Forecasting Tools for Analyzing Urban Land Use Patterns and Truck Movement

Case Study and Discussion of Results

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Many urban planning efforts have supported development in dense, mixed-use areas, but tools are not widely available to help understand the relationship between urban form and goods movement. A review is presented on the status of urban goods movement forecasting models to account for the impacts of density and mixed land use. A description is given of a series of forecasting model runs conducted with state-of-the-practice tools available at the Puget Sound Regional Council. By comparing dense, mixed-use scenarios with different baseline and transportation network alternatives, the ability of the model to capture the relationship between goods movement and density is evaluated. The paper concludes with a discussion of the implications of the results for truck forecasting and freight planning.

Some recent planning efforts have supported development in dense, mixed-use areas (*1–8*), but tools are needed to forecast the impact of these land use patterns on truck movements.

Early transportation models were concerned with high-capacity freeway networks and were focused on automobile use and monocentric city design, which minimized the predictive power of these models to consider goods movement and polycentric urban form (*9*). Spurred by the Clean Air Act Amendments of 1990 (42 U.S.C. §7401) and the Intermodal Surface Transportation Efficiency Act of 1991 (H.R. 2950), travel demand forecasting models have become more complex, with greater capabilities to consider emissions and traveler behavior. Unfortunately, advancements in activity-based models for passenger vehicles have yet to translate into practical models for freight specifically for truck movements.

Because of supply chain complexity, transportation models that can capture this diversity of goods movement activity are not readily available for comprehensive policy analysis. Meanwhile, microsimulation models and logistics routing tools able to capture detailed urban goods movements do not provide travel demand forecasts necessary to support regional planning.

This paper examines the state of the practice in regional modeling to capture the impacts of density-targeted policies on truck patterns. Understanding this relationship and capturing it in tools are critical to protecting goods movement access and economic vitality within long-range comprehensive planning.

This paper begins with a review of the current methodologies and applications of urban truck forecasting models to account for the impacts of density and mixed land use. The paper then describes a series of model runs conducted with state-of-the-practice tools available at the Puget Sound Regional Council (PSRC). Despite the limitations of existing truck forecasting tools, the model runs aim to capture the relationships of dense, mixed land use; transportation investments; and truck travel. The applications of the model highlight the strengths and weaknesses in the model's ability to capture freight dynamics. The paper concludes with a discussion of the implications of the results for truck forecasting and freight planning.

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LITERATURE REVIEW

Urban forecasting models that account for trucks are relatively common in large urban areas with many of the modeling programs operated by metropolitan planning organizations (MPOs). TRB surveyed metropolitan planning organizations about travel modeling and noted, "Truck trips are modeled in some fashion by about half of small and medium MPOs and almost 80 percent of large MPOs" (*10*). While many MPOs have some accommodation for trucks in their modeling efforts, they are inadequate for understanding the impacts on trucks from land use patterns.

Trucks and the Four-Step Modeling Process

A still relevant overview of the state of truck modeling is provided in the 2008 *NCHRP Synthesis of Highway Practice 384: Forecasting Metropolitan Commercial and Freight Travel* (*11*). That report identified urban goods movement forecasting methods in professional practice and completed a survey of organizations with active urban goods movement modeling programs. The report provided case studies highlighting more innovative goods movement forecasting methods and approaches. NCHRP Synthesis 384 noted that almost all metropolitan planning organizations and urban areas that model goods movement are actually forecasting trucks using an adaptation of the traditional four-step process common in passenger forecasting. The four-step process estimates trip productions and attractions, matches these productions and attractions into origin–destination pairs, assigns trips between origin–destination pairs to modes, and then selects routes for each set of trips (*12*). The four steps are adapted for truck forecasting as follows (*11*).

1. Trip Generation

For trucks, trip generation is usually an estimate of production or consumption linked to the economic activity represented within zones. Truck trips between internal locations or between locations external and internal to the study area can be factored in at this point. Several studies have found the linkage between land use (specifically employment) and truck trips to be weak, and better data are needed (*13*).

2. Trip Distribution

Truck data are often integrated into the overall model during the trip distribution step by the use of a zone-to-zone trip table (origin–destination matrix) accounting for truck travel between zones. For a truck model, the external and internal trips are added, and flows are often sorted by truck size or type. This process creates a correspondence between actual and forecast link counts. Validating this step requires truck classification counts and survey data.

