CAPACITY UTILIZATION OF VEHICLES FOR ROAD FREIGHT TRANSPORTATION

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ABSTRACT

This paper discusses a central aspect of freight transportation – capacity utilization and empty running of commercial freight vehicles. It provides an overview of the literature on these topics and groups the contributions into two segments according to their analytical approach and origin of research. The first approach looks at utilization based on economic theories such as the firms' wish to maximize profitability and considers how different firm and haul (market) characteristics influence utilization. The second approach stems from transport modelling literature and its main aim is analyzing vehicle movement and usage in transport demand modelling. A strand of this second group of contributions is the modelling of trip-chain and its implication on the level of capacity utilization. A key lesson from the reviewed studies is that it is important to take into account the commercial activity that initiates vehicle movements to evaluate performance. It appears that there is room for further enrichment of the modelling exercise by incorporating information regarding the operator to give a stronger behavioural basis for the vehicle movements and utilization. The paper provides an overview of the different approaches and discusses the potential combination of the two approaches. It also highlights relevant new areas where our knowledge is limited.

Keywords: Freight transportation, capacity utilization, use optimization,

INTRODUCTION

Road freight transportation (trucking) is a service that provides a vital input for most industries to ensure smooth movement of goods. It also employs a large number of the labour force and contributes positively to economic growth in many advanced countries[1]. The level of capacity utilization of vehicles used for freight transport is an important indicator of

[1] In 2003 trucking and related activities generated close to $50 billion in revenue and employed close to 320,000 full-time workers in Canada (Transport Canada 2003). The American Trucking Association (2000) estimates that trucking (including private fleets) was a $486 billion industry in 1998 or approximately 6.1 percent of GDP.

how well economic resources are used both from the perspective of vehicle operators and other sectors of the economy, which rely on their service. It is important to note that, trucking also involves negative externalities that need to be reduced, ideally, not at the expense of economic prosperity. Mackinnon (2007) indicates that vehicle utilization defined as the ratio of vehicle-km to ton-km is one of the factors, which influences the externality. If vehicle utilisation can be improved then it will be possible to reduce the amount of vehicle kilometres and the related detrimental effects. It is, therefore, interesting to investigate the factors behind vehicle utilisation and how it influences overall travel demand.

This paper studies vehicle utilization through a literature review, which includes contributions from different approaches that has followed independent paths. Through this review we will shed some light on its measurement and its determinants. In particular, we focus on how the different approaches can be combined to improve current methodologies within freight transport modelling as well as within economic modelling of the vehicle operators' decisions. There are several studies ranging from the economics and the transportation literature that analyze the issue of vehicle capacity utilization (CU). CU in these studies is usually defined as a function of the physical dimensions of a load such as weight and volume as well as the distance of shipment. Each study emphasizes different and yet key aspects of utilization from which interesting insights can be gained. Studies from the economics literature try to analyze the underlying determinants of capacity utilization giving particular weight to cost minimization and other economic incentives as the main behavioural issues behind resource allocation decisions. They show how various haul (trip), vehicle and carrier (operator) characteristics affect the level of CU. According to the economics literature there is a persistent challenge of matching capacity with demand as a result of two factors: freight movement imbalance between regions and market access cost differential between operators. Recent studies from this strand of literature show how information technology capabilities improve utilization by facilitating the matching process (e.g. Hubbard, 2003 and Barla et al, 2010).

Studies from the transportation literature, on the other hand, are interested in modelling vehicle movements as part of freight demand modelling and a vehicle routing problem with the aim of predicting directional traffic. One frontier interest of these studies is the issue of 'trip chain' or 'tour' undertaken by freight vehicles in urban areas and its implication on efficiency. As some of the studies (Figliozzi, 2007, Figliozzi et al 2007) show, the extent of empty running is a poor proxy for efficiency of vehicle movements unless the purpose of commercial activity which initiated the movement is taken into considerations.

The key lesson from both strands of literature is that capacity utilization varies depending on the specific setting in which vehicles are used. The extraordinary heterogeneity in terms of weight and volume of a load, direction and distance of movement as well as time window constraints results in varying degree of utilization even for rather identical vehicles. Future studies should focus on micro level vehicle utilization rather than a general level analysis. Empirical analysis showing the scope of potential gains from improved utilization can also be an interesting addition to this important topic.

To our knowledge there are no other review papers which have focussed on this specific issue. The reviews in transport literature have focussed on e.g. how to model freight transport demand including the ever important demand elasticities (see e.g. Goodwin et al, 2004, Graham and Glaister, 2004, de Jong et al, 2004). Most of the transport literature has focussed on the more general elements of transport demand and only very few studies have been able to really include utilisation and in particular its determinants. The average payload has been the primary indicator in the literature. This factor has not been specifically modelled, but mostly been included as an exogenous parameter in the models. This is a potentially important deficit of the models since this factor determines the actual traffic demand (number of vehicles and vehicle kilometres). The average payload is thus an interesting factor to focus on since it has a direct impact on the externalities as also described by MacKinnon (2007).

The rest of the paper is organized as follows. Section 2 gives an overview of the concept of capacity utilization and production technology in trucking as it is discussed in the literature. In section 3, the determinants of capacity utilization is discussed. 'Trip chain' and capacity utilization issues are reviewed in section 4 followed by concluding remarks in section 5.

INCLUDING CAPACITY UTILIZATION IN A STRUCTURAL FREIGHT TRANSPORT MODEL

Knowing how freight transportation is organized, the demand, the transport behaviour of trucks and especially the decision makers of transport demand is a central focus of much transport literature. The analysis of capacity utilization and how it influences the transport and traffic demand and hence externalities are related. This can be illustrated through a conceptual model of freight transport demand.

Kveiborg and Fosgerau (2007) and McKinnon (2007) use anexplanatory model to describe the impact of different factors on freight transport development. In their model capacity utilisation is not directly mentioned, but is indicated through average load and empty running...Figure 1 shows an example of the analytical approach that is used by e.g. MacKinnon (2007) as well as Kveiborg and Fosgerau (2007). The first part of the model is the determination of the demand. In the latter part two directions can be used. In one direction, the focus is on modelling the vehicle movements (the transport literature approach) and the other focuses on the amount of transport undertaken (e.g. number of vehicle trips, number of vehicle kilometres etc.). The utilisation of vehicles is directly influences these latter parts of the model and indirectly also influences the number of lifts (the haulage factor) linking Production/Consumption(P/C) demand with origin-destination (OD) demand.

