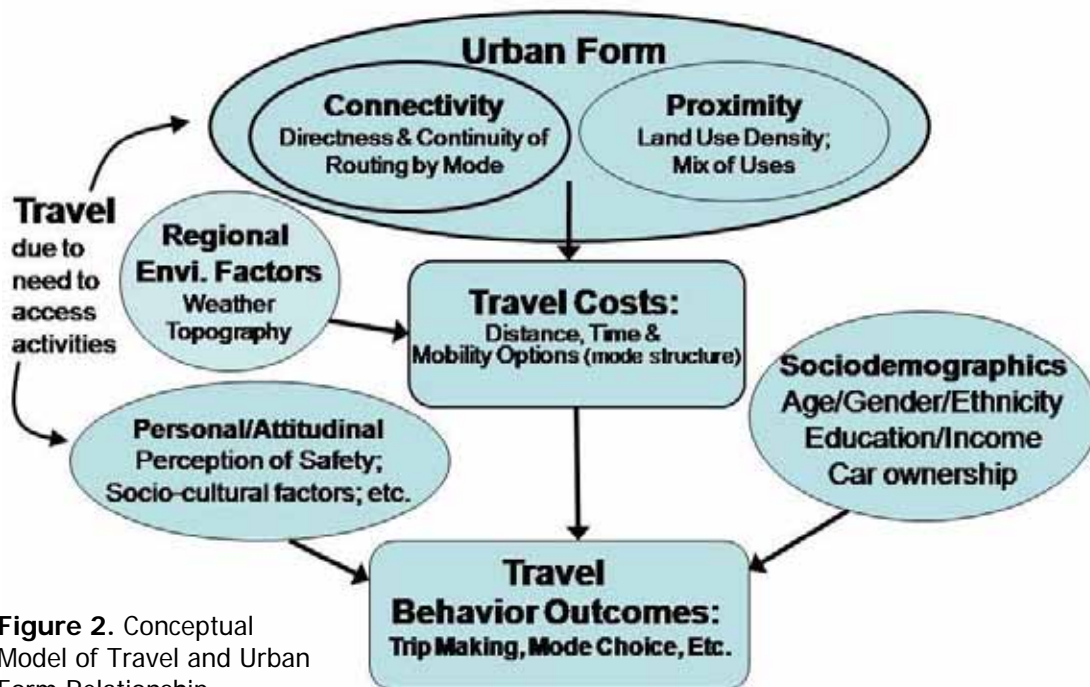


Figure 2. Conceptual Model of Travel and Urban Form Relationship

People can notice this influence when moving from place to place in an urban setting. Some routes are available, others are not, based on the arrangement of objects (buildings) and spaces (parks, plazas, and streets). Some activities are easy to reach on foot because they are close by. Others may require a different mode of travel because they are distant.

The focus of this research is on understanding the factor of connectivity: the extent to which travel routes are linked together to form an interconnected system of routes that facilitates movement. Moreover, we are interested in the differential connectivity across modes, a characteristic of the Fused Grid street design.

Over the past twenty years, a wide array of research has attempted to uncover the effects of urban form on travel behavior (Frank & Pivo, 1994; Friedman, Gordon & Peers, 1994; Moudon, Hess, Snyder & Stanilov, 1997; Holtzclaw, Dittmar, Goldstein & Hass, 2002; Frank & Engelke, 2001). Various reviews have summarized the findings of these studies and defined a research agenda (Cervero & Kockelman, 1997; Boarnet & Crane, 2001; Ewing & Cervero, 2001; Frank & Engelke, 2001; Dannenberg, Jackson, Frumkin, Schieber, Pratt, Kochtitsky & Tilson, 2003).

Studies have shown the built environment is most strongly related to distance and time traveled. Socioeconomic factors are more strongly related to other travel behaviors (i.e. frequency of trips). Both sets of factors show some relationship to people's choice of travel mode (Frumkin, Frank & Jackson, 2004). These factors are summarized here in a conceptual model (Figure 2).

The measurable factors of the built environment are generally categorized into three main areas: residential or employment density, land use mix, and connectivity. Each of these built environment factors, often referred to as density, diversity and design, has been shown to have a significant relationship with some aspect of travel behavior.

Most recently, researchers have begun to try to unravel the complex warp and weft of urban street fabric. Studies have supported New Urbanist principles, contended that there is not enough evidence to recommend one street pattern over another, or that these principles overlook key preferences associated with conventional suburban form (and in the case of streets, the cul-de-sac).

1.2 Limitations of Current Studies

Most recently, researchers have begun to try to unravel the complex set of factors comprising the pedestrian environment on travel behavior. To date there are only a handful of studies that actually capture and measure the presence or absence of sidewalks and other street furnishings that impact the ability or desirability to walk (LUTRAQ 1999; Brownson et al. 2003). It would logically follow that the presence of basic facilities such as sidewalk or even informal pathways will result in an increase in the amount of walking.

Another area of concern is the inability to separate out the effects of neighborhood preferences from built environmental influences on travel and physical activity levels. To date, nearly all studies are cross sectional and leave out the ability to determine a cause – effect relationship between built environment characteristics and travel related outcomes (Bagley & Mohktarian 2002). The much-publicized joint report of the Transportation Research Board and the Institute

of Medicine in the U.S. reviewed dozens of studies and confirmed that there is insufficient evidence to claim a causal link between the built environment and behavioral outcomes (TRB / IOM Report 282 2005). The report does acknowledge the presence of a strong association between factors such as street network design and travel choice. Subsequent research over the past year has begun to show that even after controlling for preference the built environment still plays a role in shaping behavior (Handy & Cao, 2006; Frank et al. 2006).

Following is a summary of review of the methods and scientific literature on analyzing the relationship between street networks and travel behavior. These reviews constitute the necessary background (**Task 1**) for further investigation of the transportation performance of various street network types and the Fused Grid in particular.

2.0 Historical Review: Urban Transportation and Residential Street Design

2.1 Evolution of Residential Street Design

Though street networks, and the gridiron in particular, have been built since the first cities were constructed (Grammenos & Pollard, 2005), residential streets are a more recent and now ubiquitous phenomenon in urban transportation planning. This history, then, focuses on the past century and a half of changes in urban street networks.

The history of metropolitan transportation development in the North America runs through a series of distinctive eras (Muller 1995), each powerfully shaped by the emerging transportation technologies characteristic of the era: walking/horsecar (up to 1890), streetcar (1890-1920), automobile (1920-1945), and freeway (since 1945). The rectilinear grid street network prevailed in urban areas throughout the streetcar era as people's primary transport mode continued to be pedestrian. Longer-distance transit, such as streetcars, still depended on good pedestrian access and facilities.

The spreading use of automobiles began to reshape urban areas in the first two decades of the twentieth century, prompting some obvious changes to the physical design of streets – the accelerated improvement of road surfaces, the addition of traffic lights and eventually the removal of streetcar tracks (Weiss 1988).

2.2 New Designs for Healthy Neighborhoods – Garden Cities & the Curvilinear Street

Even before these technological transformations, various street design innovations were proposed, with both aesthetic and social reform goals in mind. In fact, the appearance of urban streets as crowded and dark, and often associated with ill-health, unsafe or dangerous conditions. These perceptions often derived from the narrowness of streets, the presence of buildings at the edge of the roadway, the mixing of various often incompatible uses (like factories) (Southworth & Ben-Joseph, 1997; Frank et al., 2003). Adding to this perception was the emergence of poor function (congestion) and sanitation problems created by multiple modes of travel now competing for street space, including prevalent horse-drawn vehicles (Jacobs, 1961).

Early residential street plans by Olmstead and Vaux responded to this challenge with wide, curving and discontinuous street designs that included ample landscaping to make the street a

park-like setting of fresh air and open space, complementing larger house lots with private yards. The emphasis in the emerging land use planning and street design fields on a suburban ideal of ample “land, light, and air” provided by residential development (Robinson, 1916) coincided with increasing mobility in the form of motorized transportation.

Automobile use became increasingly prevalent during the first quarter of the 20th century. It began to supplant walking as the most basic form of transport in the middle decades. Higher volumes and speeds of vehicular traffic began to expose the weaknesses of the grid at the neighborhood scale. At a larger urban scale, the new challenge of managing traffic, regardless of local street configuration, emerged.

Table 1. Problems of Gridded Streets (from Southworth & Ben-Joseph, 1997; Kulash, 2001; Grammenos et al., 2005)

<p>A. Contributes to dispersion of vehicular travel to all streets, even for pass-through travel purposes, and hence increased traffic impacts on neighbourhoods, including:</p> <ul style="list-style-type: none"> • Pollutant emissions due to higher automobile volumes in close proximity to residences • Exposure to safety risks to children at play and pedestrians from increased volume of traffic possible on all streets
<p>B. Frequent four-way intersections also increase traffic impacts:</p> <ul style="list-style-type: none"> • Congestion, and associated increase in air pollutant emissions from frequent stops and starts, (especially as traffic volumes increase) • Exposure to safety risk for both motorists and pedestrians due to complexity of turning movements
<p>C. Monotony: if unaccompanied by design requirements, gridiron networks can be uninteresting in their regularity and discouraging to pedestrians</p>

The problems of the gridiron stem from several factors: easy traffic through-movements (and attendant impacts) in all areas; frequent, multi-conflict intersections; and its monotonous form (Southworth & Ben-Joseph, 1997; Grammenos et al., 2005). While largely unsubstantiated with empirical evidence, some of the perceived drawbacks of the grid are summarized in the table below (see Table 1). Thus, the move toward curvilinear, discontinuous street patterns was further encouraged.

A main response by municipalities was to develop standards for street construction that initially ensured a more orderly, regular appearance to the street environment (e.g. Bye-law streets, see Southworth & Ben-Joseph, 1997). Public policies, transportation technology (automobiles), and to a degree, cultural preferences, encouraged the spread of low-density, residential-only districts (Kunstler, 1993; Duany et al., 2000). These trends pushed street design in the direction of Olmstead, Vaux and the successor Garden City suburban models of residential street design. As well, existing grid networks were modified to allow more freely flowing motorized traffic (one-way restrictions, etc.).

Clarence Perry’s concept of neighborhood units comes from this historical period, partly the result of an effort to reduce the impacts of grime, noise and sound from traffic. Another goal was to build an integral community that would be safer and more private in character. Curvilinear

street configurations were the preferred form of circulation for districts that would have no continuous through streets, thereby (it was thought) avoiding the grid's pernicious effects on neighborhood quality of life (Grammenos et al., 2005).

Influential concepts emanated from proponents of suburban form, particularly Clarence Stein and Henry Wright with their design for Radburn, NJ (1929). Frank Lloyd Wright's "broad-acre city" and Le Corbusier's vision of the future of urban form made their way into the lexicon that we now call suburbia and sprawl. These designs were highly marketable to Americans seeking houses with large yards and privacy while being within driving distance of urban employment.

For developers, adopting the loop and cul-de-sac street network design had a crucial benefit: the design significantly increased buildable area – less land devoted to streets enables more saleable lots to fit into their subdivision – and reduces their infrastructure costs. The Radburn suburban street network, with its culs-de-sac and curving streets, provided the template for the street networks of most residential developments in the following half century, though usually only in pieces of the whole design concept by any given development – the 'superblock,' complete separation of pedestrians from traffic, or, least often, the large tracts of open space (Girling & Helphand, 1994).

2.3 More Traffic, More Traffic Impacts, and Street Standards – The Freeway Era

The years following World War II unleashed a huge demand for new housing. This was met in the United States by continued government support of suburban development in sprawling areas around the edges of existing development (Frumkin et al. 2004). The federal funding of the Interstate Highway system beginning in the 1950s accelerated the process.

Since that period, the housing boom has slowed somewhat, but the economic incentive of cheap land to develop at the fringes of metropolitan areas has remained largely in effect as have conventional suburban designs. Policies at all levels of government have aimed to serve supposed public expectations of particular housing types, and meeting projected steady increases in vehicle usage. The replication of subdivision street standards also date from the early years of the Freeway Era. During this period of time auto travel increased as walking and biking decreased. Figure 3 conveys reduction in pedestrian and bike travel associated with age of development – a proxy for trends in travel occurring over time.

