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Land Use and Sustainable Transportation: An Interpretive Review of Research in the U.S. and Policy Implications

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토지이용과 지속가능한 교통: 미국의 연구동향 및 정책적 시사점

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ABSTRACT : A self-reinforcing pattern of growing automobile dependence, automobile-oriented planning and development and segregated and sprawling land use have negative impacts on the economic, social and environmental system over past decades in the U.S. To address the linkage, this study examines overall trends and causes and effects of automobile dependence in the U.S., the ideas and major issues of sustainable transportation, and the relationship between land use and transportation. Some implications are suggested for integrating land use and transportation as well as accomplishing sustainability goals. First, theory and issues of sustainable transportation as a comprehensive framework needs to be studied in Korea. Performance measurement and decision-making system also need to be established. Policies and strategies for integrating land use and transportation proposed by new planning movements should be properly considered. Coherent land use policies and coordination and collaboration among stakeholders and public entities from the far-reaching perspective are required to control travel demand by land use measures. Finally, more attention should be paid to theoretical grounds, practical issues of sustainable transportation and land use and transportation integration system to establish low-carbon and energy-saving cities in Korea.

Key Words : Automobile Dependence, Sustainable Transportation, Performance Measure, Land Use and Transportation Connections

요약 : 제2차 세계대전 이후, 미국에서는 자동차 교통에 대한 의존성 심화, 자동차 중심의 도시 및 교통 계획과 개발, 무계획적인 토지이용과 무질서한 도시 확산 문제가 하나의 순환고리가 되어 각 단계를 점점 악화시켜 왔다. 이로 인해 경제, 사회 및 환경체계 전반에 걸쳐 문제점이 나타나고, 이를 해결하기 위해 지속가능한 발전 및 교통에 대한 종합적인 접근의 필요성이 제기되었다. 본 연구는 미국 내 자동차 의존성의 경향과 그 원인 및 결과, 지속가능한 교통 구상과 주요 이슈, 과제를 종합적으로 검토하였다. 주요 이슈 중 미국 내 연구를 중심으로 토지이용 및 개발이 어떻게 교통행태에 영향을 미치는지 검토하고, 토지이용과 교통의 통합을 위한 정책적 시사점을 얻고자 하였다. 우선, 토지이용과 교통의 통합을 위해서는 종합적인 틀로서 지속가능한 교통의 이론, 실제적 이슈에 대한 연구가 필요하다. 이론적 연구와 함께 지속가능한 교통을 위해 성과지표를 통한 지속적인 평가와 의사결정 지원체계에 대한 연구도 필요하다. 토지이용과 교통의 통합을 위한 스마트성장과 뉴어바니즘에서 제안하는 정책과 전략에 대한 면밀한 검토 또한 필요하다. 이와 함께 장기적 관점에서 토지이용 정책에 대한 일관성 유지, 다양한 이해관계자 및 관련 기관 상호간의 조정과 협력이 요구된다. 마지막으로 한국에서 저탄소 에너지 절약 도시의 실현을 위해 지속가능한 교통의 이론, 근본적·실질적 이슈, 통합모형의 구축을 위한 보다 많은 연구가 필요하다.

주제어 : 자동차 의존성, 지속가능한 교통, 성과지표, 토지이용과 교통의 연계

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Ⅰ. Introduction

Automobile dependence has been intensifying over past decades in the United States. Although growing automobile dependence has improved economic efficiency and competitiveness greatly, it has had harmful impacts on our economic, social and environmental systems including traffic congestion, traffic accidents, air and water pollution, energy and land consumption, ecological disruption and public health problems. The U.S. has also experienced rapid urban growth and suburbanization as well during this period. As a consequence, land use patterns are characterized as detached low-density residential communities, segregated commercial and industrial sites, and auto-oriented urban and transportation planning. A self-reinforcing pattern of growing automobile dependence, auto-oriented planning and development and segregated and sprawling land use pattern have brought detrimental effects on our economy, society, and environment (VTPI, 2008).