3. Mode Choice

The mode choice step is not commonly used for urban goods movement models because most goods move on trucks, and freight rail, shipping, and pipelines are not usually included within these roadway-focused models. Mode choice could be used to select the type or size of trucks used but is not often done in practice.

4. Trip Assignment

All vehicles, including passenger vehicles and trucks, are assigned by type or class to the roadway network, typically using shortest path or lowest-cost travel times, often by time of day.

Reviews of these adapted four-step truck models point out limitations that reduce their ability to accurately account for the impacts of dense urban environments. One significant limitation is that the four-step process fails to account for the trip and tour (chaining) behavior of truck activity in urban areas. Goods movement is more complex than person travel because multiple actors (brokers, warehouses, trucking, and consignees) are involved in transportation decisions. In response to this complexity and in support of efficient travel, many truck drivers make multiple tours with multiple trips in each tour, but existing four-step models do not account for this behavior. Therefore, many truck models cannot capture the drivers' responses, at the level of urban streets, to density-driven network changes. For example, this type of model may do a poor job of capturing the impact of the growth in large consolidation and distribution centers and their impact on the pattern of urban truck travel (*11, 14*). These four-step models are also not capable of accounting for the impacts of truck parking or the impact that other transportation modes have on truck travel choices. While some models do differentiate between truck trip generation rates for special generators such as ports, they do not generally have the capability to differentiate among truck trip types (delivery versus drayage versus third-party logistics providers) and their routing characteristics.

Dense Urban Environments in Four-Step Passenger Transportation Models

Planning efforts to encourage what is thought of as a traditional urban environment—density, a mix of uses, and a range of travel options available—are frequently labeled as smart growth policies. For the remainder of this paper, the term smart growth will be used to describe dense, mixed-use urban environments.

Growing interest in smart growth planning has led to research into the relationship between density and travel demand, and therefore travel demand modeling. Some studies have presented techniques to incorporate the effects of smart growth into passenger-oriented four-step models (*15–19*). These studies recognize that many MPO modeling practices "have very little sensitivity to smart growth land use or transportation strategies" (*17*). One study, which assessed existing models and tools used for the analysis of smart growth, noted the following model limitations for addressing smart growth:

- Models do not recognize trip chaining.
- Models generally only consider vehicle trips and have limited transit, walking, and biking modeling capability.
- Models rely on fixed vehicle trip rates by land use type.
- Building, street, and sidewalk layout do not affect traveler choices, and land use is not affected by travel patterns.
- Decision-maker characteristics are aggregated by zone.
- Models focus on travel during peak periods.
- Travel analysis zones are often too large.
- Land use is not affected by travel patterns (*17*).

Beyond these limitations that hamper a four-step model's ability to account for smart growth, given the importance of parking, curb space, and other street-level issues (*20*), many models' inability to account for street-level design is relevant.

Current adaptations of models (*15–18, 21*) adjust for these smart growth–related limitations in passenger models by implementing

- Postprocessors run after forecasts are completed;
- Stand-alone preprocessors to apply smart growth trips and vehicle miles of travel elasticities;
- Changes or enhancements of the forecasting models; and
- Integration of land use, economic, or transportation models.

Each of these techniques requires intervention into the modeling process. Modelers in the San Francisco Bay Area assumed that smart growth would decrease overall average trip length of vehicle traffic and increase transit and nonmotorized travel use to shift the mode choice to a higher nonautomobile share (*16*). The recommended adjustment for the area's four-step model was twofold. One was to use adjustments to the socioeconomic databases. The other was to adjust the model's highway, transit, and nonmotorized networks and modify zone-to-zone travel times, distances, and costs by reducing terminal costs between in high-density, mixed-use zones. That study also proposed a review panel to approve model changes.

A study by Cervero highlighted some examples by using postprocessing to account for smart growth impacts (*15*). He noted that a four-step model's traffic analysis zone structure is too gross to be sensitive to smart growth impacts and suggested postprocessing and direct modeling to correct this problem. Postprocessing involved tweaks to adjusted model output for smart growth factors such as increased transit and pedestrian travel. An offline, stand alone model can be tailored to estimate travel for specific smart growth areas. One advantage of offline models is that they can be compared with standard model results and used to enhance or direct the four-step model output.