As new development occurs currently in urbanizing areas, municipal governments require construction (or contribution towards it) of streets according to adopted standards. These street standards specify the dimensions noted above and result in the form that streets and street networks take (Chellman 1999; Kulash 2001).

Street standards have evolved over time to meet changing demands for transportation system function. The streets required by standards generally shifted from highly connected to disconnected, and from non-hierarchical to hierarchical, and in residential districts from rectilinear to curvilinear. In the past one hundred years, block sizes have increased in response to a shift toward increasing use of higher speed vehicles. (Southworth & Ben-Joseph 1997; Marshall 2005).



Figure 3. Eras of neighbourhood and levels of non-motorized trips

Responding to increasing automobile use, trends in subdivision design moved in the direction of privacy, security and child safety (Southworth & Owens 1993). These changes, in a positive feedback loop with land use and housing policy, have generally tended to create relatively greater ease of automobile travel while eroding that of non-motorized travel and transit.

Conventional suburban street networks' lack of connectivity, in single-use zones, combined with heavy vehicular traffic on frequent collector streets, make them inhospitable to walking. Problems with typical suburban street forms began to surface within the first generation of their predominant use, and are shown below as they relate to loop and culs-de-sac streets. (see Table 2)

Table 2. Problems with Loop and Culs-de-Sac Streets (Kulash, 1991; Duany et al., 2000; Grammenos et al. 2005)

<p>A. Contributing to route indirectness:</p> <ul style="list-style-type: none"> • Pedestrian routes are elongated due to dendritic (sparse) street pattern • Fewer choices of route for motorists
<p>B. Increase in bicycle/pedestrian personal safety risk:</p> <ul style="list-style-type: none"> • Pedestrian pathways, if kept separate from streets in an effort to improve their directness, have reduced natural surveillance • Separate pathways frequently result in mixing of bicycle-pedestrian modes without appropriate design treatments, creating conflicts and higher likelihood of collision (especially when paths meet or cross a roadway)
<p>C. Curvilinear streets are disorienting, and thus discouraging to walking activity</p>
<p>D. Disconnected local access streets focus traffic onto larger classification streets closer to residences:</p> <ul style="list-style-type: none"> • Diminished accessibility for pedestrians (larger streets to cross with higher volumes of traffic) closer to home and often between home and shopping or other destinations. • More difficult left turns for motorists due to infrequency of intersections, larger collector streets, and higher traffic volumes on limited number of major streets (sparse network)

2.4 Community Uprisings – Traffic Taming

Challenges to Orthodox Street Planning

At the time of Jane Jacobs' classic work (1961), various citizen movements reasserted the importance of various local street features to the livability of neighborhoods. The primary concern was about traffic volumes and the wholesale reconfiguration of urban neighborhoods to accommodate roadway widening and preferred alignments for highways and arterial streets. Jacobs articulated the principles of urban vitality (exchange fostered by urban characteristics of density, mixing of uses, and ample pedestrian-oriented pathways) that could counteract the "erosion of the city."

The street environment figured prominently in this analysis, and Jacobs described streets based on her experience of residing in a dense urban fabric that provided for many more uses than vehicular movement. To this way of thinking, how public spaces (and sidewalks and streets in particular) are designed is responsible for improved safety and either encouragement or discouragement of human activity. This is the classic urbanist message.

But multiplicity of choice and intensive city trading depend also on immense concentrations of people, and on intricate minglings of uses and complex interweaving of paths. – Jane Jacobs, The Death and Life of Great American Cities

If streets are laid out in large blocks and with wide lanes to provide more vehicle capacity, then vehicles become the chief mode of movement. Conversely, if many uses are proximate to each other along streets with ample space for casual contact and interaction as well as frequent crossings, this facilitates more visual contact, pedestrian activity, and successful city development. Variants of Jacobs' 'eyes on the street' observation of sidewalk safety were elaborated in later research (Newman 1972) indicating that streets provide natural surveillance and pointing out the problems with 'superblocks' (large development sites without streets connecting into or through them) from a public safety standpoint. Crime prevention through environmental design (CPTED) has become a major principle in cities' urban design objectives. Lastly, Jacobs' prescient analysis anticipated the advent of traffic calming as she discussed the means of accomplishing the attrition of cars by cities.

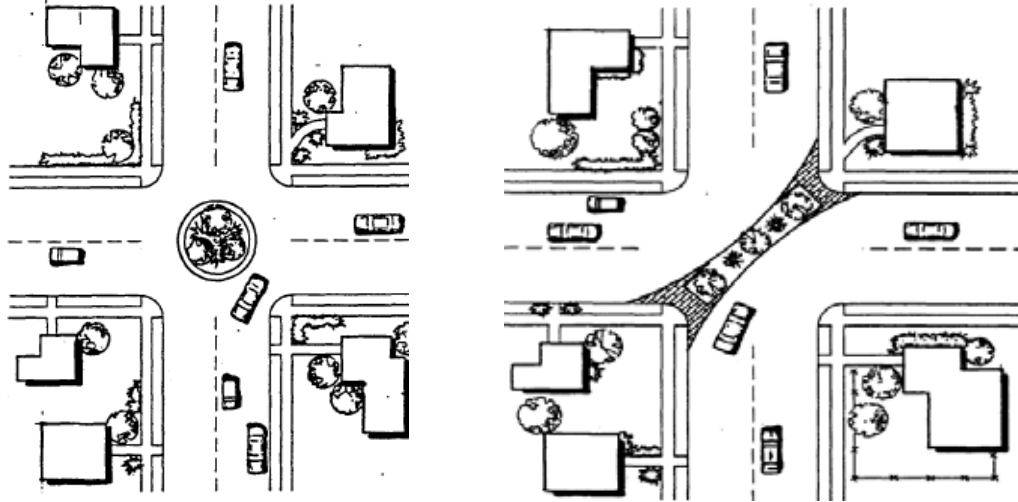
Concurrent with these overarching shifts in ideas, and later the process, of good street design, citizens, communities and neighborhoods have reacted to the ills of automobile-dominated transportation systems. Calls for increased traffic management, in the form of traffic calming, or full closure of streets, have occurred in neighborhoods of many types, beginning during the middle decades of the 20th Century in major metropolitan areas such as London or the San Francisco Bay area (Appleyard 1981).

Traffic calming and management

Some features of traffic calming known to work are street closures and diverters, which create interruptions in the street network thus blocking or redirecting through-traffic. These achieve the aims of reducing traffic speeds and volumes in the area where it is applied, and is similar to the assumed affects of the Fused Grid and other selectively closed street networks on traffic. Appleyard's research focused on how neighbors interacted along various sizes of streets (primarily in terms of volume but also speeds). He found the size of street to be inversely related to the number of interactions that occurred among residents.

Newman likewise found personal safety enhanced by grid street networks closed to through traffic (see “Private Streets” in Newman 1996). This provided evidence to suggest that if neighbourliness is a goal for urban development, designs and interventions may be needed which curtail either traffic speed or volume, or both, on local residential streets.

Figure 4. Traffic Calming Devices (Source: City of Boulder, NTMP Toolkit)



This livability finding, coupled with the traffic safety research linking collision severity (in terms of injuries and deaths) with vehicle speeds (Daisa & Peers, 1997), has led to more widespread use of traffic calming around North America in the last few decades. Such measures are often applied over whole neighborhoods or districts in an effort to manage the potential problem of traffic diversion onto adjacent streets.

Another issue with calmed street design is the potential to delay emergency response or obstruct other service/utility vehicles. These public safety and service considerations have limited the extent to which residential streets can be narrowed or have devices or parking placed on them (Burden 1999, 2000). Nevertheless, traffic calming has become an increasingly standard practice across the United States as various neighbourhoods seek to prevent the impacts of motorized traffic (Ewing, 1999). Other street design dimensions can be altered, for instance narrowing drivers' field of vision with curving alignments or vertical streetscape elements to enclose the roadway (Dumbaugh 2005) and creating interruptions in the street network ('T' intersections or closure/diverter treatments) without significantly impeding emergency response or other services requiring large vehicle movements.

Public Health, Livability Goals and Street Design

Subsequent research (Moudon et al., 1987) and public policy (ISTEA, 1991; Kulash, 2001) has continued to assert the varied uses of streets and public goals of how streets are designed. As noted above, urban form and streets in particular have evolved in response to changing transportation technology; other research (Jackson, 1985; Goddard, 1994; Frank et al., 2003) has pointed to the importance of shifts in social thought and public policy in redirecting

infrastructure investment and thereby favoring the development of particular environments and associated travel patterns.

Through most of the 20th Century, as we have seen, North American public policy favored automobile-oriented development. Over the past four decades concern for social justice and increased attention to protection of the natural environment, alongside new understandings from public health which emphasize the benefits of walking in the home neighbourhood, have prompted changes in policy and planning, some of which have implications for street design.

An outpouring of interest and research related to environmental impacts of transportation and sprawling land use patterns occurred during the late 1980s and continued throughout the 1990s to the present. The relationship between the built environment and physical health of the human population has been the target of investigation in the past ten years as an epidemic of obesity continued its spread across North America (see Frank et al., 2003; Frumkin et al., 2004; Sallis et al., 2004).

The preponderant evidence from these studies suggests that urban form influences people's travel behavior, the amount of pollutant emissions from transportation sources, and people's levels of physical activity. In addition, better understanding of non-point-source water pollution, especially stormwater runoff from streets and paved surfaces, has created a strong focus on urban form in water quality management (Arnold & Gibbons 1996; Girling & Kellet 2005). These notions of physical and environmental health are related to other behavioral responses to public space, including streets, which have been studied in sociological and urban design literature – people may have better mental health, and build more social capital, in environments conducive to face-to-face interaction and walking (Whyte 1972; Gehl 1980; Frumkin et al. 2004). Earlier notions of the influence of built environment, from Jacobs through Gehl, have been confirmed, but also to some extent confounded, through statistical scientific inquiries and methods that will be discussed in the literature review that follows.

2.5 Contemporary Responses and Barriers – Searching for Optimal Street Patterns

The Freeway Era has gone through multiple stages, and the evolution and maturation of suburban bedroom communities as uniform sociospatial clusters into cities in their own right (an urban form that has come to be known as 'edge cities' after Garreau, 1991) is a significant new phenomenon (Muller, 1995). These mature suburban centers consist of a variety of services and employment locating near highway interchanges and thus within easier reach of what had been residential-only developments. Such infill shows the long-term tendency of modern suburbs towards denser, mixed-use centers.

Moreover, it indicates, in an period of diminishing infrastructure budgets, unstable energy supplies, and rising fuel prices, the need for solutions that redesign these emerging centers in ways that balance their transportation systems with enhanced travel choices and reduced automobile dependence (Randall, 2002). The improved understanding of urban form, together with municipalities' objectives of providing multiple travel choices to achieve optimal transportation service, compels a search for better designs of streets and networks of them.

Cost Inefficiency

Because traffic calming interventions are typically done as retrofits to existing streets, they may be more expensive means of achieving the livable neighborhood and multiple-use, multi-modal residential street goals. A more cost-effective approach would seem to be designing streets well so that they perform as intended (keeping traffic slow and moderate in volume) from the moment they are opened for use.

It is important to note that traffic calming is often necessary only because streets have been built the wrong way to begin with, unnecessarily wide and with too much distance between intersections. Duany et al., Suburban Nation

Many municipalities are therefore turning to revisions of streets standards to accomplish the same effect as traffic calming. By adopting residential street standards for narrower widths, allowance of on-street parking on both sides of the street, and creating visual or physical friction (using landscaping areas and curb extensions), they are attempting to achieve new streets that are calm by design.

Residential developers in turn, look for designs that allow flexibility and maximization of buildable area, seeking to avoid as much as possible the costly infrastructure of streets. Narrow streets would seem to be attractive then, as would disconnected designs. There are, however, practical limits as to how narrow and how disconnected a street network can be while still providing the desired level of access to a wide array of users.

Compatibility with Neighborhood Livability

Tradeoffs in different approaches to the transportation network, how streets are arranged or relate to each other and how connected the system is, arise when designing streets to provide livability and balanced travel options. For example, culs-de-sac designs often leave residual open space that is poorly programmed into the neighborhood and therefore relatively underused by residents (Duany et al., 2000; Girling & Helphand, 1994), whereas pure gridiron streets often leave little open space or remain insensitive to variations in topography or the environment more broadly (Southworth & Ben-Joseph, 2004). Further, from a transportation and land use planning perspective, the effects of the local network on travel patterns at the city and regional scales are issues on par with livability within neighborhoods.