These concerns, combined with growing awareness of the consequences of dominant automobile dependence, have led the public to pay attention to a comprehensive framework called sustainable development and transportation. Sustainable transportation is an applied concept of sustainable development to the transportation field. It has become worthy of attention as the aforementioned issues in transportation and land use should be addressed in comprehensive and integrated manners. Due to the vital role of land use measures in this area, it is necessary to investigate the relationship between land use and travel behavior patterns (Zietsman and Rilett, 2002; Litman and Burwell, 2006).

There are a number of studies on the impact of land use measures on travel behavior. Relevant researches are significant in that they suggest policy implications for reducing automobile dependence and achieving the goals of sustainability. Significant improvements have been made in land use measurement, estimation methods and methodological framework. However, the adequacy of land use policies still remains questionable. This is mainly due to lack of consistent results and an integrated approach toward sustainability of previous studies.

Attention has recently been paid in Korea to the research on the urban spatial structure for lowering greenhouse gas emissions and enhancing energy efficiency in urban areas, termed low-carbon, energy-saving cities. They focus attention upon integrating land use and transportation in Korea whose policies have been considered essential for achieving the goals of sustainable development. The literature generally falls into two streams. One group of studies examine energy-efficient urban spatial structure (Song and Nam, 2009); another group of studies, on the other hand, introduce land use-transportation integration models and develop simulation models to analyze long-term impacts between them in Korea (Rho and Ryu, 1995; Lee, 2000; Yu et al., 2010; Lee, 2010).

This research focuses upon the role of land

use for achieving the goals of sustainable transportation because theoretical grounds and framework, issues and approaches in this field yet to be well addressed in Korea. The study intends to review the literature on land use and sustainable transportation in the U.S. where extensive research on the issues has been conducted for about twenty years. It also aims to epitomize relevant issues and suggest policy implications for connecting land use and transportation. For the purpose, automobile dependence in the U.S. is examined in terms of its trends and causes and consequences. The ideas and issues of stainable transportation including performance measurement and the connections between land use measures in transportation sustainability are also explored. Finally, some implications are addressed.

Ⅱ. Automobile Dependence : A Problem

1. Definitions

Automobile dependence is a social trend indicating that an automobile has been indispensable for sustaining a wide variety of human activities including commute, business, shopping and social gathering. It can also be defined and measured as higher proportion of automobile use and ownership, fewer numbers of available alternative modes, and auto-oriented land use or urban form (Newman and Kenworthy, 1999; Litman and Burwell, 2006).

Newman and Kenworthy (1989a, 1989b) specified automobile dependence as the interrelation of land use and transportation. A negative relationship was found between urban density and gasoline consumption per person. Some have expressed sharp criticism of the research due to its oversimplified definition of urban structure and method (Gordon and Richardson, 1989; Gomez-Ibanez, 1991; Goodwin, 1997; Mindali et al., 2004).

Automobile dependence has also been explained with a high percentage of auto driving and less available modes caused by the interaction between automobile transport and land use patterns (Litman, 2002; Litman and Laube, 2002). Goodwin (1997) explained it as a dynamic and developmental process of personal and social behavior by times. Based on the psychological approach, Stradling (2001) defined it as a degree for satisfying individual travel needs. while suggesting both absolute and relative measures of automobile dependence.

2. General Trends

People in the U.S. have been more and more depending on automobiles over past decades as they have been keeping up their growing demands on various activities including commuting, recreation and shopping. Between 1960 and 2006, total population, households and housing units have grown by about 66%, 116% and 116%, respectively. During the same time period, the numbers of vehicle registration and vehicle licenses have increased by 120% and 132% each, indicating that auto ownership and related demand have become greater than net

increases of socio-demographic figures. In addition, total vehicle miles traveled (VMT) and passenger miles traveled (PMT) have become longer by 187% and 132%, respectively. They imply automobile use in the U.S. has expanded more than socioeconomic growth over the decades (see Table 1). Moreover, yearly increases of total VMT per household, total PMT per person, total VMT per vehicle, and total expense related to personal vehicles suggest that the trends of growing automobile dependence, however, are significant in the U.S.