Similarly, *NCHRP Report 684: Enhancing Internal Trip Capture Estimation for Mixed-Use Developments,* which attempted to capture trip estimates for mixed-use developments, suggests an improved methodology for internal zonal trip generation from mixed land use neighborhoods (*20*). The modification suggested in this report would "include the effects of proximity (i.e., convenient walking distance) among interacting land uses to represent both compactness and design." If used as an input into a model process, the new input would likely reduce local overall automobile trips.

Another study using California data adjusted standard ITE trip generation estimates in smart growth areas. Land use, transit, parking, and other variables were correlated with lower vehicle trip generation. This information was used to create a smart growth factor used to adjust the generation rates (*21*).

The Environmental Protection Agency supported an effort to "accurately predict the impacts of mixed use studies" and suggests

> . . . the potential vehicle trip reductions from MXDs (Mixed-Use Developments) were significant enough to demonstrate that conventional trip generation methods could exaggerate roadway impacts . . . (*22*).

The resulting trip generation tool accounted for more internal zonal trips, more walk and transit trips, and shorter trip lengths. This spreadsheet tool is designed to update or replace the trip generation rate that had traditionally been used and derived from the ITE manual (*23*) and reduces the number of vehicle trips.

Alternative and Future Modeling Approaches

Alternatives to the four-step model are both in use and being developed. These models can be placed into two broad categories—activity based and commodity based (*11, 14*). Both styles of models have been used because they are seen as an improvement over the traditional methods of forecasting goods movement. In some cases, they also may be better at representing the impacts of smart growth.

Activity-based models, also known as trip-based or tour-based, use a demand-based approach. Unlike the traditional four-step model that uses single trips as the basic modeling step, these models forecast flow based on travel demand derived from activities that people (or goods) need to perform. Travel is based on the activities to be completed and modeled in tours. This is a significant modification to the four-step approach. Activity models may offer a more effective approach to modeling smart growth because trips made by trucks are not independent of each other and can be connected for efficiency or convenience.

A notable example of a goods movement activity-based model is the Calgary tour-based commercial vehicle model (*11, 24*). The commercial vehicle model is a combination of three models that, taken together, account for about 10% of the total travel. The tours are derived from travel diary surveys conducted at 3,000 businesses. The numbers of trips in tours are decided by an aggregate trip generation module, and then each trip is completed using a random process. This model has a stop duration module that could be modified to account for the smart growth impacts such as limited curb space and greater interaction with nonmotorized modes. Tours are also given start times, allowing flexibility to respond to time-of-day restrictions. This model has significant potential to account for the impacts of dense urban environments on truck patterns, but it requires more effort to develop and collect data.

Goods movement is a derived demand related to the need to move commodities, and not vehicles, in our economy. Critics of traditional truck models suggest that a commodity-based (as opposed to trip- or vehicle-based) model is structurally superior. One major limitation to this family of models is a notable lack of commodity flow data at the urban scale; there are not yet any full commodity-based urban freight models currently in use (*11*).

While efforts are being made to extend truck modeling (*25–28*), these are mostly research efforts and the current state of practice is inadequate to address the impact of land use patterns on truck movements. Nonetheless, it is necessary to continue to use and refine currently available tools to provide information on goods movement related policies, to better understand the limitations of the tools and their results, and to ultimately refine them. The modeling effort described further in this paper represents state-of-the-practice truck forecasting that most jurisdictions can realistically implement with limited modification to their existing tools.

MODELING METHODOLOGY

To understand the capabilities of existing tools, the analytical tools available at PSRC were used to conduct a series of model runs. These tools include state-of-the-art modeling tools (e.g., UrbanSim, a parcel-based land use model) and more traditional analytical tools familiar to other MPOs or local jurisdictions (trip-based travel demand model) [see the PSRC report for more detail on the modeling tools (*29*)]. The tools were chosen because, while they are at the forefront of available tools, other researchers and practitioners could still readily replicate this analysis to evaluate policies in their own regions.

In the model used, trips are initially developed as tours but are treated as individual trips within the later modeling steps (destination, mode, time of day, and route choice). Commercial vehicles are defined as any vehicle used for commercial purposes and can include autos, vans, sport utility vehicles, and small trucks, as well as medium and heavy trucks. These commercial vehicles are forecast by using a truck model, which includes all commercial vehicles based on relative weight classes and separates light, medium, and heavy trucks.