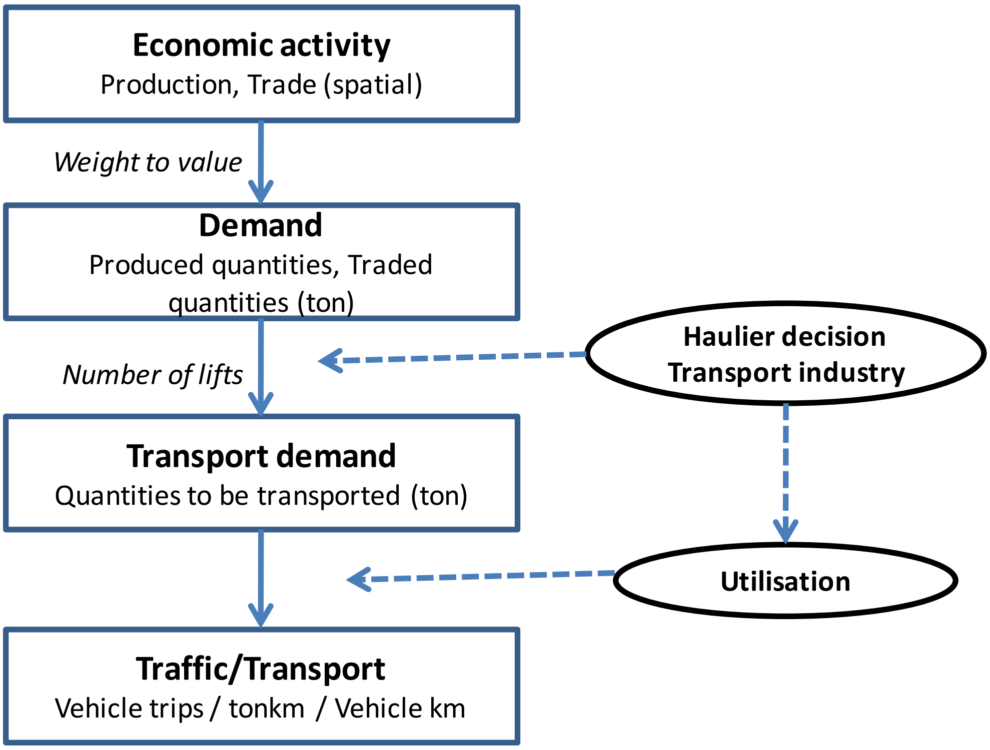

Figure 1. Structural modelling of freight transport and traffic.

The model links economic activity to freight transport and traffic through a number of steps; the first part is linking production values to physical production through the value density. This is entirely an economic/production aspect not involving any elements of transport. The second step of this conceptual model is the handling of the produced goods. This is done using a so-called handling factor indicating the number of individual lifts of each commodity. This involves decisions by the producers (e.g different production sites in the production chain), the transport industry, who may use distribution centres. These choices are obviously also influenced by the possibility to exploit vehicles to their maximal capacity, where a trade off between higher utilization and more handling is central. The calculation of transport and traffic is directly influenced by the usage since a higher utilisation leads to a reduced number of trips and vehicle kilometres.
The link between the overall drivers of freight transportation and traffic demand and the individual operation and use of vehicles is difficult to establish due to the many different decision makers. The decision about where an individual truck is running is seldom made by the driver of the truck. This decision is determined by a number of different actors that operate both independently and jointly in a complex set-up. In the transportation literature the objective has most often been to determine freight transportation or traffic demand measured in ton, ton-km or vehicle kilometres. This objective has often been pursued by modelling the demand independent of the actual decision makers such as the forwarder and often as though it is the shipper (or sometimes also the driver) who makes the choice of origin and destination of the trips. In reality, it is a combination of factors that are determining. There are differences between optimising behaviour of one individual truck and optimising an entire fleet in a logistic system. In some of the later freight transport models (starting with the

SMILE model) the logistic decisions involving shippers, forwarders, distribution centres etc. are to some extent included in the models.

CAPACITY UTILIZATION AND PRODUCTION TECHNOLOGY IN TRUCKING

Capacity utilization is broadly defined as the ratio of actual output to the output corresponding to the maximum potential output consistent with a given capital stock (Nelson, 1989). It may have specific definitions depending on an economic activity under consideration; however attaining the maximum possible output out of a given set of inputs is the underlying idea. This definition focuses on physical productivity rather than economic productivity since price and cost variables are not considered. For trucking activity, capacity utilization is defined usually along the lines of its physical meaning. Aspects such as distance of movement as well as weight, volume and economic value of a cargo carried by a vehicle are considered independently or simultaneously to evaluate utilization of vehicle capacity. The extent of empty running, fuel efficiency and quality of service with regard to time performance also describe how well a vehicle is used. In the following paragraphs starting with description of production technology in trucking, a summary of various definitions (measurement) of truck capacity utilization is presented.

Production Technology

In trucking road freight transportation, the physical part of production involves a simple process of hauling a load from one point to another by a vehicle and a driver. The production technology is a simple Leontief type where always a single labour (driver) and capital (vehicle) combination is needed to produce an output (hauling a load). A driver never drives two vehicles simultaneously, or two drivers never operate a vehicle at the same time. Loading capacity of a vehicle, speed and hours of service are also limited with an implication on attainable level of productivity. As pointed out by Boyer and Burks (2009), the scope for getting more output (ton-kilometers) per truck per year by the classic manufacturing method - substituting capital for labour through automation - appears to be very limited in road freight transportation. Therefore, in order to use a vehicle-driver combination to produce a maximum level of output, it has to be driven long distance with the maximum loading capacity of the vehicle.

A unique feature of freight transportation services is that it is by nature a joint-product[2]. A vehicle movement from origin ‘A’ to destination ‘B’ (a front-haul direction) is usually followed by a reverse movement from ‘B’ to ‘A’ or to the base of operation of the vehicle if it is different from ‘A’ (a backhaul direction). Unlike passengers, freight rarely returns to its origin implying less-than optimal vehicle utilization during backhauls (return trip). This problem is referred to as “the back-haul problem” in the literature (see e.g., Felton, 1981, Wilson, 1987 and Demirel

[2] The concept of joint-product defined here should not be confused with a general treatment of a transportation firm’s out-put as a multi-product; for instance as ton-kilometers and passenger-kilometers. See Winston (1985) for an interesting discussion.

et al, 2010). Hence, optimal utilization of capacity availed to distinct directions depends on the extent to which trucks are moving loaded between them[3].