These trends of growing automobile dependence in the U.S. have also been observed in different ways. Average total automobile cost per mile shows every American has been spending more and more upon owning and operating automobiles for several decades (see Figure 1). In addition, the survey result as presented in Figure 2, indicates that the share of driving mode is dominant; on the other hand, the proportion of workers using alternative modes including transit, walk and telecom-muting are relatively small.

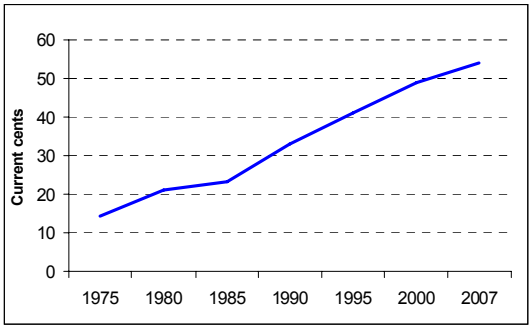

Figure 1. Average Total Automobile Cost per Mile (Source: BTS, 2008)

Table 1. Summary Statistics of the Trends of Automobile Dependence in the U.S.

	1960	1970	1980	1990	2000	2006	1960~2006(%)[5]
Total population[1]	179.3	203.2	226.5	248.7	281.4	298.4	66
Total households[1]	53.0	63.4	80.4	91.9	105.5	114.4	116
Total housing units[1]	58.3	68.7	88.4	102.3	115.9	126.2	116
Registered vehicles[1] [3]	61.7	89.2	121.6	133.7	133.6	135.4	120
Vehicle license[1]	87.3	111.5	145.3	167.0	190.6	202.8	132
Total VMT [2] [3]	587.0	919.7	1121.8	1417.8	1600.3	1682.7	187
Total PMT[2] [3]	1145.0	1754.2	2024.2	2140.9	2544.5	2658.6	132
VMT / household	11,071	14,495	13,955	15,420	15,171	14,711	33
PMT / person	6,385	8,632	8,935	8,608	9,041	8,911	40
VMT / vehicle[3]	9,518	9,989	8,813	10,277	11,976	12,427	31
Total auto expense per person[4]	222	361	925	1,518	2,235	2,778	1,149

Notes: 1) millions; 2) billions; 3) only for passenger cars; 4) million dollars; 5) net increase

Sources: 1) U.S. Census Bureau, 2009; 2) U.S. Census Bureau, 2008; 3) U.S. Census Bureau, 2002; 4) U.S. Census Bureau, 2007; 5) BTS, 2008.

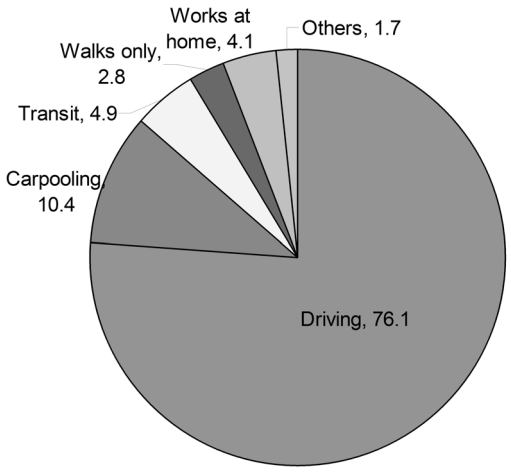

Figure 2. Principal Modes of Commuting
(Source: BTS, 2008)

3. Causes and Consequences

There are a number of causes of growing automobile dependence. Lee (2006) identified some factors in the U.S.: progress in transportation technology, improvement of transportation infrastructure, land use patterns, reduced availability of alternative modes, socioeconomic characteristics, and personal attitudes.