Resistance to adoption

Under current street standards for new development, communities continue to have disputes about various dimensions of streets, including the extent to which the street network should be connected (Handy et al., 2003) and how much traffic should be diffused through neighborhoods versus channeled onto major streets (Olympia, 2005). Into the 1990s the focus of urban design and planning had been on revitalizing the urban centers and protecting older neighborhoods from traffic impacts. Such planning efforts are important, yet the predominant growth of metropolitan areas, in population and employment, has been on the edges, either as the maturation of former edges (noted above) occurs or as land is converted from rural uses to suburban ones.

The solutions proposed often ignore the particular needs of edge communities. There is wide and continued use of street patterns that allow the maximum number of buildable lots: loop and culs-de-sac street networks (Southworth & Owen 1993). These are designs whose results are seemingly well-known and therefore more acceptable to local governments. The challenge is, in part, an issue of scale. The conventional suburban street design does address the desire for safety

and livability for individual residents. But in a larger neighborhood and city-wide context, there are concerns about auto-dependency and growing traffic congestion, especially along the limited number of busy collector streets common in these areas.

2.6 Street Design Debate - New Urbanist Walkable Grids vs. Neighbourly Culs-de-Sac

In debates about design and planning of urban form, recent attention has been focused on street networks as a key feature of livable neighborhoods and the achievement of more sustainable land use and balanced transportation systems (defined as a better range of mode choice and more even mode split). The contention of New Urbanists (Calthorpe, 1993; Duany et al., 2000) is that use of a gridiron street network is the basis for achieving the needed access and legibility to encourage and support pedestrian travel. There is some acknowledgement that the grid should be interrupted (Ewing, 1994).

Opposing this response to the street design problem is the notion that loop and culs-de-sac street patterns of the past half century have been responsible for significant benefits: quieter, safer neighborhoods. These factors derive from restrictions on vehicular access that funnel most traffic away from neighborhoods onto major streets which bound them (Southworth & Ben-Joseph, 1997).

This debate has continued in recent articles (Southworth & Ben-Joseph, 2004; Grammenos & Pidgeon, 2004) as a fusion of gridiron and loop and culs-de-sac street networks, the Fused Grid design (Grammenos et al., 2005), has been proposed to retain the benefits of both street patterns while mitigating their obvious defects.

This Fused Grid proposal marks the starting point for this research to develop an empirical basis for describing and analyzing the travel behavior effects of street network design. This project aims to provide insights into the likely transportation and associated quality of life outcomes of implementing designs that provide a high degree of connectivity for non-motorized travel modes and relatively disconnected neighborhood routes for motor vehicles.

The prescriptions of New Urbanists for areas like new towns, infill development, and edge cities are one attempt at correcting the problem of street networks that do not support a maturing suburb with a settled population. These areas increasingly demand more travel choices than driving the car and more livability than sprawling development along major roads. Traffic calming and street re-designs like the Fused Grid may be used as interventions to improve quality of life for these maturing suburbs or as a way to revive older suburbs or even inner city districts with gridiron street networks. New development can be guided by street standards that offer a more full range of travel choices and improved opportunities for healthy living through active recreation. What has been lacking is not only empirical evidence to back up design prescriptions but also clarity about the problem and its structure being addressed (Marshall 2005).

3.0 Methods Literature Review

3.1 Overview

The goal of this assessment is to provide improved understanding of the influence that street networks have on travel behavior. A central, persistent question of planners and officials grappling with how to best plan and guide development, especially when considering new design proposals, is will the traffic work? What are the implications for transportation system function? Because the subject of this assessment is a residential street network design, we are interested in how a neighborhood's street network design affects the travel patterns of its residents. How does people's travel, measured in miles traveled, number of trips taken, and modes chosen, differ among neighborhoods with different street network types? The salient distinguishing dimension among street network types is the kind of routing that it provides, usually evaluated with a measurement of its circuitry or connectivity, because this affects travel distance and thus the comparative costs of various travel mode choices.

To date, the research on travel behavior and urban form has not isolated the influence of variation in street network connectivity across different travel modes, yet this is a critical feature of new neighborhood design proposals and of related efforts such as traffic calming. These techniques, as noted in the previous section, aim to reduce motor vehicle impacts while enhancing and encouraging walking or other non-motorized transportation. Often research projects have not utilized the econometric frameworks that are the basis of travel demand modeling. The scope of this study is primarily descriptive but will also assess differing street network types for their association with individual travel behavior (and associated outcomes). It builds on the extensive literature of urban form and travel behaviour research to offer improved understanding of the nature of the relationship.

3.2 Literature on urban form and travel behavior: assessing street networks

The measurement and evaluation of street networks has generally been focused on motor vehicle movement and level of service over the past century. The main concern in the consideration that has been given to non-motorized transportation in North America during this time has been how to keep these travel modes safe by separating them from motor vehicles, a bias stemming from such works as Buchanan's Traffic in Towns (cited in Marshall 2005). Accessibility and mobility of pedestrians, and to a lesser degree bicyclists, have emerged as key topics of recent research, prompted by the foregoing history and debate. Perhaps the most significant aspect of street design that affects the re-balancing of transportation systems to encourage more walking is the connectivity of the street both internally and to nearby destinations. This section will review current knowledge on the urban-form travel behavior before outlining the research on the connectivity dimension relevant to this assessment.

Travel Behavior Affected by Urban Form

Various research has descriptively (comparing different regions or other large areas that have distinct characteristics – Newman & Kenworthy, 1989; Friedman et al., 1994) and experimentally (among the first being Handy, 1993; Holtzclaw, 1994; Frank & Pivo, 1994) investigated the relationship of urban form to travel behavior. The evidence points to significant

effects of land use density and mix as well as neighborhood design characteristics, particularly transit (Cervero & Kockelman, 1997) or pedestrian access (Holtzclaw, 1994). These studies – typically conducted at broad spatial scales such as a metropolitan region – have argued persuasively that three main factors do relate to differences in travel behavior. The three main variable factors are: density of residences or employment, mix of uses, and urban design (including transportation system configuration).

Efforts to understand the impacts of urban design at a smaller scale have also been undertaken. Some research has pointed to the importance of distinguishing between different travel purposes (work vs. non-work) and different spatial scales of trip-making (local vs. regional) (Handy, 1993; Rajamani et al., 2003), and has also recognized the importance of site design (Moudon et al., 1997). Several studies have tried to distinguish which urban form covariates of travel behaviour matter most (Cervero & Duncan, 2007; Frank et al., 2006; Saelens et al., 2003; Lee & Moudon, 2003).

Urban Form – Travel Behavior Link Challenged

These findings have come under scrutiny because of their policy implications for land use and urban design. This is part of a larger debate about the claims of New Urbanism including the claim that its recommended practices will result in reduced automobile travel demand. The criticisms have ranged from inadequacy of methods, i.e. not isolating one aspect of urban form from others to know where intervention is warranted (Crane & Crepeau, 1998), to poor methodological robustness, i.e., lack of an adequate explanatory theoretical framework (Boarnet & Crane, 2001). These studies point out the multiple confounding factors, including urban form and non-environmental variables, that can affect travel behavior and result in various prescriptions potentially having the opposite of intended outcomes for travel (Crane, 1996).

For instance, requiring new street connections that improve route directness or constructing a new street network as a gridiron could benefit (i.e. improve access for) automobile travel as much as it does pedestrian activity. This would result in no change of behavior and may even enable more vehicle trips. Another criticism leveled at urban form-travel behavior research is that it fails to account for residential self-selection (i.e., a person choosing to live where they can travel most easily in their preferred manner), another plausible explanation of relationship between urban form and travel (Krizek, 2003).

Disentangling Influential Factors of Urban Form

A number of urban form characteristics vary together as location changes. Many of the characteristics thought to be more supportive of non-motorized activity or transit use occur together in space. For example, in a former streetcar suburb the density is higher than in a newer neighborhood, but so is the mix of uses and continuity of sidewalks. Such spatial covariation (Frank et al., 2003) confounds easy conclusions about any one built environment variable of interest because the same travel behavior in a given area may be due to any number of several contributing environmental factors. One variable may be masking another that is a stronger correlate with travel outcomes. Some of the researchers noted above have pointed out that the built environment variations are really just more contributors to the cost of travel, which should be regarded as the most direct influence on individuals' travel decision making.

Finally, while travel surveys have been in use for decades and the practice is well-established for collecting travel activity information, data on non-motorized travel have only been systematically collected more recently. There are problems of underreporting on short trips, which are more likely to be traveled by non-motorized modes (Frank & Engelke, 2001). The difficulty and expense of collecting very localized data on the built environment leads it being generally unavailable – another complication in attempting this research. Thus, efforts to understand the relationship between urban form and travel behavior have produced significant, though inconsistent (Crane, 2000), results and continue to face major methodological challenges.

3.3 Framework, Methods and Data to Address Challenges

Behavioral Framework/Theory & Pedestrian Travel

As noted above, a framework or theory that has ample explanatory power in relation to travel activity is needed in order to interpret results from built environment - travel behavior analysis. The most robust model for explaining travel behavior is a rational choice framework (Boarnet & Crane, 2001) that posits travel demand derived from the need to get to and from activities and decisions affected primarily by costs (in time and money). In this model, these costs, or the travel impedance, are theorized to determine the extent of travel, and, as the individual weighs the relative utility of different ways to travel by comparing their costs, his or her choice of travel mode.

The rational choice framework, as the basis for standard traffic modeling, is the most widely used means of explaining and predicting travel behavior for transportation and land use planning. It will form the basic theoretical framework for this research, thus addressing this challenge.

Walking activity in particular has been shown to be influenced consistently by distance to destinations and the quality of the built environment (Moudon et al., 1997). Distance, then, becomes a main cost in this analysis. Walkability has been summarized in indices that attempt to capture the key dimensions of density, diversity and design. These factors attempt to encompass the whole of urban form, but the interest of this study is the effects of street configuration, and in order to capture streets affects on travel behavior, this study must address some of the existing gaps in methods for measuring street networks.

Gaps in Measuring the Urban Form – Street Networks

There are three primary areas that have been used to characterize urban form: density, mix of uses, and design. The urban form measure for this assessment is in the design realm, specifically transportation system design, and this analysis must be able to distinguish among street networks to provide a spectrum of possible network types which can then be tested and compared. The chosen method should build from the experience of a number of studies that have attempted to assess the influence of street networks (Cervero & Kockelman, 1997; Frank et al., 2000; Pushkar et al., 2000, noted in Ewing & Cervero, 2001). The other influential urban form variables and design features should be accounted and controlled for.

Despite decades of concern about the effects of the transportation system on travel behavior, and which if any interventions will support desirable transportation outcomes contributing to overall quality of life, appropriate solutions are still being sought. The relationship between various

aspects of urban form, and more specifically street networks, and those travel outcomes is poorly understood or has undergone limited empirical investigation (Ewing & Cervero, 2001).

Furthermore most research that has included consideration of street networks has not distinguished between motorized and non-motorized modes, though the networks for different modes may have varying degrees of connectivity (Handy et al., 2003; Dill, 2004). Frank et al. (2000) found that street network has a significant effect distinct from other land use variables on vehicle miles traveled and thus air pollutant emissions, but did not focus on street networks' influence alone on such travel behavior elements as mode choice. Later research using a slightly different measure (intersection density) found that the street network alone did not have a significant influence on walking activity (Frank et al., 2005), whereas another study (Frank et al., 2006) found stronger evidence of its influence.

This study picks up where others leave off, in attempting to answer the question of how the greater connectivity of a modified version of the pure gridiron street network will function for transportation. The particular urban form characteristic under consideration as the factor that shapes travel behavior is the configuration of a residential street network. Because the unit of analysis is household travel behavior, the appropriate scale of study is the sub-neighborhood level – urban form characteristics in the immediate vicinity of residences. Additional research could be needed to build on this work and answer questions of how residential street networks might influence behavior at different (regional versus local) spatial scales or to model transportation system function as a whole.