Output Measures and Capacity Utilization

In the framework of the above production process, capacity utilization of trucks is defined in several ways. A key issue in characterizing utilization is that different pictures of utilization are portrayed depending on how the output of a vehicle is defined. Spatial dimension of a trip and physical characteristics such as weight and volume of a load relative to the laden capacity of a vehicle feature independently or simultaneously. Hubbard (2003) identifies two concepts of capacity utilization. The first one relates to share of 'loaded miles' (the number of miles a truck is driven with cargo) during periods trucks are in operation away from their base. Accordingly, the relative size of 'loaded miles' to 'unloaded (empty) miles' reflects the level of capacity utilization for a vehicle. The second concept considers the number of periods trucks are in use in a given period. Seen this was, the longer the period trucks are in use, the higher will be the level of capacity utilization[4].

Using these two concepts on Danish data from 1999 to 2009 show developments like those in Figure 2.

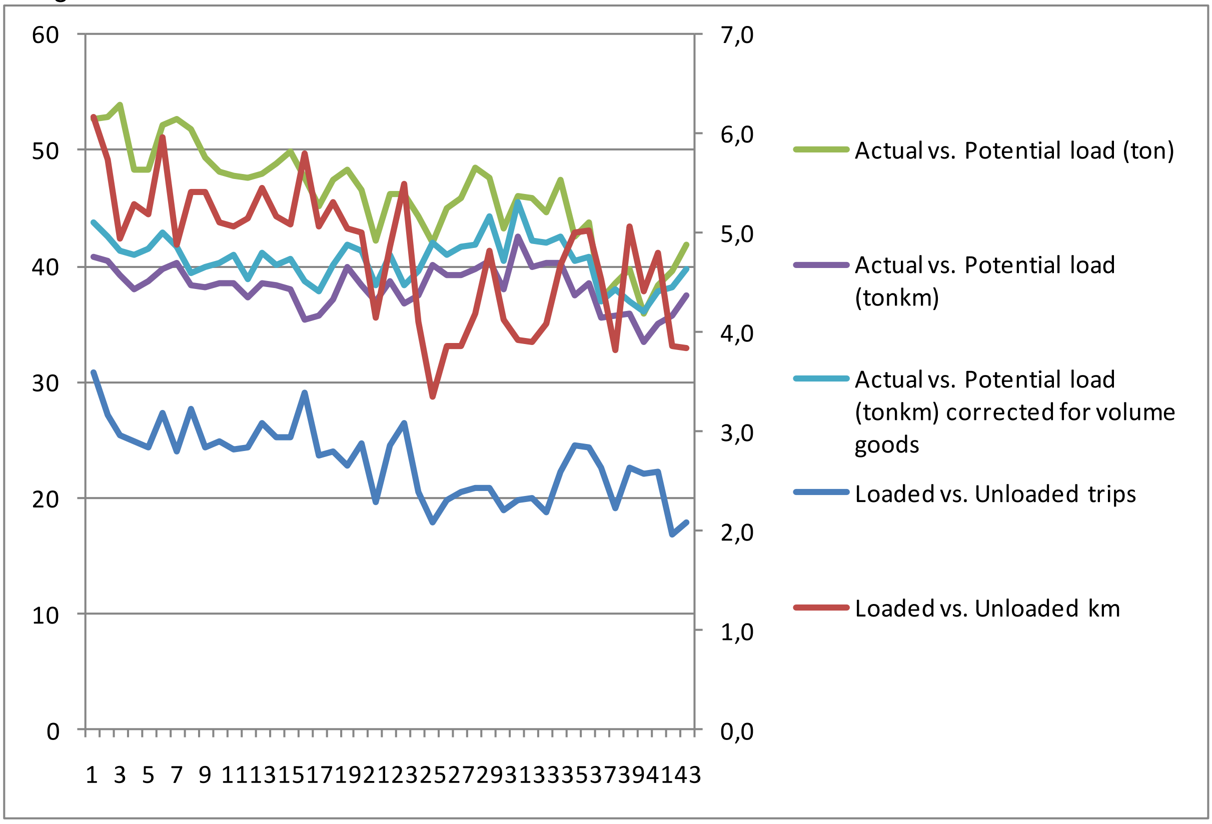

Figure 2. Different measures of capacity utilisation on Danish freight transport each quarter from 1999 to 2009

[3] Jointnes' of transport services results in cost complementarities forcing firms to serve multiple markets to minimize cost (Beilock and Kilmer, 1986).

[4] It is assumed here that being away from base of operation more often implies higher level of utilization. Such temporal consideration of truck usage is not common in the literature, but it adds an interesting perspective.

An important dimension overlooked in Hubbard's definition is the weight of a load. Failing to consider weight can be misleading since utilization also depends on how much of a vehicle's loading capacity (in terms of weight) is used. According to Hubbard's definition, two identical vehicles which transport a load over the same distance where one is carrying 1 ton and the other carrying 2 tons are considered to have equal level of capacity utilization (defined as 'loaded miles' performed)[5] . An informative comparison of utilization can be made using Ton-Kilometers (TKM) as an output measure. TKM is defined as the product of cargo weight carried and the distance over which it is shipped. Boyer and Burks (2009) use TKM to define capacity utilization (productivity) at a vehicle level as the annual ton-miles per truck-and-driver combination. As pointed out earlier, to have higher utilization a vehicle has to be driven over long distance and loaded to its maximum capacity. However, unless both dimensions - distance and weight - are taken into account it is difficult to fully capture utilization. Moreover, TKM does not consider the type of transportation service undertaken since the more kilometres a vehicle is running the better the capacity utilisation is. For instance, , if a truck is used for a specific type of delivery service, where loading and un-loading takes extended time then the truck will run only few kilometres and will not be able to have large TKM. But it may be fully loaded when it is operating. To overcome this problem, capacity utilization can also be defined as the extent of the actual versus the maximum laden capacity of the vehicles on the trips that they have actually performed. Such a definition using TKM is also shown in Figure 2.

An important dimension, volume of a load, is missing when one looks only at TKM performance. Light and voluminous items fill up physical space of a vehicle before its maximum laden capacity is reached. Vehicles carrying such items will appear less productive compared to those moving less voluminous and heavy item over the same distance. Ideally, one needs to consider distance travelled by the vehicle, weight and volume of the load carried to make comparison of capacity utilization of vehicles. As indicated by Femie and McKinnon (2003), quality of service with regard to 'time utilization' and deviation from schedule as well as fuel efficiency should also be quantified to know how truck hauling capacity is effectively utilized. Finally, note that the above definitions of capacity utilization take into account only the physical (engineering) aspect of freight transport service since their focuses is on vehicles rather than firms.