Description of Land Use Scenarios

PSRC completes planning activities in a four-county region in the central Puget Sound area. This 6,290-mi^2 region includes 82 cities and towns ranging from Index (population 160) to Seattle (population 662,400) (*30*). The land use scenarios employed in this analysis represent two different policy outcomes for the year 2040, measured from a base year of 2000, developed as a part of PSRC's long-range land use planning process, VISION 2040 (*31*).

Two distinct development scenarios were created to compare the impacts of broad policies such as smart growth on transportation investments (see Table 1 for details). One scenario was baseline. This scenario extended current growth patterns, without changes, to 2040;

TABLE 1 2040 Regional Growth by Scenario

Scenario	Metropolitan Cities (%)	Core Cities (%)	Large Cities (%)	Small Cities (%)	Unincorporated Urban Growth Area (%)	Rural Area (%)
Baseline						
Population	26	17	9	10	24	13
Employment	45	28	7	9	8	3
Smart growth						
Population	32	22	14	8	18	7
Employment	42	29	12	6	8	2

it relied on individual jurisdiction comprehensive plan targets. The other scenario was smart growth, which represents regional policy, countering past trends and refocusing growth in major cities and the densest urban areas.

Travel Network Scenarios

The main focus of this research is the relationship between land use patterns and truck movements. However, because smart growth land use changes often include transportation efficiencies, a transportation scenario reflecting a smart growth orientation was included to model the interaction between land use and transportation. Finally, for the sake of completeness, a highway-heavy transportation investment scenario was also evaluated. Thus, three discrete transportation networks were modeled to accompany the two land use scenarios: a baseline scenario, one that favors smart growth investments, and one that favors traditional roadway investments.

The transportation networks were developed originally for Transportation 2040 (*32*), the Puget Sound region's long-range transportation plan adopted in 2010. These three scenarios are described as follows.

Baseline Alternative

The baseline transportation network consists of the existing transportation systems and a limited series of future investments. This alternative is meant to illustrate what would most likely occur with the transportation system, assuming no interventions.

Roadway Investments Alternative

This alternative network adds roadway capacity through lane additions to existing highways, creation of several new highways, and added lanes on the regional arterial network. It adds considerable light rail capacity and a new auto ferry route across Puget Sound. The alternative adds pedestrian and bicycle infrastructure in key locations. Its demand management, bus service, and system management investments are similar to the baseline alternative. The alternative's most significant management strategy is the establishment of a two-lane, high-occupancy vehicle and toll system on much of the regional freeway network (with some one-lane, high-occupancy vehicle and toll facilities) to manage congestion and provide revenue to supplement traditional tax-based funding sources, which would provide the majority of the financing.

Smart Growth Alternative

The smart growth alternative addresses the region's transportation system needs through a combination of investments in system efficiency, many of which follow smart growth principles: strategic expansion; transit, ferry, bike and pedestrian improvements; and investments to preserve the existing transportation system. The alternative's financial strategy is based on a phased approach transitioning away from current gas taxes toward the implementation of user fees.

Model Outcomes

The model used here is not sensitive to the impacts of parking, size restrictions, or multimodal environments on truck patterns. It is, however, able to consider the impacts of density from employment-based trip generation and the routing choices associated with secondary effects of transportation improvements. The results are intended to evaluate the model's ability to illustrate these impacts, as well as the impacts themselves.

RESULTS

Six model runs were conducted to better understand the relationships among smart growth land use, transportation system investments, and truck travel. This section presents the results for the model runs by the relevant and available model metrics.

Truck Miles of Travel

Across all three transportation networks—baseline network, roadway investments, and smart growth—the smart growth land use patterns produce lower truck miles of travel. This trend is consistent across individual time periods, daily totals, facility type, and truck type (see Tables 2, 3, and 4). Notably, truck miles of travel are higher in the altered transportation networks (roadway and smart growth investments) as compared with the baseline transportation network, presumably because of induced demand associated with additional roadway capacity.