Methods for Measuring Street Configurations

Street network connectivity has been measured in a number of ways in the past two decades of urban form-travel behavior research. In studies that included a factor for street network characteristics, the following measures have been used:

- *Number of street intersections, dead-ends or 4-way intersections* (Cervero, 1994; Ewing, 1996b). These are all early proxies for street network connectivity, used primarily in indicating whether pedestrians can easily reach transit stops or stations.
- *Block size, block density* (Frank et al., 2000) measures capture the spatial relationships, or topology, of streets to buildings, and are again proxies for network connectivity.
- *Intersection density* (Frank et al. 2005; Schlossberg & Brown, 2004). More recently this measure has come into use for its ease of computation, and has been as a component of walkability indices.
- *Route directness* (Gauthier 1999; Dill 2004). Non-motorized modes of travel (bicycling and walking) are highly sensitive to distance, and thus a most appropriate way to measure the built environment vis-à-vis pedestrian movement is route directness. This measure takes into account the continuity of the routes because route directness is a measure of distance to travel, not the more abstracted ratios or sizes of space as in other measures.
- *Space syntax modeling methods* (Hillier et al., 1993; Penn et al., 1998) are coming to the fore of methods to estimate pedestrian volumes and route choice on various travel networks, and are rooted in algorithms of route directness. These methods show how

transportation networks co-determine, along with the activity patterns that they influence, the overall shape of urban space.

- *Various network indices* (Dill, 2004; Tresridder, 2005; Schlossberg, 2006). The most recent research on bicycle and pedestrian networks has sought to measure streets using connectivity indices borrowed from geographic analysis or to introduce some degree of distinct measurement for the mode being analyzed (pedestrian catchment or effective walking areas)

While the first three sets of measures give an indication of the ‘grain’ of the street network, they fall more into a class of variables that could be termed indicators. Each of these measures, while offering quick assessments of connectivity, are too coarse in their discernment of connectivity to capture differences in system function across modes *unless each mode’s network is measured separately*. Because they are street or block based, they may in fact miss much of the network that is available to pedestrians (Yi & Zhang, 2006).

Space syntax, an extension of route directness measurement, is powerful for predicting pedestrian volumes and associated phenomena (Raford & Ragland, 2005); however, this study of travel networks required a simple measurement of network connectivity across different modes rather than a means of predicting pedestrians volumes.

Route directness can be complemented with an area measure of facility extents (network density), in order to gauge both connectivity and continuity. If conducted for each mode’s available infrastructure, this second network measurement, similar to a network service area measurement such as effective walking area, allows the research to achieve a more nuanced measurement of the disparities of travel networks offered to each mode by different street configurations.

Another measure, coming into wider use by local governments, is the link-to-node ratio, which like intersection density is focused just on the network itself and is an abstract measure that offers an indication of the number of dead-end segments (an increase of which makes the ratio lower, indicating poorer performance). This can be effective for use in assessing motor vehicle connectivity, but again this method is not able to capture cross-modal connectivity well particularly since distance along routes is not specified and this can be the most critical dimension for non-motorized activity. Various other indices have been developed, including a Pedestrian Environment Factor. While these are more complete and nuanced measures for assessing walkability, they are difficult to integrate into a regression model such as is proposed for use in this research.

Vehicles, because they are not as sensitive to distance, may be more influenced by the continuity of routing than by distance per se. The key for this analysis is to distinguish between each network’s connectivity by mode, in order to show how the different patterns established will create differences in the relative utility of the different travel modes.

The characterizing of street networks is a difficult task. Recent work (Marshall, 2005) provides very systematic analysis for categorizing types of street patterns. The concept of street network

connectivity in this present study encompasses dimensions that Marshall describes as connectivity and continuity. In order for a street network to be considered connected, routes through it must be continuous.

By using the measure of route directness, this assessment is able to include both connectivity and continuity in the measure of street networks as urban form. Further, by including consideration and separate measures of the distinct networks available to distinct modes, the research can more effectively assess the effects on mode choice and travel behavior more broadly.

Statistical Analysis: Using quasi-experimental methods

A growing volume of research has been using descriptive and inferential statistical methods (Handy 1993; Frank & Pivo 1995; Cervero & Kockelman, 1997; Frank et al. 2000; Rajamani et al. 2003) to characterize and assess urban form - travel behavior relationships. These methods allow the isolation of urban form variables of interest from those other environmental factors and from demographic characteristics, provided that there is sufficient data available about these other factors. Strength of hypothetical relationships between urban form and travel behavior, though not direction of influence, can be tested using case-control quasi-experimental methods (Frank et al., 2003).

These methods have the advantage of using existing data sources such as travel surveys conducted by urban transportation planning programs. Longitudinal methods, involving a cohort of people who move to a newly built Fused Grid neighborhood, could be used to study causal relationships in street design and travel behavior. However, this would require gathering extensive new data over a long time period, making it infeasible to produce results in a timely manner. Establishing correlation and statistical strength of relationships between urban form and travel will produce results from which further inferences can be made as to the likely effects of particular street network configurations. Care must be taken in specifying variables and processing them in order to get valid analytical results. See Part II. for further details on this methodology.

Data for Travel Behaviour Analysis

The use of data from travel diaries, self-reported by individuals, offers the best opportunity to capture the actual travel behavior of individuals in various residential locations. Neighborhood scale spatial information is crucial for distinguishing among different residential street patterns. Using the neighborhood-scale analysis frame will allow very localized measurement of urban form variables and the eventual linking of individual's reported travel behavior in their local walking range and within what are the normal aggregated zones of analysis in transport planning. This helps to overcome the errors that stem from variation of street networks within zones and the edge effects from an adjacent zone on some nearby households (Frank & Engelke, 2001). The use of data within the same region allows research to avoid possible geographic variations of travel behavior among regions. Further detail on this aspect of the research is provided in the next part of the report.

Other Dimensions of Street Networks

There are several other aspects of street network design that may be influential to how people travel and make other activity choices. This study does not investigate all of these directly but

instead views them as correlates of connectivity. As the degree of connectedness increases, more activity occurs and natural surveillance, the perceived and actual safety of the environment (Newman, 1972), would be expected to increase. If, as hypothesized, vehicular travel is moderated by the street network, higher connectivity for this mode would result in greater impact to public space/neighborliness (Appleyard, 1981). By contrast, lower vehicular connectivity would reduce driving levels and concomitant impacts.

Marshall (2005) identifies a number of different dimensions of street networks in helping to unpack the problem of understanding how street networks function and how they can best be designed. Legibility, how easily one discerns routes in the pattern of street connections, may be an important qualitative factor of the built environment. Transportation networks co-determine, along with the activity patterns that they influence, the overall shape of urban space. While we will not use space syntax modeling methods directly (Hillier et al., 1993; Penn et al., 1998), their implications underscore the importance of understanding the influence of street networks in urban activity patterns and including travel. These analysts have suggested that controlling urban design alone, especially the configuration of street networks and their width, can be used to better manage interactions among modes of travel in urban environments and lead to more suitable overall urban form.

Finally, real or perceived safety risk can have a strong effect on behavior. While studies have linked safety risk to speed of vehicles, and speed of vehicles to widths of roadways, and then related these concerns to different intersection types, the investigation of street network effects on safety has not yet occurred. This study will not delve into the safety question except to acknowledge that it deserves further research, in particular on the question of separated versus conjoint networks.

4.0 Conclusion

Research to describe and test the relationship between the built environment and travel behavior is needed, particularly with regard to street design. Municipalities should be aware of the potential that street network design has to assist in attaining various transportation and livability objectives. Investigating the relationship of travel behavior to various street network configurations, especially the Fused Grid design, is the goal of the present research. This review has discussed relevant methods for analyzing the Fused Grid and other street network configurations. Measuring connectivity across different modes of travel is the main gap in capturing the urban form of street networks. Once quantified, this urban form characteristic can then be combined with others, matched to individual travel behavior in a GIS, and statistically analyzed. Finally, results will provide assessment of the likely performance of the Fused Grid street design on several travel outcomes of interest to urban transportation and community planning.

A residential street design, in order to gain acceptance and come into use, must be proven to work for a variety of municipal objectives. Chief among these are vehicle movements (traffic flow), pedestrian and overall traffic safety, air and water quality, community health, municipal services, and neighborhood impact or livability. In light of their health and environmental outcomes, the automobile dependent designs of sparse street networks are in need of retrofit and

correction and new street designs are urgently needed. Yet the traditional grid has its own problems. Local governments are caught between competing objectives – improving connectivity for its transportation benefits but retaining closed streets for their benefits in improved safety and neighbourhood quality.

The Fused Grid design, an interrupted or modified gridiron pattern, offers a proposed middle ground among street network types, and suggests the possibility of more optimal solutions than currently exist in most municipal street standards. The methods by which the Fused Grid can be assessed will be developed from the findings of this review.

PART II Method Framework/Data Development

1.0 Introduction – Methods for Analyzing Travel in Relation to Street Design

This assessment of the Fused Grid street network design seeks to understand the travel implications of street patterns using a quasi-experimental approach situated within an activity-based, rational choice framework (Boarnet & Crane 2001). The research statistically relates travel activity to urban form measured, using GIS, around each location (household) self-reporting the travel in a two-day survey. Such methods have been used increasingly in recent years to develop better understandings of the interaction between urban form and travel behaviour and other outcomes.

This methodological framework considers travel to be a derived demand; that is, people's travel is driven by their desire or need to access a variety of activities in the urban area around them.

This approach is consistent with standard transportation planning. Trip origins and destinations are identified and then travel costs (in terms of money and time) are assessed on various routes and across various modes in order to model travel behaviour (e.g. number of trips, distance traveled, mode choice). People make decisions and act on the basis of routes and travel options that offer the greatest utility – lowest costs and highest benefits – while accessing desired activities.

The present study's method framework and data development are summarized in this section.

2.0 Testing the relationship - street networks & travel

The empirical approach of spatially matching and statistically relating the measured built environment to reported travel behaviour is the analytical method used here. Because of the interest in understanding street networks, this project focuses on isolating the effects of street connectivity and continuity as explanatory factors in travel activity.

To date, empirical analysis of travel outcomes has not contrasted the levels of connectivity for the distinct modal networks of walking and driving.

In previous analyses of urban form's influence on travel behaviour, streets have been treated as single networks and their patterns measured using a variety of coarser methods.

This research attempts to disaggregate the network patterns for distinct modes, measure them, and then compute ratio between the separate networks to reveal congruency or disparity. A disparity in connectivity that favors walking over driving is precisely the quality that distinguishes the Fused Grid from many other network designs. Traffic calming retrofits to existing neighbourhood streets may also lead to similar results.

This relationship of street design to travel behaviour is both a theoretical question and one with practical significance. For the purposes of this study, streets are considered to be a bundle of

largely overlapping yet distinct modal networks, or separate systems of interconnecting lines in a GIS file.

2.1 Units of Analysis

The unit of analysis is individual trip-making behaviour by persons in the households located within the study area. It is analyzed in an effort to identify likely outcomes from street configuration in terms of total trip length (distance walked or vehicle miles traveled) and frequency (number of trips) as well as mode choice (or share of travel by walking or driving modes).

Urban form characteristics are measured at the parcel level, using a GIS to relate these characteristics spatially (features within walking distance buffers -1km on the street network) to the exact locations of the households participating in the travel survey.

2.2 Sampling

The research first identified travel survey households within the cities for which good pedestrian network data was available. The three cities that constituted the study area are Bellevue, Redmond and Seattle, Washington.

2.3 Data Sources

The primary data source used in this study is the 1999 Travel and Activity Survey conducted by Puget Sound Regional Council (PSRC), August to November 1999. This is the same dataset as that used in previous urban form travel behaviour research, as noted in Frank et al. 2006, under the Land Use, Transportation, Air Quality, and Health (LUTAQH) and WSDOT (2005) studies in the Seattle, Washington region. The survey process included a two-day travel diary completed by individuals and a pre-diary questionnaire about household characteristics. This data thus provides information at the level of trips, individuals and households on their travel mode used, start and end time of the trip and the activity, origin and destination locations and individual and household socio-demographic information.

3.0 Analysis Process

The goal of the analysis phase is to generate a refined understanding of the relationship of street network design (connectivity) with patterns of travel behaviour. An approach involving descriptive and inferential statistics to explore associations or accomplish investigation of hypotheses has yielded significant results in previous research of travel behaviour-urban form.