Empty Running and Capacity Utilization

Empty running is another important indicator of the extent of capacity utilization. It arises when trucking carriers provide capacity to several locations (markets segments) and choose to access only some of them due to unavailability of load or vehicle routing decision. A vehicle moving in a round trip between two locations may choose to carry a load on the front-direction and run empty during backhaul or vice-versa. For a vehicle moving in a complex pattern, empty runs occur at several stages of its journey. Barla et al (2010) identify three such stages: first, at initial stage of a journey empty runs occurs if vehicles' base is not close to the shipment origin; Second, empty runs arise during a backhaul trip, since demand from a

[5] Hubbard (2003) acknowledges this limitation and refers to lack of reliable data on weight as the main factor to resort a capacity utilization measure solely based on distance.

client is rarely bidirectional (typical feature of freight movement); and finally, empty runs occur during return trip if a truck is diverted in order to pick up a backload. It is important to note that in some of these situations empty running is inevitable. For example, geographical imbalances in freight movement forces trucks to run empty during backhaul from a net freight importing region. It is also impractical to find a back load for specialized vehicles such as oil tankers in to which loading edible oil is impossible (McKinnon and Gee, 2006)[6]. Seeing vehicle utilization solely based the extent of empty runs may portray incomplete picture since utilization also depends on vehicle routing problem faced by the operators and the activity which initiates the movement at first place.

Generally, empty running can be considered as a reflection of sub-optimal capacity utilization when it arises due to a matching problem between demand and supply. From an individual operator's point of view there might be cases where running empty in specific direction is optimal and hence load is not searched (for example, to pick a load in another location). For an operator choosing to operate in this fashion, the price received for a movement of load in the accessed market reflects the cost of operating a vehicle to locations for which capacity is supplied but not utilized. From societal point of view, however, where the objective is sometimes to minimize vehicle movements due to environmental concerns, empty runs that could have been loaded are considered as underutilized capacity. In the next section, studies which discuss underlying determinants of capacity utilization are discussed.

The 'capacity utilization of Danish trucks indicated by the share of empty running is also shown in Figure 2 above. When we compare the different utilization measures it is evident that they each tell us something different about the usage and that they cannot be interchanged for each other. This shows the importance of choosing the right capacity measure that suits the specific purpose for the analysis and that comparing capacity utilization should be done with care.

DETERMINANTS OF PRODUCTIVITY IN TRUCKING

Lessons from the Economics Literature

Studies from the economics literature aim at finding determinants of empty running and capacity utilization of trucks giving particular emphasis to underlying behavioural issues. They give theoretical and empirical analysis for questions such as: why does a truck or a carrier to be precise, choose to access some market segments (origin-destination pairs) and not others? why do we see empty trucks alongside fully loaded trucks starting from the same origin and going to the same destination? Answers to the first question explain the determinants of individual carrier's vehicle utilization while answers for the second question explain carriers' market behaviour. The two common factors, more or less exogenous, that determine how well trucking carriers use their capacity are distance and the respective freight movement imbalance between market segments. The effect of these two factors and

[6] McKinnon and Ge (2006) also indicate lack of transparency in the road freight market, short haul lengths, scheduling constraints and the incompatibility of vehicles and loads as possible causes of empty running.

regulatory environment on rate of capacity utilization is thoroughly analyzed by Wilson and Beilock (1994), Wilson and Dooly (1993) and Beilock and Kilmer (1986) for the US trucking industry. Recent studies focus more on the structure and the relative efficiency within the trucking sector arising from information technology capabilities of trucks (Barla et al, 2010 and Hubbard, 2003). In what follows, we review these studies in some detail.

Market Access Decision

We summarize Beilock and Kilmer's (1986) conceptual model that is based on net revenue maximization to demonstrate the effect of regional freight imbalance and distance between market segments on the rate of truck capacity utilization (particularly market access decision of a trucking carrier. The model one of the first approaches to investigate the carrier decisions process. Although it is simple, this model generalizes how subsequent studies frame the capacity utilization and empty running problem in trucking. In a general sense, carriers consider the difference between freight rate and cost of providing service comprising fixed costs, running costs and opportunity cost. The model gives interesting insights into the two questions raised earlier; why does a truck carrier choose to access some locations and not others? And why do we see empty trucks alongside fully loaded trucks starting from the same origin and going to the same destination? According to Beilock and Kilmer (1986), regional freight flow imbalance results in 'committed carrier' and 'uncommitted carrier'. 'Committed carriers' are defined as carriers moving in a specific direction regardless of being loaded or empty. On the other hand, 'uncommitted carriers' move in this direction only when they are loaded. In the outbound direction from a net importing region, where the marginal suppliers are 'committed carriers' it is more likely to see a prevalence of empty running since trucks move regardless of being loaded or not. Conversely, carriers heading to a net importing region are largely 'uncommitted carriers' since they go to the region only if there is an inbound load.

For a carrier committed to go between locations 'i' and 'j', a decision to haul a load between them is based on the following net revenue function:

$$\pi_{ij} = RATE_{ij} - DSC - PLU - RCD_{ij} + (RATE_{jk})(DPR) \quad (1)$$

Carriers consider the difference between freight rate between 'i' and 'j' ($RATE_{ij}$) and the direct costs and opportunity cost of providing the transportation service. The second and third terms on the right hand side are direct search costs (DSC) and peaking, loading and unloading costs (PLU) respectively. They are incurred only when the carrier decides to haul a load and hence avoidable if no load is carried. RCD_{ij} Stands for a running cost differential defined as the cost differential between empty running cost (ERC) and full running cost (FRC)[7]. The last term on the right hand side captures the proportional change in freight rate from 'j' to 'k' ($RATE_{jk}$) to which the carrier expects to haul a load after reaching at location 'j'. The proportional change is captured by $DPR,$ which in turn is the difference between the proportions of $RATE_{jk}$expected to be in force when the carrier arrives at 'j' from 'i' with a full

[7] ERC are sunk costs such as expenditures on drivers wage and fuel that are incurred whether a truck is loaded or not. FRC include all incremental costs such as increased fuel consumption as a result of moving loaded rather than empty.

load and the expected proportion in force if it arrives empty. If $RATE_{jk}$ are expected to go down as the carrier spends more time searching and hauling load between i and j, net revenue from accessing segment i and j goes down.