Although the truck miles of travel are consistently lower under the smart growth land use as compared with the alternative, freeway travel increases and arterial travel decreases under the two improved transportation networks. For the investments in roadway facilities, the improved freeway facilities provide less congested and faster routes than was previously the case. The smart growth transportation investments stimulate mode shift away from single-occupancy

TABLE 2 Truck Miles of Travel by Time Period

Time Period	Truck Miles of Travel (million)					
	Baseline Network		Roadway Investments		Smart Growth	
	Baseline	Smart Growth	Baseline	Smart Growth	Baseline	Smart Growth
a.m.	2.7	2.6	2.9	2.8	2.9	2.8
Midday	5.6	5.4	5.9	5.7	5.9	5.8
p.m.	2.7	2.6	2.9	2.8	2.9	2.9
Evening	1.3	1.2	1.3	1.3	1.3	1.3
Night	1.0	1.0	1.1	1.0	1.1	1.0
Total	13.3	12.8	14.2	13.7	14.2	13.8

TABLE 3 Truck Miles of Travel by Facility Type

Facility Type	Truck Miles of Travel (million)					
	Baseline Network		Roadway Investments		Smart Growth	
	Baseline	Smart Growth	Baseline	Smart Growth	Baseline	Smart Growth
Freeway	9,272	8,908	10,567	10,228	10,672	10,404
Arterial	3,066	3,019	2,608	2,534	2,550	2,462
Connector	974	934	976	936	976	936

TABLE 4 Truck Miles of Travel by Truck Type

Truck Type	Truck Miles of Travel (million)					
	Baseline Network		Roadway Investments		Smart Growth	
	Baseline	Smart Growth	Baseline	Smart Growth	Baseline	Smart Growth
Light	3,090	2,931	3,656	3,509	3,685	3,587
Medium	4,950	4,772	5,099	4,904	5,140	4,949
Heavy	5,272	5,158	5,395	5,284	5,373	5,267

vehicles and open up capacity on the freeways. However, truck travel on the connector facilities remains unchanged across all of the transportation investments, most likely because truck origins and destinations are fixed and must use local facilities to arrive at the arterial and freeway facilities; and certain types of trucking activities (e.g., package delivery, waste management) must travel on all roads for their freight-hauling purposes, creating an inelastic demand for use of those facilities.

Truck Hours of Travel

Similar to truck miles of travel, total daily truck hours of travel are generally lower in the smart growth land use scenario than in the alternative (see Table 5). However, unlike truck miles of travel, the truck hours of travel are not universally lower. Further, investments in the transportation system considerably reduce overall truck hours of travel. This second result is likely because of improved capacity on the transportation facilities, especially owing to shifts away from single-occupancy travel for passenger modes because the smart growth investments (transit and nonmotorized) have a much more pronounced effect than the roadway capacity improvements.

There are several exceptions (shown in bold) where the smart growth land use scenario has a small increase in truck hours of travel over the baseline land use scenario. In regard to overall truck performance, the fewest truck hours of travel are seen under the smart growth land use scenario with commensurate smart growth investments in the transportation system.

Truck hours of travel on different transportation facilities are also consistently lower under the smart growth land use scenario as compared with the alternative. Unlike miles of travel, the decrease in hours of travel is uniform across facilities and investments. Under the roadway and smart growth transportation investments, both freeway and arterial hours of travel are reduced. Again, the biggest

TABLE 5 Truck Hours of Travel

	Baseline Network		Roadway Investments		Smart Growth	
	Baseline	Smart Growth	Baseline	Smart Growth	Baseline	Smart Growth
Time Period						
a.m.	98,174	**96,500**	88,400	**86,311**	77,847	**76,821**
Midday	187,734	**195,332**	177,634	**170,024**	154,844	**150,975**
p.m.	113,721	**105,466**	102,819	103,555	85,604	86,094
Evening	37,768	**35,273**	36,830	**35,759**	34,513	**33,927**
Night	29,490	**28,112**	27,813	28,479	26,690	**26,449**
Total	466,887	**460,683**	433,496	**424,128**	379,499	**374,265**
Facility Type						
Freeway	270,881	**267,273**	260,905	**254,958**	211,676	**210,489**
Arterial	146,579	146,622	123,049	**122,279**	118,238	**116,849**
Connector	49,427	**46,789**	49,543	**46,890**	49,586	**46,928**
Truck Type						
Light	124,244	**120,097**	124,155	**121,741**	114,102	**112,911**
Medium	178,786	**176,064**	160,643	**156,145**	137,224	**134,091**
Heavy	163,858	164,523	148,698	**146,242**	128,173	**127,263**

NOTE: Numbers in bold indicate instances in which the smart growth land use scenario performs better than the baseline land use scenario.

impact in terms of reduction of truck hours of travel is present under a smart growth land use paired with the transit and nonmotorized transportation investments. Similar to truck miles of travel, hours of travel on collector streets are unchanged across transportation scenarios, reflecting the inelastic demand for those facilities.