PART III. Descriptive Analysis

1.0 Introduction

This section of the report conveys results of the first phase of analysis of street patterns in relation to travel and of the assessment of the Fused Grid street pattern. The research followed a process of conducting descriptive statistics followed by exploration of relationships among personal, urban form and travel variables using correlation and regression statistics. The main areas of interest in this research concern the influences of street network pattern on walking and driving travel behaviour. Analytical results were sought to gather information relevant to testing an hypothesis that more direct pedestrian routing (relative to vehicular routing) results in higher walking mode share (increase in % of trips by pedestrian mode) and less automobile use (lower vehicle miles of travel, or VMT). The descriptive assessment reveals possible relationships between urban form and travel behaviour.

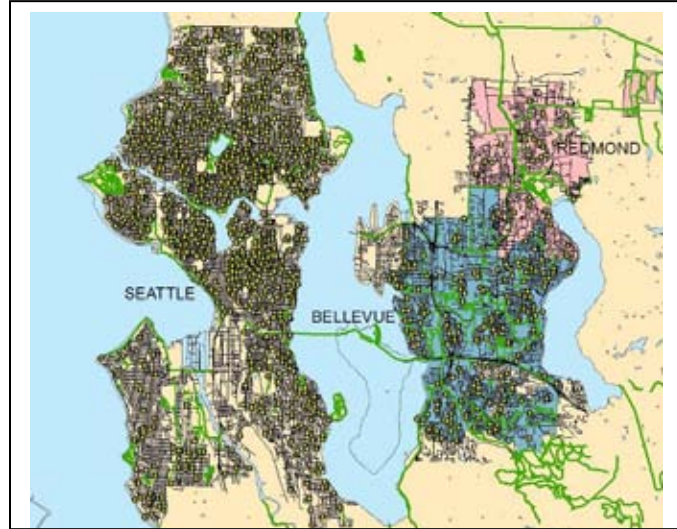


Figure 5. Study Area – Seattle, Bellevue, Redmond

2.0 Area/Regional Characteristics

Location

The Seattle, Washington metropolitan region shown in Figure 12 was chosen as the area for conducting this research because of extensive available urban form and travel behavior data. The cities of Bellevue (83 km²), Redmond (41 km²) and Seattle (216 km²), encompass a land area of 340 square kilometers. The geography and climate are similar across the study area, with steep slopes occurring near the extensive shorelines (lake and Puget Sound), several hills interspersed across the urban area, and waterways creating both links and barriers.

Transportation Networks

The street networks in these cities include over 3800 kilometers of roadway network (segments, not total lane length) with a roughly 85% as much length of sidewalks, multi-use trails and other walking pathways. Seattle has a much greater extent of transportation network and, though much larger in area, a much greater network density than its neighbouring cities for both streets and walking facilities (see Figures 13, 14 and 15). Topographical conditions and, less frequently, intentional transportation facility designs or retrofits of existing street networks create the sort of street pattern that modifies standard types and exhibits characteristics of the Fused Grid in various parts of the study region.

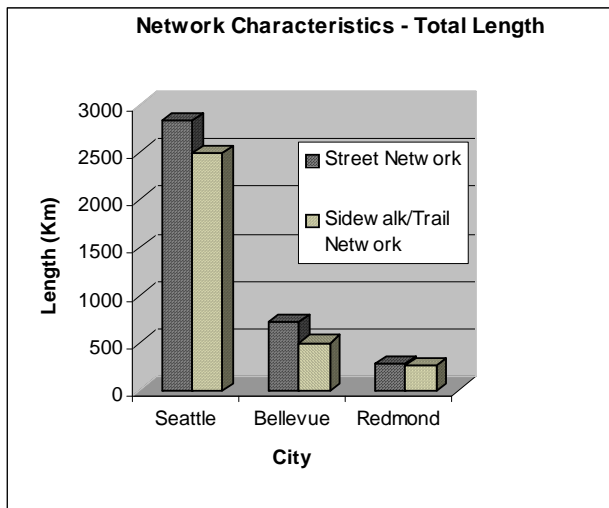


Figure 6. Measured Travel Networks - Length

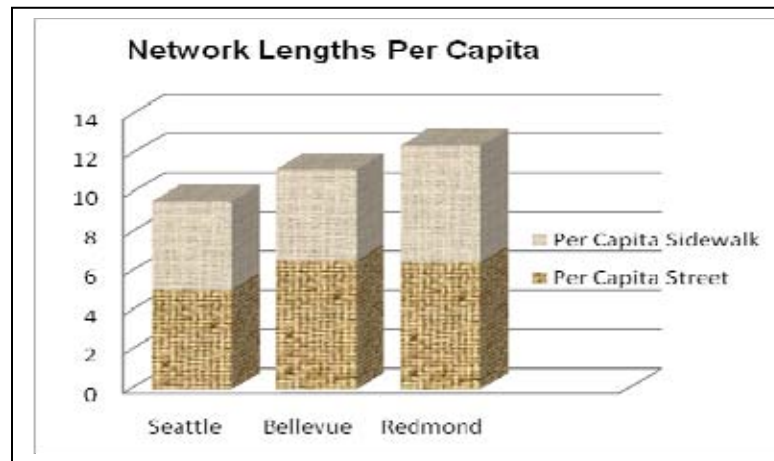


Figure 7. Measured Travel Networks Length in Km per capita

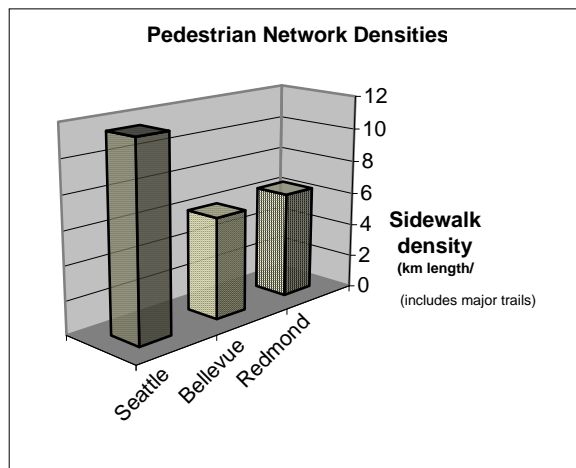


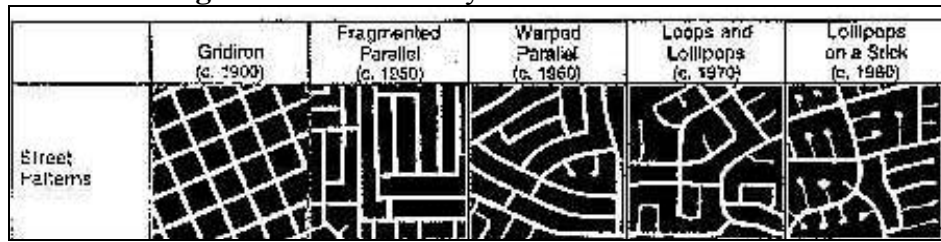
Figure 8. Measured Street Networks – Network Density

Figures 9 and 10. *Capital Hill Modified Gridiron and Pedestrian Connection* – approximating the Fused Grid



In other locations (south and east Bellevue), the street network was built to a loop and cul-de-sac standard, providing people walking with very indirect routes to neighborhood destinations.

Figure 11. 20th Century Street Network Patterns



From Southworth & Ben-Joseph, 1997

This contrast of street connectivity is essential to the process of testing the research hypothesis. The variation in street design in the study area, though having limited actual disparity between modes' network connectivities across the region, runs from traditional gridiron to conventional post-World War II dendritic patterns ending in culs-de-sac (see Figure 17). The City of Seattle and its suburbs were largely constructed within the past century, limiting variability in street design during its development, but more recent retrofits with traffic calming, pathway development, and other modifications have resulted in patterns that seek to overcome the flaws, e.g. of resulting high traffic volumes or speeds in neighbourhoods, of various standards, or lack thereof, by which street networks were originally built.

3.0 Sample Characteristics

Demographics & Household Characteristics –

The set of data on personal demographics and household characteristics used for this project was drawn from Puget Sound Regional Council's Travel and Activity Survey of 1999. The Travel and Activity Survey was designed to generate a representative sample of persons and households across the Central Puget Sound region and within its subregions. The descriptive statistics relating to this population are listed in the Tables 6 and 7 below.

Households

There were a total of 1504 PSRC survey households in the three city study area. Of these, approximately 1400 have valid connectivity measurements of the buffer areas around the household.

Table 3. Descriptive Statistics – Households, final sample.

		Total vehicles in household	Household size
N	Valid	1402	1402
	Missing	0	0
Mean		1.70	2.70
Median		2.00	3.00
Std. Deviation		.795	1.206
Range		4	4
Minimum		0	1
Maximum		4	5

Table 4. Categorical Household Variable: Income.

		Freq.	Pct.
Valid	11 = < \$10,000	30	2.1
	12 = \$10,000-14999	23	1.6
	13 = \$15,000- 24999	81	5.8
	14= \$25,000- 34,999	100	7.1
	15 = \$35,000- 44999	153	10.9
	16 = \$45,000- 54999	177	12.6
	17 = \$55,000- 74999	323	23.0
	18 = \$75,000 or more	348	24.8
	Total	1235	88.1
Missing	System	167	11.9
Total		1420	1402

Persons

These households included 3080 persons, consisting of a wide range of ages and ethnicities. 1787 of the individuals reported local, non-work travel or activity during the travel survey.

Travel Behaviour

Trips and Tours

The households within the study area took a total of over 24,000 trips, with a total distance traveled of 113,000 miles. Of these trips, approximately 60 percent were part of non-work-related tours, but only about half that number could be described as home-based (occurring within the neighbourhood around the household) and less than 7850 miles was traveled within a walkable area (trips \leq 2.5 miles or 4 km).

The trips for local travel (any tour with all trips within in it being less than 2.5 miles (or 4km) in length, one way of selecting only the travel occurring in the home neighbourhood) numbered 7851. This trip tally amounts to nearly a third (32%) of all trips reported.

Walking

Of the 3080 persons in the study area, 754 (17%) reported some walking during the course of their 2 day travel diary, a total of 2794 trips, while only 125 (4%) reported sufficient walking distance (\geq 1.4 miles per day, or 2.25 km) to be considered moderately active.¹ 597 of these persons (37%) took at least one walk trip, all told walking 1066 miles and 2324 trips.

A smaller valid sample of people (n = 1387) reported travel of a kind potentially influenced by their home neighborhood (i.e. at least one of their tours of travel did not include any trips longer than a walking distance, 4 km (2.5 miles). This sample was used to analyze the association of variables in the inferential phase of the study. The sample also accounted for kinds of travel where car mode choice was still a likely option (i.e. trip distance \geq 0.1 mile) and removed outliers (\geq 3 standard deviations from the mean).

¹ Recommendations for chronic disease prevention relating to obesity and diabetes generally specify at least 30 minutes per day of moderate physical activity like walking. This would translate into approximately a 1 - 1.5 mile walk.

Table 5. Descriptive Statistics – Persons’ Travel Behaviour – Distances traveled by mode.

Person-level Travel Distances	Walk	Drive	Total
N	1387	1387	1387
Mean	.5108	3.7674	4.2782
Median	.0000	3.0300	3.7000
Std. Deviation	1.17505	3.61622	3.53979
Range	11.11	31.21	31.21
Minimum	.00	.00	.00
Maximum	11.11	31.21	31.21

Driving

In contrast, 63.4% of persons reported driving during the same 2-day survey. The vehicle miles of travel averaged 39.03 to work and 26.20 for non-work trips. Driving made up close to 80% of all trips reported and a slightly lower proportion of local, home-based trips.

The descriptive statistics reported in each of the tables that follow are at the person level

4.0 Descriptive Measurement and Typology of Street Networks and Urban Form

Describing the urban form focus of this study, street or travel network connectivity across pedestrian and vehicular modes of travel, is a necessary basis for the later correlation and regression analysis. A description of the dataset follows on the key variables that have been used to measure street patterns and their connectivity.