If all carriers are offered identical rates at i and all the cost components are assumed to be similar across carriers, it is easy to show that the cost differential between 'committed' and 'uncommitted' carriers is the empty running costs (ERC). 'Uncommitted carriers' treat the full running cost as marginal (avoidable) cost while for 'committed carriers' the marginal cost is the running cost differential (RCD). If ERC is an increasing function of distance, which is clearly the case, as the distance between 'i' and 'j' increases large number of 'committed carriers' would seek a load[8]. Therefore, distance between locations is a key determinant for a carrier's market access decision.

Beilock and Kilmer (1986) also consider the case of multiple 'committed carriers' decision to haul a load to a net importing region to explain market behaviour. Why do some carriers go empty and others go loaded when all start from the same city and travel to the same location? This is a similar question to why does net revenue differ among 'committed' carriers. Assuming the distribution of rates offered at i are identical and small difference in RCD_{ij} between carriers (at least for carriers operating similar equipment), the difference in net-revenue between the carriers arises with respect to DSC,PLU, and the expected proportional change in rate expected at j $(RATE_{jk})(DPR)$Note that the cost variations between carriers leading to differences in net-revenue between carriers are not distance related. Hence, the difference in costs can be captured in a probability distribution which is not distance related. The expected net revenue for an average committed carrier is[9]

$$E(\pi_{ij}^{a}) = \{(RATE_{ij} - RCD_{ij}) - \int_0^\infty CST[dF(CST)]\} \qquad (2)$$

Where CST is DSC+PLU, - and dF is the cumulative distribution of CST. If the condition holds, the expected net revenue has a positive slope with distance. Equation 2 summarizes the two main conclusions of Beilock and Kilmer (1986). First, with distance increasing between i and j, an increasing proportion of 'committed' carriers would seek a load. Second, the net revenue variation and hence the market access decisions between similar carriers arises from cost variations not related on distance. Hence, to the extent to which there are differences in 'access costs' which are not distance related across similar carriers we see some of them hauling load while others running empty. As a specific example, Wilson and Beilock (1994), Wilson and Dooly (1993) and Beilock and Kilmer (1986) show that systematic variation of access costs across carriers stemming from restrictive regulatory regime is the reason why there are loaded and unloaded trucks going to the same destination starting from the same origin.

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[8] If rates tend toward the costs of the marginal supplier (i.e., competitive conditions) and if uncommitted carriers are the marginal suppliers (as would be expected for hauls to net importing regions), then the differential between rates and committed carrier costs will increase with distance. Thus for committed carriers hauling into a net importing regions$\frac{\partial \mathrm{RATE}}{\partial \mathrm{DIS}} > \frac{\partial \mathrm{COST^C}}{\partial \mathrm{DIS}}$, this in turn implies$\frac{\partial \pi}{\partial \mathrm{DIS}} > 0$.

[9] This generates a distribution of net-revenues across carriers with a mean which may be influenced by distance but with the other moments of the distribution being invariant to distance Beilock and Kilmer (1986).

Finally, note that optimal decision in net revenue maximization framework assumed in the studies summarized above may not be similar to other alternative objectives of firms such as fleet optimization and/or deriver optimization. For example, drivers may have to call at their home base at a pre-specified time to pick another load, for vehicle maintenance or to change derivers as a result forcing them to skip a loading opportunity during a backhaul[10]. Note that the reviewed studies focus on trucks travelling on round trip between two locations (Wilson and Beilock, 1994) or only on one leg of a truck's journey (Barla et al ,2010). This is a rather simplistic depiction of a complex freight vehicle movement which involves a journey with several segments or trips. The reasons often cited for such an approach is limited data availability and analytical tractability. A realistic analysis, however, needs to consider all segments of a truck's movement.

Information Technology and Capacity Utilization

Banister and Stead (2004) note that logistics and freight distribution is the area in which the impact of information and communication technology (ICT) on transportation is the greatest. The 'perishable' nature of transportation services requires strong coordination to match specific vehicle capacity with specific demand. Higher capability to match capacity with demand gives an edge to carriers to keep their trucks on the road and loaded more often. Insofar as carriers' access cost is affected by such capabilities, market access decision and rate of utilization of capacity is expected to vary between them. This is the basic assertion recent studies by Barla et al (2010) and Hubbard (2003) aimed at finding the impact of information and communication technology (ICT) on the productivity of trucks. They claim that the level of capacity utilization of trucks equipped with ICTs is higher. The following paragraph briefly summarizes these studies.

Hubbard (2003) analyzes the effect of on board computers and electronic vehicle management systems on truck's physical productivity. He shows the number of periods trucks are in use and the number of loaded miles per period in use is positively affected by this capabilities[11]. Aided by ICTs, dispatchers can allocate trucks across existing orders and market excess capacity better than they otherwise could. This, in turn, can lead to better matches between truck capacity and demands within and across firms. Furthermore, better matches boost capacity utilization and productivity in the industry[12]. Hubbard finds $ 16 billion as the general productivity gains associated with ICTs use as of 1997. Barla et al (2010) also study the impact of specific type of ICT namely, electronic vehicle management systems (EVMS), on the load factor (LF) of heavy trucks. LF is assumed to be a function of truck, trip, and carrier characteristics. They argue that by reducing coordination costs between demand and supply, EVMS reduce empty runs. Using data at operational level they

[10] Under some circumstances trucks with company logo on their body may simply choose to go empty to do a moving advertisement (this could be more prevalent in the case of own-account operators).

[11] However, this finding is recently questioned by Boyer and Burks (2009) arguing that Hubbard (2003) did not take into account traffic composition effect that may inflate productivity gains. Using similar dataset but controlling for firm heterogeneity and changes in traffic composition, Boyer and Burks (2009) demonstrate that physical productivity improvements in the U.S. trucking industry have been relatively modest.

[12] Chakraborty and Kazarosian (2001) also find positive impact of IT capabilities on productivity by controlling for marketing objectives such as on-time-performance vs. lower rate carrier.

also show that the positive impact of EVMS on loading backhauling trucks is to some extent reduced by the carriers' decision to accept less attractive front-haul shipments[13].