Truck hours of travel for individual truck classes show similar results. The smart growth land use scenario generally provides a reduction in truck hours of travel of the baseline land use scenario. In addition, the smart growth land use scenario coupled with investments in transit and nonmotorized transportation improvements leads to the largest potential reductions in overall truck hours of travel for all three classes of trucks as compared with the other potential alternatives.

Truck Delay

Overall daily delay for trucks is slightly higher for the smart growth land use scenario than under the baseline land use scenario (see Table 6). Across the three transportation systems, the delay under

TABLE 6 Daily Delay

	Baseline Network		Roadway Investments		Smart Growth	
	Baseline	Smart Growth	Baseline	Smart Growth	Baseline	Smart Growth
Time Period						
a.m.	39,604	39,732	27,995	**27,911**	17,172	17,962
Midday	69,320	80,369	54,972	**51,458**	32,162	**31,962**
p.m.	53,522	**47,496**	40,620	43,252	23,243	25,551
Evening	10,677	**9,255**	8,450	**8,370**	6,136	6,418
Night	7,702	**7,133**	5,048	6,399	4,056	4,478
Total	180,825	183,985	137,084	137,391	82,768	86,370
Truck Type						
Light	45,844	**45,277**	37,468	38,363	27,201	28,567
Medium	73,818	**74,714**	54,593	**54,178**	30,928	31,828
Heavy	61,163	63,994	45,023	**44,850**	24,639	25,975

NOTE: The analysis did not include a measurement. Numbers in bold indicate instances in which the smart growth land use scenario performs better than the baseline land use scenario.

the smart growth land use scenario is roughly 0.5% higher than for the baseline land use. Given the magnitude of overall system delay, the difference in delay between the two land use scenarios is essentially indistinguishable. However, investment in the transportation system has a striking effect on delay, where the roadway investments reduce daily delay by 24% over the baseline, and transit and nonmotorized investments reduce delay by 54% over the baseline transportation scenario. These results are repeated for the freeway and arterial facilities in addition to the overall network.

Performance of the smart growth land use scenario as compared with the baseline land use scenario in regard to delay has a fair bit of variance across time periods and transportation investments. There does not appear to be a distinguishable pattern across the transportation investment scenarios in which specific time periods have more delay in one land use scenario over the other. However, for the smart growth transportation investments (transit and nonmotorized), the smart growth land use seems to have slightly more delay than the baseline land use scenario in most time periods, despite the small overall impact.

The exception to the delay results is seen when delay is examined by truck type. Medium and heavy trucks perform slightly better under the smart growth land use scenario compared with the baseline in the context of the roadway investments transportation scenario. This result follows the logic that an investment in freeway facilities will improve conditions for all users, but it will also benefit the goods movement users of the transportation system.

DISCUSSION OF RESULTS

The modeling conducted here produced truck miles traveled, hours of truck travel, and delay for various evaluation scenarios. These metrics cannot comprehensively describe the impacts of density and urban form on truck travel patterns, but they can provide some insight into the effects given the relationships built into the examined model type. In addition, these results expose some of the weaknesses of current modeling tools to examine the land use and truck trip relationship.

First, the results of the model runs suggest there are some benefits to, and stemming from, goods movement from a dense, mixed land use configuration. The largest benefits were observed when a smart growth land use scenario was coupled with commensurate transit and nonmotorized transportation investments. These benefits include a reduction in overall travel distances for trucks and truck hours of travel—which would result in lower costs—when development is concentrated. However, truck delay is generally higher in the smart growth land use scenario. While results for truck travel distances are consistent across all cases, lending support to the notion that the model is illustrating an effect of smart growth, results are mixed in regard to truck hours on the road and delay across the cases. This variation raises questions about the model's ability to comment on the impact on truck hours and delay owing to smart growth land use.

CONCLUSIONS

The current state of travel demand forecasting relative to truck movements allows evaluation of some impact of density on truck travel. However, the relationship between land use patterns and truck movements is generally limited to some aspects of truck trip generation. Because truck trip generation is employment based and denser areas generally have higher employment, the model illustrates some changing patterns due to density. As anticipated, the models do not provide insight into changes to truck trip generation owing to system performance or land use mix, nor do they provide insight into travel impacts associated with the urban environment, including street design or presence of other modes. They also do not provide insight into mode choice changes owing to system performance, urban environment, or changes to the local road network. Focus group research indicates that logistics managers will make accommodation in truck type or size because of the limitations in urban environments, and these type and size changes may affect the total numbers of trucks (*20*). These adaptations are not reflected in travel demand forecasting models currently. If they were in place, one might expect that the efforts of logistics managers to optimize performance would show greater benefits to trucks than are currently observed in the model runs, but that would come at a higher operating cost to the operators.