Intersection density

The number of intersections per square kilometer, or intersection density, was used as a measure of street connectivity in the LUTAQH analysis of urban form in Central Puget Sound. It was generated from GIS analysis of street networks. This variable was grouped by the current study according to intersection classes drawn from Southworth & Ben-Joseph (1997). A pattern emerges in visual inspection of the data in GIS and analysis in the literature on street networks. The gridiron street network type corresponds with the median of this study’s sample (median 71.43 intersection density; mean 73.95; Std. Dev. 27.10). Thus the sample includes large proportion of all neighborhood streets networks that would be characterized as medium to high density classes in the Southworth & Ben-Joseph classification.

Southworth and Ben-Joseph (1997) categorize street network designs by number of intersections per 2000’ x 2000’ area (4,000,000 ft² or 91.8 acres) –

- Loop and cul-de-sac streets = up to 12 intersections
- Warped parallel and modified grid networks = >12 – 17 intersections
- Fragmented parallel = >17 - 22 intersections

- Modified gridiron and classic dense grid = >22 intersections

The number of intersections per 91.8 acres must be multiplied by 2.6962 (1/.37) to find the number per km².²

The result is that the following street network types are matched to a level of intersection density in the PSRC dataset:

Low:

< 32.35 intersections/square kilometer (equivalent to Loop & culs-de-sac or lower density)

Medium:

32.36 – 40.44 Int. / km² (Warped Parallel)

40.44 – 53.92 Int. / km² (Fragmented Parallel and other long block grid or curvilinear networks)

High:

> 53.92 Int./ km² (Neotraditional/Modified Grid to Classic central area Gridiron)

The Fused Grid ranges in intersection density from 72 / km² (Barrhaven District, Nepean, Ontario) up to 82 / km² (pedestrian quadrant) depending on the length of the block faces planned and the type of Fused Grid district configuration proposed, putting it on par with the mean of the sample. In terms of this intersection density measure, the Fused Grid appears to be well within the range of values that occur in the Seattle region sample.

Measurement of Disparity: Ratios of Route Directness and Network Density

Street network patterns vary in the kinds of movement and modes of travel they support. One way to assess this variation is by measuring the route directness (itself a ratio of available network distance to crow-fly or airline distance) to a destination by mode on each mode's respective network. Another way to assess the different types of street pattern is to assess relative levels of network density across modes. These two measurements were at the core of the Fused Grid assessment.

A typical gridiron street, or any street with regular, continuous sidewalks on it but no street closures or diverters, pedestrian permeable park lands or plaza blocks, or mid-block foot passageways, will have a pedestrian to vehicle ratio of route directness of 1:1 (or 1.0). Other street networks may create a less direct pedestrian network (ratio >1.0) by omitting sidewalks or including large streets that may be crossed only at lengthy intervals (eg. safe crossings far apart along the length of a multilane arterial). Within a loop and cul-de-sac neighborhood of the post-World War II era, such omissions of sidewalk, even on collector streets, were routine. Another type of street network ratio of route directness (ratio <1.0) occurs where additional walking facilities are provided, or barriers placed, that shorten the pedestrian (and often other non-motorized) paths relative to driveable routes. This is characteristic of the Fused Grid street network, which is featured in Table 8. The distribution of these connectivity patterns across the study region can be noted in images generated from the GIS analysis. The clusters of green

² The conversion factor to the units that have been used in this UBC research project is # of acres * 0.00404685642 to derive the quantity in square kilometers. 91.8 acres = .37 km². 1/x converts this number to 2.6962.

points (circled in green) indicate a predominance of more direct pedestrian routing; the red points (similarly circled) indicate more direct vehicular routing; purple indicates a 1:1 ratio.

These images give a sense of the range of network connectivity across the three cities. One would expect that as the crow-fly distance and pedestrian route directness variables increase (i.e. walking becomes less direct relative to crow fly path), the amount of walking would diminish. The opposite would be true of intersection density, where an increase is associated with smaller, more walkable blocks, and which, as previous studies have demonstrated statistically, should foster higher levels of walking.

Figure 12. Route Directness Examples

Queen Anne – Pedestrian Supportive Grid



East Bellevue – Auto Oriented Streets



Route directness ratios are shown as household (square) points. Stars indicate higher pedestrian directness to two nearby destinations; triangles indicate higher vehicular directness. Clusters of modal route/directness roughly correspond to types of street network: the former to modified grids, the latter to dendritic loop and culs-de-sac.

Finally, comparative network density, expressed in this study as ratio of sidewalk/trail to street is another way of assessing a street pattern's connectivity and continuity for travel by different modes. Where this ratio is increased (as in a grid pattern with added shortcuts or vehicle-restricted segments), this study expects to find increased walking mode choice. The Fused Grid street patterns' measurement on these network variables is shown in Table 6.

The measurements allow the investigators to test the relationship between urban form at an enhanced level of detail and to match the travel behavior of those neighbourhood street characteristics that most closely resemble the Fused Grid in their pattern and configuration. The characteristics of the Fused Grid are as follows:

Intersection Density

70-85 per square kilometer (lower than gridded networks in the study region, and so within the interval of data used).

Table 6. Fused Grid Measurement

The table below summarizes measurements of the Fused Grid on the connectivity parameters, the one from previous work (intersection density) and the new variables (ratio of route directness to nearest commercial and ratio of lengths of sidewalk and major trail to street segments).

Measurements of Fused Grid on Connectivity Measures

	Intersection Density (# / sq. km)	Ratio Route Directness	Ratio Sidewalk-to-Street
Range	70 to 85 / km ²	0.61 to 1.0	1.19 to >1.4
Mean		0.89	1.3

Measurements were obtained by hand measurement of Fused Grid designs for Barrhaven in Nepean and the basic pedestrian quadrant, averaging repeated measures of distinct 1 sq. km areas applied to the designs. Highways or limited access automobile-only roads were not included in the measurement of streets.

Figure 13. Contrasting Networks, Seattle Region Study Area (same scale)



Route Directness Ratio

Average of .89 ratio of pedestrian to vehicular routing, on the lower end of range of values for street patterns in the study area (meaning this route directness by the Fused Grid would correspond to the most pedestrian-direct streets in the study).

Comparative Network Density

A wide range of values is possible on this measurement for the Fused Grid, but in general values are greater than 1.2, associating the Fused Grid with upper values in the study's range of data.

Neighborhood Patterns

As noted in the methods section (Part II), the difficulty of using partial measures (i.e. measurements of just two routes from each household) of connectivity is that the overall

neighbourhood pattern could be missed or poorly represented. An average value of the ratio of route directness (to park and commercial) was computed by aggregating to logical neighborhood areas. The neighborhood areas that most closely approximated the Fused Grid, are Capital Hill/Miller Park; Queen Anne; and Fremont/Wallingford. Neighborhoods with contrasting street patterns and the opposite network connectivity (better vehicle than pedestrian route directness) include north Seattle's North Beach, Haller Lake, Olympic Hills and Wedgwood as well as south and east Bellevue. This provides another sample for analysis. See circled areas of Figure 18.

Table 7. Network Measures – Descriptive Statistics – Person

		Ratio of Route directness to Commercial (Ped/Veh)	Ratio of Sidewalk/Trail length to Street length
N	Valid	1420	1420
	Missing	0	0
Mean		.99	.82
Median		1.00	.95
Std. Deviation		.10	.25
Range		1.16	.92
Minimum		.40	.21
Maximum		1.57	1.13

Urban Form Covariates (Controls)

This group of variables constitute an important set of controls for the experiment because they are known covariates in the relationship between urban form and travel behavior. Intersection density was described in more detail above because of its close relation to the new network connectivity variables created in this research. Neighborhood retail, or the number of this kind of commercial use within the household buffer, has been shown to be associated with walking behaviour in previous studies (LUTAQH 2005). Likewise, residential density and mix of uses have been shown to be influential to the outcome variables both within this region and in similar studies of other metropolitan regions (Cervero & Kockelman, 1997; Frank et al. 2005).

Table 8. Other Urban Form Descriptive Statistics – Household Sample

		Neighbourhood Retail (number in 1km buffer)	Net Residential Density (units/acre)	Intersection Density per sq. km	Crow Distance to Commercial
N	Valid	1271	1271	1271	1271
	Missing	0	0	0	0
Mean		29.39	2.9939	74.9163	1000.88
Median		21.00	2.2010	73.0770	803.64
Std. Deviation		28.129	2.54556	25.35994	780.32
Range		121	23.41	142.42	3765.57
Minimum		0	.95	10.13	.00
Maximum		121	24.37	152.55	3765.57

Table 9. Urban Form Descriptive Statistics – Person Level

	Neighbourhood Retail (number in 1km buffer)	Net Residential Density (units/acre)	Intersection Density per sq. km	Crow Distance to Commercial
Mean	28.67	2.74	75.25	1019.92
Median	22.00	2.07	74.60	814.27
Std. Deviation	26.762	2.29	24.48	763.46
Range	121	23.38	149.48	3746.46
Minimum	0	.99	13.13	.00
Maximum	121	24.37	162.61	3746.46

An initial description of walk behaviour associated with high and low levels of connectivity across the two modes is presented in the tables below.

Tables 10. Disparate connectivities and walking behaviour (to commercial)

Table 10. <i>Disparate street connectivity and walk shares</i> (by person to commercial)		<i>Pedestrian Connectivity</i>	
		<u>Low</u>	High
Vehicular _Connectivity	Low	SE and Central Bellevue; SW Seattle – Loop and Culs-de-Sac Mean Walk Share: 10% walking n = 985	Queen Anne, Capital Hill (Seattle) – Modified grid with connectors Mean Walk Share: 18% walking n = 66
	High	N and S Bellevue, N Seattle – Grid and major streets w/o sidewalks Mean Walk Share: 10% walking n = 59	Downtown and Older Seattle Neighbourhoods – Gridiron Mean Walk Share: 14% walking n = 966

These exploratory findings are a preliminary indication of the relationships between walking and street patterns. The boxes in the tables above are cases (persons) grouped by pattern of street connectivity. Those people living in the neighbourhoods with high pedestrian and low vehicular connectivity (ratio of route directness < 1) have the highest levels of walking for their local trips. Where pedestrians are offered a more direct route, as is the case with the Fused Grid, there tends to be more travel on foot, both in mode share and total distance. These descriptive results offer hints about relationships that deserve further investigation to draw conclusions more generally, for whole populations, about travel behaviour relating to street design.

Table 11. <i>Disparate street connectivity and walk distances</i> (by person, in home neighbourhood)		<i>Pedestrian Connectivity</i>	
		<u>Low</u>	High
Vehicular Connectivity	Low	SE and Central Bellevue; SW Seattle – Loop and Culs-de-Sac Mean Walk Distance: .49 miles walked n = 714	Queen Anne, Capital Hill (Seattle) – Modified grid with connectors Mean Walk Distance: .74 miles walked n = 47
	High	N and S Bellevue, N Seattle – Grid and major streets w/o sidewalks Mean Walk Distance: .32 miles walked n = 41	Downtown and Older Seattle Neighbourhoods – Gridiron Mean Walk Distance: .66 miles walked n = 766

Table 11. Disparate connectivities and walking behaviour (in neighbourhood).

Tables 10 and 11 show the top two quartiles of connectivity (route directness by mode to nearest commercial) as high connectivity and the bottom two as low. There are comparatively few cases of disparity (low-high or high-low). The reported mean values, for share of trips by walk mode (Table 12) and total walking distance traveled (Table 13), are home-based travel from PSRC travel survey data aggregated to the person level. The neighbourhoods listed are examples.

The ranges in each of these classifications of connectivity are as follows:

Pedestrian (sidewalk, pathway and local streets)

Low corresponds to Pedestrian Route Directness (PRD) = over 1.33

High corresponds to PRD = 1 to 1.33

Vehicular (street)

Low corresponds to Vehicular Route Directness (VRD) = over 1.34

High corresponds to VRD = 1 to 1.34

5.0 Summary

The foregoing descriptive statistics provide the foundation for a more detailed exploration and analysis of street network design and travel behaviour. Enough variation in street network pattern occurs within the study area and travel data samples selected to draw conclusions in final phase of statistical analysis. The preliminary indication is that street networks' variations in connectivity do relate to travel behaviour. These conclusions, after being tested more thoroughly, can be applied to other patterns of street network connectivity. The next parts of the report will summarize of results from correlations and regression analysis, including assessment of likely travel behaviour outcomes associated with streets patterns, especially the Fused Grid.