The impact of ICTs on vehicle utilization can be viewed within the Beilok and Kilmer's market access decision conceptual model. Congruent to the models conclusion, ICTs lead to different utilization levels for rather similar vehicles by creating access cost differential between carriers not related to distance and freight imbalance between regions. Distance between market segments targeted to serve and freight flow imbalance between them feature as main factors in the short run when carriers choose their principal base of operation. In the long run, any location advantage is exploited by all carriers as they will conveniently locate their base near major traffic generators like ports, retail outlets and distribution centres etc. Systematic cost differential to access freight markets is, therefore, expected to come from other sources such as ICT capabilities.

Lesson from the Transportation Literature

In the transportation literature the issue of vehicle capacity utilization and the empty running problem is discussed under freight demand modeling and a vehicle routing problem (VRP). Interested readers are referred to Jordan and Burns (1986 and 1984) for interesting discussions of truck backhauling as part of a VRP. In the present study, we give a short review from the freight demand modeling studies with particular emphasis on trip chain or tours in urban freight movements. We think this is the area where there is a potential for the two strands of literature to complement each other. Little is known about the behavioral underpinnings resulting commercial vehicle tours. What we know already is from studies based on either simulation or limited data. Starting with general discussions on freight demand modeling, we present review of these studies in this section.

Freight Demand Modelling

There are two major freight demand modeling platforms: commodity based modeling and vehicle based modelling (Holguın-Veras and Thorson, 2000; Federal Highway Administration, 2007)[14]. The difference between them lies on the level of emphasis put on various dimension such as weight, volume, number of vehicle trips, and economic value of the commodities being transported. In the case of commodity based modeling, the weight and volume of the freight are the main units of analysis. The assumption is that by focusing on the characteristics of the commodity being transported, it is possible to capture the underlying economic activity which gives rise to vehicle movements. The limitation of commodity based models is their inability to predict empty trips and hence the level of vehicle capacity utilization. The limitation is ameliorated by vehicle based models which use vehicle trips to estimate freight demand. As pointed out by Holguin-Veras and Thorson (2000),

[13] Barla et al (2010) also report that EVMS have improved the energy efficiency of adopting trucks by about 5%.

[14] Here, the concept of demand refers to the flow of freight or the level of freight transportation demanded. See Boyer, 1997 for an interesting comparison of this concept to when demand is defined as a relationship between the amount of freight transportation and the price paid for it. In addition, refer Winston (1983) for review of freight demand studies based on econometric aggregate and disaggregate econometric models.

vehicle based models in turn overlook the characteristics of cargoes that play an important role in the vehicle selection, mode choice and routing process. Furthermore, these models have limited applicability to multimodal freight transportation systems because of their focus on the vehicle trip which is an outcome of prior choice process (Holguin-Veras and Jara-Diaz, 1999, McFadden et al., 1986 and Abdelwahab, 1998).

There have been two different approaches to overcome the problems that arise from focusing either on commodity or vehicle movements in the context of urban freight movement. Wang and Holguin-Veras (2008) refer to them as: 'Hybrid models' (which estimate commodity flows between origin-destination pairs and delivery routes) and 'tour models' (which directly estimate tours based on logistic considerations, tour-based behavioral models, activity models or profit maximization behavior). The common feature of these approaches is consideration of vehicle tours directly or indirectly. But they differ on the extent of treatment of underlying behavioral support for the way individual tours are generated. What is lacking in both is a deeper analysis of the determinants of capacity utilization of vehicles used for goods-transport. There are further rooms to improve our understanding by including the role played information technology capabilities on trip chaining behavior. In addition, explicit inclusion of operators' objective function disparities as a result of being an own-account operator or for-hire operator and its impact on a type of tour undertaken can make the analyses complete.

As indicated in section two, the level of capacity utilization of freight vehicles depends on the distance range they are used. Inter-city (regional) freight movements usually tend to be more efficient since high emphasis is put on load aggregation to avoid empty running and less-than-fully loaded movements. On the other hand, in short range or urban settings, vehicles are usually used in a less efficient manner since several stops are involved. Recent studies on freight demand modeling try to characterizing 'trip-chain' or 'tour' based vehicle movements involving several stops. Their main theme is incorporating empty trips and 'trip-chain' behavior in freight demand modeling. These studies are analyzed from a traffic modeling point of view in which the aim is estimation of directional traffic. Other than depicting directional traffic, they do not deeply analyze underlying causes of why some vehicles run empty and others don't. However, there are interesting behavioral analyses of capacity utilization of vehicles with regard to 'trip chain' movements. In what follows, brief review of some of these studies is given.

Trip chain and Capacity utilization

'Trip chain' or 'tour' is used interchangeably in the literature to describe vehicle movement involving several stops. According to Wang and Holguin-Veras (2008) a trip is defined as an individual vehicle movement connecting an origin to a destination for a specific purpose, and an entire journey comprising two or more trips is 'trip chain' or 'tour'. Trip-chain is a typical feature of urban freight vehicle movement. Vehicles usually serve several destinations in succession before finally returning back to their base which usually lies in peripheries of cities or near major traffic generators such as distribution center or ports. Previous studies from Denver, USA (Holguin-Veras and Patil, 2005), Calgary, Canada (Hunt and Stefan, 2005), and Amsterdam, the Netherlands (Vleugel and Janic, 2004) report an average stops per tour of 5.6,6 and 6.2 respectively.

Figliozzi (2007) gives theoretical analysis of efficiency of urban commercial vehicle tours with regard to their generation of vehicle kilometres travelled (VKT) assuming a simple scenario where several destinations in urban area are served from a single distribution centre. He argues that the efficiency of tours depends on the requirements of commercial activity which initiates the tours and vehicle routing constraints imposed by truck capacity, frequency of service, tour length and time window length. Similarly, Holguin-Veras and Thorson (2003) also depict the number of empty trips as a function of the routing choices that the commercial vehicle operators make, which in turn are based on the commodity flows in the study area. Figliozzi's (2007) findings indicate that multi-stop tours are shown to generate more VKT than direct deliveries even for equal payloads. Another interesting finding is that the percentage of empty trips has no correlation with the efficiency of the tour regarding VKT generation. According to Figliozzi (2007) looking at the share of empty trips as a measure of efficiency can be misleading since direct delivery tours, the most efficient tours, have always 50% share of empty trips while for the less efficient multi-stop tours the share declines with number of stops. Using data from a single truck engaged in less than-truck-load (LTL) delivery tours in the city of Sydney, Figliozzi et al (2007) also shows that there is no clear relationship between tour distance, percentage of empty trips, and percentage of empty distance. It has to be noted that the context of these studies is urban transport where distance travelled is already short and as such the gain from lower VKT and efficiency is limited.