Available regional modeling tools have limited ability to address some of the more detailed changes or effects of dense urban environments. These model results do not comment on the impact on the last mile of travel, since that is captured in the zonal terminal time. This information can be incorporated into the model as an input by modifying this number manually, but adequate data are not available to ensure that changes to terminal times are appropriate. Because the question here relates to the impacts of dense urban environments on truck travel, neglecting the impacts of the last mile is not trivial. If sufficient loading areas are available for trucks in dense, mixed-use places, one would expect the benefits to trucks to be higher, while the need to double-park or seek other parking accommodations in dense areas would suggest that less dense areas would be better for trucks.

Suggested Modeling Techniques

While researchers have begun identifying ways to improve models to be sensitive to truck travel, these models are generally not observed in practice. On the basis of existing limitation of forecasting models, the following summarizes techniques that can capture the impact of dense urban environments on truck mobility and where extensions or additional data are still necessary in models used by agencies today.

Access, Parking, and Loading Zones

Traditional four-step models could be adjusted to account for the impact of truck access conditions by changing intrazonal travel times for trucks. Locations where parking is difficult for trucks could receive a penalty added to a terminal cost. Such improvements to a model would require additional research and data about truck dwell times at locations where it is expected truck trips are longer because of parking constraints.

Road Channelization and Bicycle and Pedestrian Facilities

Intrazonal travel times could be adjusted for slower truck travel resulting from complex multimodal environments. Empirical data demonstrating slower truck travel, and the extent of the slower travel, would need to be obtained for areas where intermingling and conflicts with other modes are expected. If available, bike and transit volumes could be factored into the modal mix.

Land Use Mix

Special trip generator zones such as ports or major warehouses can be added to a model to reflect ports, freight-oriented land use, and consolidated warehouse areas or facilities. Reasonable trip generation data exist for these types of uses. Additional trip generation information is needed in regard to truck rates in mixed-use environments. These types of special generators are in practice in some models—for example, within the model used in this research.

Time and Size Restrictions

The impact of time of day or vehicle size restrictions on a firm's logistics decisions can be reflected in a model network structure (such as road links limited to smaller trucks) and trip assignment step (time-of-day travel time limitations). However, to fully capture the impact of these types of restrictions, truck models would need to include the mode choice step adapted to consider different truck types and sizes.

Policy Implications

In addition to identifying specific data and model extension research needs, this work has identified several planning and policy implications for truck models within the travel forecasting context. Greater attention should be placed on freight planning for local streets. As seen in the modeling results, truck miles of travel remain unchanged on local facilities regardless of transportation investment scenario. Most models do not adequately account for the need for goods to travel on lower-level, local streets for warehouse access and local deliveries. Microscale models may better reflect impacts from urban environments, and links between microscale and regional models should be considered. More attention to this interaction and conflict reductions between trucks and other modes would help facilitate better movement for goods and ameliorate the impact that goods movement can have on surrounding residents.

The modeling results showed that improvements to smart growth transportation infrastructure produced greater benefits to trucks than roadway investments did. With limited financial resources, these types of investments could be supported over capacity enhancements because roadway facilities, even those that appear to be mostly designed to accommodate truck movements, generally have far greater benefits for passenger vehicles and may, as the modeling results show, reduce benefits to trucks. Strategies that remove vehicles from the roadway, maintain or preserve the existing system, or add strategic capacity for a defined purpose should be preferred over general roadway expansion.

Land use planning should also consider the impact of warehousing and distribution center locations on travel demand. The modeling results showed that truck miles of travel, though lower under a dense, mixed land use scenario with commensurate transportation improvements than under the alternative, are higher owing to increased travel because of the overall demand to access urban centers. Delivery trips from locations closer to urban centers or at times when demand is lower for transportation facilities would also improve the benefits of smart growth developments for trucks.

In a longer time frame, the planning profession may begin to better connect the principles of smart growth to goods movement. As smart growth developments mature to include further consideration for goods movement, the benefits of smart growth for and from goods movement will likely increase.

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