Part IV. Inferential Analysis

1.0 Introduction – Inferences on relationship between street patterns & travel behavior

This section reports the results of the final phase of analysis: an assessment of the Fused Grid conducted **inferential statistics**. Previous sections have set the stage for this level of analysis, allowing for predictions about street network and the Fused Grid design.

The descriptive assessment provided basic measures of central tendency and dispersion for the travel and urban form datasets used for this study.

The salient conclusions from the **descriptive analysis** are that street networks do differ in how much connectivity they provide to various modes and that there appears to be a relationship between measured disparity in street connectivity and the travel of people living within these street networks.

This section will help determine how significant and generalizable the descriptive results are, through the provision of additional statistical information. More importantly, correlation and regression statistics can indicate the magnitude of the change in travel behaviour that could be expected from changes in street patterns.

2.0 Correlations

Correlation statistics were used to explore relationships among variables. The correlation process does not assume a particular direction of influence in the relationship between the variables input. Instead it provides information about direction (positive or negative), form and degree of association. Pearson coefficient of correlation (r) results indicate whether an association is statistically significant (i.e. non-random) and how strong (i.e. how well fit) it is. Correlation results are shown in the tables (17 and 18) that follow.

Results of bivariate correlations

The correlations between demographic and household variables and the travel behavior data for this sample showed moderate associations of walking mode share and distance walked with total vehicle ownership and household size. Weaker, yet still significant, were the relationships of these travel outcomes with income and education. Age, ethnicity and gender were not significantly associated.

This person-level walking travel data also showed significant and mainly stronger relationships to urban form variables. When present in a localized area around households, neighbourhood retail and mix of use associate strongly with walking behaviour. Residential and intersection densities within the household buffer reveal weaker, yet still significant association with walk share and distance.

Our main variables of interest had the following correlated results with travel behaviour:

The relationship of the ratio of route directness to walk distance traveled has a negative sign, as expected. When pedestrian routing becomes more indirect relative to vehicles, the associated travel by walking decreases.

The sidewalk to street ratio has a highly significant, moderate strength correlation, and positive association with walking mode share. As more sidewalks or other formal pathways are built within an area, walking travel would be expected to increase.

Table 12. Correlation – Walk Distance Traveled and All Factors

Demographic Measures	Pearson Correlation (r)	Sig. (p)
Total vehicles in household	-.229(***)	0.000
Household Size	-.128(***)	0.000
Age	-0.045(*)	0.099
Urban Form Measures	r	p
Crow-fly Distance to Commercial	-.149(***)	0.000
Intersection Density	.202(***)	0.000
Mix of Uses	.196(***)	0.000
Neighbourhood Retail (number in 1km buffer)	.276(***)	0.000
Net Residential Density (units/acre)	.098(***)	0.000
Bus Stop Density (# / square km)	.273(***)	0.000
Network Connectivity Measures	r	p
Ratio of Route directness to Commercial (Ped/Veh)	-0.044	0.104
Ratio of Sidewalk/Trail length to Street length	.186(**)	0.000

* = significant at the 90% level

** = significant at the 95% level *** = significant at the 99% or higher level

Similar findings occur for driving behaviour (see Table 13) and at the trip level for both modes of travel. The signs on the coefficients for driving distance are opposite that of the walking travel, as would be expected.

Table 13. Correlation - Distance Driven (VMT) and All Factors

Demographics Measures	Pearson Correlation (r)	Sig. (p)
Total vehicles in household	.238(***)	0.000
Household Size	.202(***)	0.000
Age	0.009	0.731
Urban Form Measures	r	p
Crow Distance to Commercial	.207(***)	0.000
Intersection Density	-.174(***)	0.000
Mix of Uses	-.194(***)	0.000
Neighbourhood Retail (number in 1km buffer)	-.238(***)	0.000
Net Residential Density (units/acre)	-.091(***)	0.001
Bus Stop Density (# / square km)	-.199(***)	0.000
Network Connectivity Measures	r	p
Ratio of Route directness to Commercial (Ped/Veh)	.069(***)	0.010
Ratio of Sidewalk/Trail length to Street length	-.121(***)	0.000

3.0 Travel behaviour regression modeling

Several different regression models were tested in the course of this research. All models attempt to ascertain more specifically the kind of relationship that exists among the hypothesized predictor (urban form) factors and response (travel activity) behavioral phenomena.

The cross-sectional research approach used here can provide greater clarity on the kind of relationship that likely exists. It allows some degree of prediction about behavioural results from modifications of the design of urban form and street patterns in particular.

Results

The logistic regression models provided significant explanation of walking and driving behaviour.

Walking

The odds of walking (probability that one will walk for any given local travel) shows consistent, statistically significant increase with increases in each of the following variables:

- Net Residential Density
- Neighbourhood Retail
- Ratio of Network Density

Odds of walking decreases significantly with increases on:

- Total vehicle ownership
- Household size

There is a significant negative relationship between ratio of route directness and trip-level pedestrian travel. A significant association does not occur at the person level nor when individuals are aggregated into households. In fact, though ratio of network density remains significant, this block of variables together does not add significantly to the explanatory power of the person-level model.

Household size, net residential density and intersection density similarly become insignificant at this more aggregated level of data. At the household level, the direction of the relationship for household size becomes positive and significant. Net residential remains highly significant, as does the comparative network density.

Driving

Another major travel outcome variable is distance (or vehicle miles) traveled. This variable was similarly regressed using the same sample as the walking analysis.

Again, the block of network variables is significant. The ratio of network density is again stronger and more significant than ratio of route directness

Continuous variables, like number of trips or distances, can be analyzed in a linear regression statistical model, and this was conducted for a few key outcomes: number of local trips and vehicle miles of travel.

The ratio of route directness is significant (at $p < .1$) and positively associated with number of trips. That is, as the route directness for vehicles increases relative to that of pedestrian networks, the number of trips a person takes increases.

The result for ratio of sidewalk to street indicates that as the density of pedestrian pathways increases relative to motor vehicles paths, the number of trips increases.

A similar result occurred when regressing vehicle trips, although ratio of route directness became slightly insignificant ($p = .118$) and ratio of network density became largely insignificant.

Part V. Discussion & Conclusion

1.0. Findings interpretation

The results of this assessment indicate that there is a relationship between street connectivity and travel outcomes of walking mode share, and walking and driving distances traveled. The significant findings in relation to both ratio of route directness and ratio of network densities across walking and driving modes signal that we should accept the hypothesis that there is an association between street network patterns and travel behaviour, walking levels in particular. The correlation results are by themselves grounds for accepting the hypothesis. When a transportation network's connectivity or continuity favors one transport mode over the other, travel increases on the favored mode.

Change in odds of walking is affected by numerous factors, including the covariates that constituted the independent variables in the foregoing analyses as well as others not measured here (see *Limitations* below). As shown in previous studies, the strongest factors that contribute to more walking are the presence of proximate neighbourhood retail stores (more walking) and the total vehicle ownership of the household (less walking). The magnitude of change in walking behaviour associated with total vehicle ownership is a decrease of about 11% in the odds of walking from the addition of a single vehicle. This change is likely to be affected by thresholds such as going from zero cars to one, or one car to two. Adding one more neighbourhood retail destination within a 1km buffer around a person's home is associated with a 1.8% increase in the odds a person will walk for some portion of their local travel.

This study's complementary variables relating to street network patterns, the ratio of route directness and ratio of network densities, were significant predictors of travel. The regression model allows us to make the following predictions:

- If route directness for pedestrians is increased 10% relative to motor vehicles (e.g. a change in the ratio from 1.00 (or 1:1) to .90, would be very similar to changing a pure gridiron pattern to a Fused Grid design) in a given area, the odds of a trip being walked rather than taken in another mode would increase by 11.3%, all else being equal.
- At the trip level, a 10% increase in the pedestrian-to-vehicular network density ratio, the equivalent of adding less than a half-block length of pedestrian-only pathway to each block of network area), is associated with a 6.6% increase in odds of a trip being walked.
- For persons, the same increase in relative pedestrian continuity associates with a 9.5% increase in odds of walking, all other factors remaining the same.

There is somewhat less confidence in these models for predicting sufficient levels of walking to be considered physically active. However, the model does indicate that:

- a 10% change on the ratio of route directness is associated with more than 25.9% increase in odds of walking 30 minutes per day or more, and
- the same magnitude change on the ratio of network density in favor of pedestrian travel is associated with an 18.2% increase in odds of being active through walking.

Finally, and perhaps most importantly for a variety of immediate environmental outcomes, the changes in ratio of route directness are linked with decreased vehicle miles of travel. The linear regression model indicates that:

- a 10% increase in the relative directness (to a nearest destination) of a street network for pedestrians (going from 1.0 to 0.9 on the ratio of route directness continuum) is associated with a 23% decrease in distance traveled by automobile.
- Increasing vehicular route directness relative to pedestrians is also associated with an increase in the total number of trips a person will take (10% change associated with 16.3% increase). Linear regressions indicate that increasing the pedestrian network density relative to that of vehicles relates to increases in both distance walked (+3.1% for a +10% network change) and number of walk trips (+4.6%).

Regression models for of active transportation, and trip-level regression analyses certainly provide evidence that the odds of a person walking are associated with changes on the connectivity disparity measures. The association of route directness (connectivity) to walking mode share and other aspects of travel behaviour appears weaker than the relationship with overall extent of the pedestrian path facilities available (relative network density).

2.0 Implications - Street Pattern Association with Travel Behaviour

Pedestrian connectivity, as measured by directness of routing to commercial destinations relative to that for vehicle travel, is significantly associated with levels in walking and driving for local trips, even when local streets are not weighted by the extent of sidewalk in the area. Specifically, an increase in pedestrian route directness in the home neighbourhood is associated with a larger proportion of trips being made by walking and a diminished share of travel by driving for local trips.

Disparity in pedestrian to vehicular network density as measured by the length of pedestrian network relative to street segment length for vehicles in the area immediately around households, is significantly and more strongly associated with the same travel behaviours. This study also found significant relationships between increase on this pedestrian continuity/connectivity measure and reductions in total number of trips. While model-estimated air pollutant emissions are not significantly associated with these new connectivity measures, one may derive such an association from the already well-established link between air quality and vehicle miles of travel (WSDOT, 2005, Frank et al., 2000). Since decreased distance traveled by motor vehicle is associated with increased relative route directness or network extent for pedestrians, one would expect a corresponding reduction in overall emissions.

These connectivity measures are significant predictors of increased odds of walking. Based on the Fused Grid's measurements (see Part III, Tables 8, 12, and 13), and this study's results, this street design appears to be more walkable than other street networks lacking the same distinct modal network patterns. On ratio of route directness to commercial, the Fused Grid street pattern design represents a change of 10% or more of increased walkability (relative directness or network density for pedestrians). This route directness change corresponds, at the trip level, to an increase of 11.3% in odds of walking.

On available length of pedestrian facilities (relative to street segment length), the Fused Grid design represents a 20-40% increase over a street with pedestrian facilities only along open streets in the form of sidewalks. This corresponds to a change of 13.5% to as much as 42.5% greater odds of walking.

It should be noted that these results are additive. That is to say, one could expect more shift in travel such as increased walking levels by the combined effects of changes to the network pattern which make it more direct for walking *and* increase the length or continuity of pedestrian network while the vehicle network remains unchanged.

3.0 Methods & Data, Limitations

Methods

The travel behaviour analysis framework as described in Part II is consistent with other research on the associations with and influence of urban form. It builds not only on the substantial base of Central Puget Sound knowledge of these relationships, but also on evidence from across North America. In this regard, it is not new. The methods employed to investigate a particular feature of street design, are where this project has advanced the methods and analytical understanding of urban form. The disparity of the connectivity provided to different modes, using variables computed as ratios of separately measured modal connectivities (walking and driving networks), and how it relates to travel, has not been studied previously. This project has pioneered a means of measuring this phenomenon and used a second measure that parallels and refines ones used in other studies (Schlossberg, 2006; Moudon et al, 1997).

The study would like to note that this research corresponds with other connectivity work being conducted – on perception and as a part of the experienced pedestrian environment and other travel behavior – in urban design research. Dill (2004) and others, with results forthcoming from Active Living Research, are investigating how to measure connectivity for bicycling and walking. This study has advanced methods to a sub-link level – assessing sidewalk at increments of 100' on the street network.