An empirical analysis using a synthetic dataset of trip chaining behaviour is given by Wang and Holguin-Veras (2008). Even though their study is entirely based on simulation, it gives interesting insights into determinants of destination choice and decision to end a tour using discrete choice models. Destination choice is modeled using Multinomial Logit where the choice set is updated at every nod of the trip chain. At each node, a vehicle is faced with four alternative destinations randomly selected based on criteria set by the median distance between all nods in the network (this is similar to a 'Stratified Importance Sampling Technique' suggested by Ben-Akiva and Lerman, 2000). Wang and Holguin-Veras (2008) report that the choice of next destination is negatively affected by the distance from the current location to the potential destination and it is positively affected by the amount of cargo available for pickup and delivery. As for tour termination decision, the utility derived from tour termination declines with the increase of return distance and increases with the accumulation of cargo delivered.

A detailed analysis of urban tour-based vehicle movements for the city of Calgary in Canada is given by Hunt and Stefan (2007). The analysis uses a tour-based micro-simulation to model movements made by light vehicles and heavier vehicles with single unit and multi-unit configurations operating in all sectors of the economy. The overall simulation is based on models of tour generation and subsequent sub-models which determine vehicle and tour purpose, next stop purpose and next stop location. To determine the probability of the next stop's purpose in a tour (which includes carriage of goods, service stops, return-to-establishment and other stop categories), a Logit model is used. The total number of previous stops is shown to decrease the propensity to return to establishment, indicating that tours with a large number of stops are less likely to end on a given next stop. In addition, the time elapsed in travel is shown to impact the propensity to end tours more than the total time elapsed (including both travel time and stop time). Once the purpose of the next top is known, they use another Logit model to determine the location of the next stop. Accordingly, they show that the tendency for the next stop on a tour to be near the current stop is greater than the tendency for the next stop to be near the establishment. Both models are estimated for 13 different segments of commercial movements based on combination of industry category, vehicle type and tour (stop) primary purpose.

The reviewed literature in this section highlights the importance of explicit consideration of trip chaining behaviour to gain insights into commercial vehicle movements. The amount of VKT generated can be an interesting aspect to look into to evaluate efficiency. However, the share of empty trips of a tour is a poor indicator of efficiency with regard to VKT. It appears that there is a big challenge with regard to finding data as some of the studies are based on simulation and information gathered from operation of a single vehicle. To test some of the theoretical findings, future studies should be based on dataset that contain both the full movement of vehicles over several weeks or months and information on the owners of the vehicles.

CONCLUDING REMARKS

In this paper a review of studies on capacity utilization of freight vehicles is presented. We classified the studies to general categories of either transportation or economics literature, which appeared to address the issue from different perspectives. The two approaches have apparently not benefitted from each other. According to the economic theory approach, vehicle capacity is underutilized as a result of constant challenge of matching capacity with demand arising from freight movement imbalances between regions and market access cost differential between operators. The problem caused by freight imbalances is considered as an external (exogenous) problem that operators can only minimise through appropriate location of their principal base of operation near major traffic generators at least in the long run. However, operators have to make continual market access decision as part of the challenge to match specific demand with specific capacity based on net revenue considerations. Accordingly, to the extent to which there are differences in access costs which are not distance related, we see some vehicles running with a load while others running empty across similar market segments and carriers. Recent studies from this strand of literature show the effect of information technology capabilities to match capacity with demand by enabling carriers to keep their trucks on the road and loaded more often by lowering market access costs. We note that despite simple production process involved in the physical part of transportation process, measuring capacity utilization is complex due to the extraordinary heterogeneity in terms of weight and volume of a load, direction and distance of vehicle movement. Therefore, a realistic efficiency analysis should account for such heterogeneity that may lead to productivity differences arising from the various settings in which vehicles are used.

In the transportation literature, the recent focus is on the relationship between 'trip-chain' and the vehicle routing problem faced by operators in urban freight transportation context where utilization is lower compared to long haul operation. It is shown that unless the commercial activity which initiates vehicle movements is taken into consideration, measures such as the share of empty trips (or distance) can be a poor proxy as efficiency measure when utilization is compared with regard to creation of vehicle kilometres travelled (VKT). The trip-chain approach to analyze urban freight movement can improve the modelling of freight transport demand greatly. An even more interesting analysis is the potential of using the information contained in data about trip chaining in relation to the firm optimisation behaviour investigated in the economics literature. The trip chain approach also adds a spatial element to the firms' desire to match capacity with demand. The analysis of the operators' choice of optimal location of their principal base may very well be affected by the specific inclusion of trip chain information. Moreover, including trip chains and/or the relationship between loaded trips and empty trips in the analysis of the matching behaviour will increase the predictive power of such analysis.

Finally, empirical analyses of the scope of possible gains from improved capacity utilization are limited. More studies are needed along MacKinnon and Ge (2006) study to put into perspective how much can be gained by improving empty runs. It is also interesting to know how the desire for sustainable transport can be accommodated within the objective of transport operators which is usually based on economic efficiency. The recent freight transport modelling approach, where the logistic decisions are involved to better predict vehicle movements is an obvious link between the operators' pursuit of efficiency analysed in the economics literature and the freight transport models. The determinants in the operators' decision making influence capacity utilisation and thus also the vehicles that are loaded onto the network in the assignment models. A joint estimation of firm optimising behaviour and the logistics of freight transport models will thus be a natural research objective to investigate further

References

Abdelwahab, W.M., 1998. Elasticities of mode choice probabilities and market elasticities of demand: evidence from a simultaneous mode choice/shipment size freight transport models. *Transportation Research. Part E: Logistics & Transportation Review* **34** (4), 257–266.

American Trucking Associations. *American trucking trends 2000*. Alexandria, VA: Transport Topics Press, 2000.

Banister, D., Stead, D. (2004) Impact of Information and Communications Technology on Transport, *Transport Reviews*, **25**(5), pp. 611–632.

Ben-Akiva, M., and S. R. Lerman. *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge, Mass., 2000.

Barla, P., Bolduc, D. and Boucher, N, 2010. Information Technology and Efficiency in Trucking. *Canadian Journal of Economics*. **43** (1), 254-279.

Beilock, R. & Kilmer, R. 1986, The Determinants of Full-Empty Truck Movements. *American Journal of Agricultural Economics*, **68**(1):67-76.