This micro-scale of measured pedestrian network environments is something called for by reviewers of urban form-travel behaviour research (Ewing & Cervero, 2001). It will help answer questions about what street standards should be used for residential neighbourhoods. It will also assist discussion of what sorts of regional network patterns may be most supportive of broader public policy goals aimed at reducing automobile dependence, and related environmental goals. It also provides a foundation for continuing research on street networks, which will be discussed below.

Data

The most critical data for this study was the sidewalk and other pedestrian pathway locations and lengths. It was only available in a digital form useable for GIS analysis in three cities of the study region, but more cities are beginning to develop inventories in a useable format. The availability of this data is crucial for both travel behaviour research and for enhanced planning related to non-motorized transportation. This study has demonstrated the importance of this kind of information, and the researchers hope that the various levels of government involved with

transportation planning will continue to improve the collection and availability of mode-specific network and spatial data.

Some other important data to consider for future studies are crossing/intersection quality as well as more detail on the micro-scale pedestrian environment: topography, streetscape, lighting and other factors affecting personal safety. Quality of destinations is another factor that can be assessed for future research on pedestrian behaviour that relies on origin-destination pairs. More sophisticated modeling of behaviour is possible with the availability of these kinds of data. They can indicate where crossings are possible, or safest. As well, they can more adequately estimate how a pedestrian's comfort and convenience are affected by various routes. Having such detailed data would permit more accurate simulation or control for factors influential to walking.

Limitations

As noted previously, this study is cross-sectional in design, providing a thorough understanding of relationships between travel and urban form during one discrete period of time for one metropolitan study area. This is useful for predicting some likely responses in behaviour and associated outcomes. It does not prove causes of behaviour or attribute direct causation to the built environment factors.

The results therefore should be viewed as indications of more general patterns in behaviour that could be expected in other circumstances. A different study design would be needed to attempt to overcome such confounding factors as self-selection, and replication of this study in other regions would be necessary to form general theories for these relationships.

The study made assumptions about travel when constructing the built environment measures. This adds some uncertainty to the analytical results. The main assumption of measuring route directness – that pedestrians might use local access streets whether or not they have sidewalks – may reduce the variability in how street networks were assessed. Nevertheless, sidewalk continuity is an important element affecting the route a person walks, or whether they walk at all. With regards to destinations, the study attempted to accurately and consistently model where they were accessed from the street networks, treating them as equally attractive. This approach may or may not reduce the accuracy of the route directness measurement as an indication of connectivity.

Each of these limitations was partially addressed through sensitivity testing and the inclusion of related variables (sidewalk density measure and neighbourhood retail or mix of use factors) in the model.

The study also could not control for many additional factors that were potentially influential. This includes factors related to the resource-intensive nature of collecting and refining data for analysis, including personal attitudes, perception of environmental conditions and safety, and the details of routes' suitability for various forms of transportation. Each of these can be highly influential to travel decision-making. This data was not collected on the individuals who participated in the travel survey nor were the routes they took.

Other measurable aspects of the street environment – accessibility of design, streetscape, crossing quality - were not measured. Such data is very difficult to reconstruct for the time period of the travel survey. Likewise, quality of destinations and site design can be factors in how people travel. Thus there are several areas where greater control would be desirable. Including them may have led to better explanatory models with more accurate analysis of street networks. Acquisition of enhanced data on these other factors should be part of future analysis of street pattern relationships with travel behaviour.

Finally, the study did not find significant results for the ratio route directness to parks, which is a result consistent with recent findings in the same region (Olympian, 2007). The logistic regression model also did not explain non-work travel better than all travel including work-related tours. This may be due in part to the travel survey relying data gathered during 2 weekdays, rather than weekends, when more recreation-purpose and non-work travel, including walk trips, occurs (Bhat & Lockwood, 2004).

Future research on the topic would benefit from travel survey data that captures more of the non-work travel that constitutes a majority of all travel in North America. Notwithstanding these limitations, the Fused Grid assessment has generated significant results for better understanding of street design and its association with travel and activity patterns.

The next section summarizes the conclusions that can be drawn from the findings, including recommendations for policy and practice as well as further research.

4.0 Conclusions

This study provides an assessment of residential street design vis-à-vis travel behaviour. It was prompted by the need for evidence as to likely outcomes from application of the Fused Grid, a street design that attempts to find a balance between the benefits of street connectivity for transportation efficiency with the use of street space to enhance neighbourhood quality of life for local residents. Residential street design is one element of ensuring healthier communities by design, and a debate over whether connected streets such as traditional gridiron patterns or closed streets such as loops and culs-de-sac provide greater benefits locally and across a region continues to this day.

While the effects of various street designs have been or are being modeled for their effects on traffic flow, this research has focused on empirical investigation of the outcomes from varying levels and disparities of travel network connectivity and continuity in terms of walking and driving behaviour. Its core hypothesis is that street network designs that enhance connectivity for pedestrians relative to vehicles, by including closures or diverters on the motor vehicle network (streets) or providing separate, more direct paths for pedestrians, results in increased share of travel by walking.

Such changes to street design, like requests for traffic calming and narrower streets to slow traffic, have been in high demand during the past few decades by both local residents and nationally known experts in walkability. Yet solid evidence, based in scientific research, has difficult to attain. This assessment begins to answer the question of whether new designs and street standards, in addition to the retrofit programs of traffic calming, will result in the desired

outcomes of increased levels of walking and decreased reliance on automobiles. The study has demonstrated that there is a relationship between the urban form of local street networks and travel behaviour, and that modifications to street patterns are associated with changes in levels of walking and driving for local travel.

Key findings

The two main assessment measures in this study, relative route directness and relative network density across walking and driving modes, have an association with odds of walking, odds of driving, distance walked, distance traveled by vehicle, and number of trips. The former ratio measure, when more direct for walking, is associated with increased levels of walking and decreased driving. When there is a higher density of walking pathways than driveable streets, an increase on the second variable, even greater increases in walking and reduction of driving would be expected.

The implications of this primary finding are that street designs which serve to increase the relative utility of walking by improving the directness of routes, relative to those enjoyed by other modes on their respective networks, are associated with more walking. The Fused Grid street design provides a transportation network pattern that achieves this kind of change in the relative utility of walking. The same would likely be true of certain traffic calming measures (i.e. creating pedestrian only malls within an existing street network, other partial or full closures and diversers for motor vehicle traffic). A corresponding reduction in driving behaviour is also a likely outcome.

The relative directness of routing across modes appears to matter more than route directness for one mode alone. This makes sense intuitively – as this research has hypothesized, greater route directness for one mode relative to another will enhance its utility relative to the other mode, thus encouraging a corresponding shift in travel behavior to the more convenient or useful means of transportation. This appears to matter more for nearby commercial destinations than for nearby parks, and the result is the same, albeit with greater strength of association, when contrasting whole neighbourhood areas' relative walking-driving route directness.

The network density measure exhibits a stronger relationship to the travel behaviour being correlated and regressed. This suggests that adding more pathways for pedestrians, regardless of how well they improve connectivity to destinations, increases levels of walking. The Fused Grid street design is characterized by a higher density of pedestrian pathways than vehicle pathways. Other factors held constant, this kind of street network would be associated with more walking and less driving. It bears repeating that these two factors, ratio of route directness and ratio of network density between the two modes, are additive in their effects, so even larger benefits on the travel outcomes would be expected from designs or projects that create improvement on both measures.

A street pattern that has more direct connections for people traveling on foot is associated with more walking activity. The strength of association between this particular aspect of urban form on walking has been clarified by this study. It appears to be somewhat less influential (smaller correlation coefficient) than the relative density of walking facilities in a neighbourhood as well as the sheer presence of nearby retail stores. The regression model demonstrated that, in this

study region, a change from a pure small-block grid to a modified grid (same intersection density but ratio of route directness around .90) 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 is 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) increases by 10% in the area around a household, odds of pedestrian travel increases by at least 7.7% and that of driving drops by 4.6%.

Recommendations for Community Planning Policy, Practice and Research

The Canada Mortgage Housing Corporation works to create better community design by assisting the local governments who set standards for street construction. These practitioners, from the federal to the local level of government, are understandably interested in how various street designs, and the Fused Grid in particular, might perform on key transportation dimensions such as levels of walking and vehicle miles traveled. Based on the research results noted above, this assessment project therefore offers a set of policy and practice recommendations for community design and planning along with suggestions for further research.

Community planning and design implications

Both traffic calming and street design standards that offer increased directness of routing for pedestrians relative to motor vehicles can be used to help achieve increased levels of walking, reduced motor vehicle use, or both.

Increasing the extent of sidewalk or other pedestrian pathways is likely to be useful to reach desired walkability outcomes. Such outcomes can be achieved by adding pathways and sidewalks as stand-alone projects, or by building a higher density of paths and walks relative to street lengths in new neighbourhoods. This change to the built environment is also associated with walking a sufficient amount to have a healthy level of physical activity.

These kinds of measures will be particularly effective when they result in both reduction in the connectivity of the motor vehicle network (i.e. street closures or other interruptions in the network for motorized vehicles) relative to the walking network and increase the pedestrian network's extent relative to the vehicular network.

Further research

Continuing study of street networks is needed to validate these results, confirm their generalizability, and extend the empirical knowledge base regarding effective transportation system design. The influence of street design on travel behaviour is an area of research with great potential for policy implications.

Empirical evidence of the impacts of various urban form features on desired outcomes is often necessary in order to demonstrate the desirability of change in practices, standards and investments in infrastructure. To this end, the Fused Grid assessment study has identified some key areas for continued research.

Fused Grid and Street Networks, further assessment

Efforts are under way to model the traffic implications of the Fused Grid, e.g. how well will it function for the movement of vehicles. This effort would be enhanced with the addition modeling of pedestrian or bicycle movement on Fused Grid networks. Regional travel implications from introduction of Fused Grid neighbourhood areas were not the focus of this study, but could be investigated by aggregating travel data at a larger scale. The enhancements noted below could also be applicable to continued study of the Fused Grid and other street networks.

Enhanced urban form analysis

This is needed to account for other factors that are suspected and emerging as covariates with walking and overall travel behavior. Several of these other factors were not possible to develop in this assessment due to time constraints or the difficulty of ensuring accuracy for a time period that is now quite remote from the present (travel behaviour data was collected nearly seven years before the data development for this research began). Here is a partial listing of the kinds of data that would be required for an enhanced analysis using the same methodological framework:

- Quality of destinations
- More detailed qualitative analysis (streetscape and pedestrian environment quality)
- Other key factors in pedestrian accessibility (slope and quality of crossings).
- Bicycle facilities and transit-pedestrian factors

Enhanced analysis using fuller travel dataset

A related effort involves gathering better travel and activity data. This is already being accomplished, through a variety of means, such as use of accelerometers.

- Perceptual or attitudinal factors
- Bicycle travel
- Data on weekend travel behaviour

Longitudinal research

Given its use of a discrete travel database from the past and cross-sectional research design, this study cannot attribute causality or provide additional explanation that would overcome control for self-selection. In addition, these factors may be overwhelmed by others in the remaining seventy five percent or more of the basis for travel behaviour that the model does not explain.

This could be done by following a cohort of people living in a range of different street patterns. Even better, however, would be to compare the travel before and after of persons who recently moved to a Fused Grid neighbourhood from a variety of different street network types (and vice versa), which could offer a more definitive assessment of the travel implications of the Fused Grid.

Summary

This study demonstrates that relative improvements to the pedestrian network can be expected to result in gains in walking mode share for home-based travel. Residential street patterns that improve pedestrian connectivity or density, but leave motor vehicle networks and directness unimproved, can be expected to generate higher walk mode shares. This results hold true, when demographic characteristics and other built environment conditions remain equal.

This study indicates that transportation projects for retrofit situations, such as traffic calming diverters or street closures, would likely produce the same result. While further research is needed to confirm the generalizability of these results, there is significant evidence from this assessment that local streets can influence local travel patterns.

The Fused Grid street network design exhibits precisely these kinds of travel network connectivity and continuity patterns. The application of Fused Grid designs for residential neighbourhoods would be associated with higher levels of walking and reduced motor vehicle traffic.

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