Boyer, K.D., 1998. Principles of Transportation Economics. Massachusetts, Addison-Wesley Reading. pp. 48-49.

Boyer, D. Kenneth and Burks, V. Stephen, 2009. Stuck in the Slow Lane: Undoing Traffic Composition Biases in the Measurement of Trucking Productivity. *Southern Economic Journal* **75**(4), 1220-1237

Chakraborty, Atreya & Kazarosian, Mark, 2001. "Marketing strategy and the use of information technology: New evidence from the trucking industry," *Research in Transportation Economics*, Elsevier, vol. 6(1), pages 71-96, January.

Demirel, E., van Ommeren, J., Rietvelde, P. (2010) A matching model for the backhaul problem *Transportation Research Part B*. **44**(4) 549–561.

de Jong, G., Gunn, H., Walker, W., (2004). National and International freight transport models: an overview and ideas for future development. *Transport Reviews* **24** (1), 103–124.

Federal Highway Administration (2007). Quick Response Freight Manual. U.S. Department of Transportation, Washington Dc.

Felton, J.R., 1981. The impact of rate regulation upon ICC-regulated truck back hauls. *Journal of Transport Economics and Policy* **15** (3), 253–267.

Fernie, J., Mckinnon, A., 2003. The grocery supply chain in the UK: improving efficiency in the logistics network. *International Review of Retail, Distribution & Consumer Research* **13** (2), 161–175.

Figliozzi, Miguel A. 2007, Analysis of the efficiency of urban commercial vehicle. *Transportation Research Part B*, **41**,1014–1032

Figliozzi, M., Kingdon, L., Wilkitzki, A., 2007. Commercial vehicle tours and road congestion in urban areas: implications for carriers' operations and public data collection and dissemination efforts. In: Proceeding of the 86th Transportation Research Board Annual Meeting CD rom – January 2007, Washington, DC, USA.

Goodwin, P., J. Dargay, and M. Hanly (2004). Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. *Transport Reviews*. **24** (3), 275-292

Graham, G. and S. Glaister (2004). Road Traffic Demand Elasticity Estimates: A Review. *Transport Reviews*, **24** (3), 261-274

Holguın-Veras, J., Jara-Dıaz, S., 1999. Optimal space allocation and pricing for priority service at container ports. *Transport Research Part B* **33** (2), 81–106.

Holguın-Veras, J., Thorson, E., 2000. An investigation of the relationships between the trip length distributions incommodity-based and trip-based Freight demand modeling. *Transportation Research Record* #**1707**: 37–48,September 2000.

Holguin-Veras, Jose and Patil, Gopal R, 2007. Integrated Origin-Destination Synthesis Model for Freight with Commodity-Based and Empty Trip Models. *Transpiration Research Record*, JTRB No**. 2008**, 2007, pp 60-66.

Holguin-Veras, J. and Thorson, E, 2003. Modeling commercial vehicle empty trips with a first order trip chain model. *Transportation Research Part B*, Vol. **37**, pp. 129-48.

Hubbard, Thomas, 2003. Information, decisions, and productivity: On board computers and capacity utilization in trucking. *The American Economic Review* **93**(4): 1328-53.

Hunt, J., and Stefan. K., 2007. Tour-based microsimulation of urban commercial movements. *Transportation Research Part B, 41* ,981–1013

Jordan W. C. and Bums L. D. (1984) Truck backhauling on two terminal networks. *Transportation Research B*, **18**(6) 487-503.

Jordan W. C. and Bums L. D. (1987) Truck backhauling on networks with many terminals *Transportation Research B*, **218**(3) 183-193

Kveiborg, O. And M. Fosgerau (2007). Decomposing the decoupling of freight traffic growth and economic growth. *Transport Policy*, **14**, 39-48, 2007.

McFadden, D., Winston, C., Boersch-Supan, A., 1986. Joint estimation of freight transportation decisions under nonrandom sampling. In: Daugherty, A. (Ed.), *Analytical Studies in Transport Economics*. Cambridge University Press, Cambridge.

McKinnon, A. (2007) Decoupling of Road Freight Transport Economic Growth Trends in the UK: Ana Exploratory Analysis, *Transport Reviews*, **27**(1), pp. 37–64.

McKinnon, A., Ge, Y. (2006) The potential for reducing empty running by trucks: a retrospective analysis. *International Journal of Physical Distribution & Logistics Management*. **36**(5) 391-410

McKinnon, A. C. (1996). The empty running and return loading of road goods vehicles. *Transport Logistics*, **1**(1) pp. 1–19.

Nelson, Randy A. 1989, On the Measurement of Capacity Utilization. *The Journal of Industrial Economics*. **37**(3):273-286

Raothanachonkun , p., Wisetjindawat , W. and Matsumoto, S., 2007. Estimating Truck Trip O-D with Commodity-Based and Empty Trip Models. *Transportation Research Record*, JTRB No. **2008**, 2007 pp 43-50

Transport Canada (2003) *Les transports au Canada, Rapport Annuel 2003 et 2004.* Available on line. http://www.tc.gc.ca/pol/fr/rapport/anre2004/toc f.htm

Vleugel, J., Janic, M., 2004. Route choice and the impact of 'logistic routes'. In: Taniguchi, E., Thompson, R. (Eds.), *Logistics Systems for Sustainable Cities*. Elsevier.

Wang, Q., Holguin-Veras, J. (2008). Investigation of Attributes Determining Trip Chaining Behavior in Hybrid Microsimulation Urban Freight Models Transportation Research Record: *Journal of the Transportation Research Board*, No. **2066**, Transportation Research Board of the National Academies, Washington, pp. 1–8.

Wilson, W.W., 1987. Transport markets and customer behavior: the backhaul problem. *Journal of the Transportation Research Forum* **28** (1), 325–333.

Wilson, Wesley and Beilock, Richard. 1994, Market Access in Regulated and Unregulated Markets: The Continuing Cost of Interstate Motor Carrier Regulation. *Journal of Regulatory Economics* **6**:363-379

Wilson, Wesley and Dooley. 1993, Frank. An Empirical Examination of Market Access. *Southern Economic Journal* **60**(1): 49-62

Winston, Clifford, 1985. Conceptual Development in the Economics of Transportation: An Interpretive Survey. *Journal of Economic Literature*, American Economic Association, 23(1): 57-94,

Winston, Clifford 1983 . The Demand for Freight Transportation: Models and Applications. *Transportation Research* 17(a): 419-27.