VTPI (2008) also examined some factors in terms of transportation practices: conventional transportation planning, evaluation, and current investment. Conventional practices forecasted vehicle traffic demand in the future, and execute projects for constructing and improving roadway and parking capacity (Litman and Burwell, 2006). It made transportation system and land use more automobile-dependent.

It has increased automobile mobility and convenience, affordability of vehicle travel Also, increased mobility has positive impact on economic productivity and efficiency. Dupuy (1999) argued that higher level of automobile dependence is a natural result of more positive effects over negative effects. On the other hand, it has had negative effects on our economic, societal and environmental systems as shown in Table 2. They are well documented in Raad (1998), WHO (2000), Black (2005), Lee (2006), and Litman, (2008a).

To summarize, automobile dependence has been growing for many decades in the U.S. when automobile ownership and use, economic spending and modal splits are considered. It is a result of a self-reinforcing cycle of growing auto ownership and use, limited alternative modes and auto-oriented transportation and land use planning. Therefore, land use and

Table 2. Transportation Impact on Sustainable Development

Economic	Social	Environmental
Traffic congestion Mobility barriers Accident damages Facility costs Consumer costs Depletion of Non-Renewable Resources	Inequity of impacts Mobility disadvantaged Human health impacts Community interaction Community livability Aesthetics	Air and water pollution Habitat degradation Hydrologic impacts Depletion of Non-Renewable Resources

Source: Litman and Burwell(2006: 335)

development policy is important to reduce automobile dependence.

Ⅲ. Sustainable Transportation

Much attention has been paid to the issues of sustainability or sustainable development[1] recently in almost all organizations and agencies of both private and public sectors. There is no general agreement on the definition of sustainable development; rather it has been defined and applied according to the goals of each agency or group (Beatley, 1995; Litman and Burwell, 2006). However, the Brundtland definition (WCED, 1987) combined with 27 principles specified by the 1992 Rio Declaration on Environment and Development (UNEP, 1992) provide the framework of sustainable development now used throughout the world. It is generally agreed that sustainable development considers three dimensions: environmental, economic and social dimensions.[2]

Various consequences caused by dominant automobile dependence as discussed in the previous section are closely linked to the tripod of sustainability. In addition, growing concern about its negative effects and recent policy changes in the U.S. have required comprehensive framework and actions to address the issues in transportation (Litman and Burwell, 2006; Litman, 2008a). These challenges and requirements have led to the introduction of sustainability into the transportation sector, called sustainable transportation or transportation sustainability.

There is no standard definition of sustainable transportation. European Council of Ministers of Transport (ECMT, 2004), for instance, proposed that sustainable transport system "allows the basic access and development needs of individuals, companies and society to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations," and "is affordable, operates fairly and efficiently, offers a choice of transport mode and supports a competitive economy, as well as balanced regional development."

Most transportation agencies addressed the issues and concerns of sustainability without explicit definition in their vision statements and plans (Jeon and Amekudzi, 2005; Zietsman et al., 2008). The definitions and goals of sustainable transportation are summarized in Jeon and Amekudzi (2005), Hall (2006) and Jeon et al. (2006). Based on the definitions,

1) As a matter of fact, the idea of sustainability is not exactly same as that of sustainable development in that the latter combines two unique concerns, i.e. sustainability and development (Gudmundsson, 2004). Sustainability takes environmental, economic and social concerns in general with a long-term perspective. Sustainable development, on the other hand, is thought of as a process toward an ideal state of sustainability. However, these two terms are considered interchangeable in this research as most studies have used them in similar contexts.

2) It has been also maintained that there is an additional dimension, termed institutional or governance dimension that addresses institutional arrangements and reforms (Gudmundsson, 2004).

sustainable transportation is linked with three dimensions of sustainability as presented in Figure 3 (Jeon, 2007).

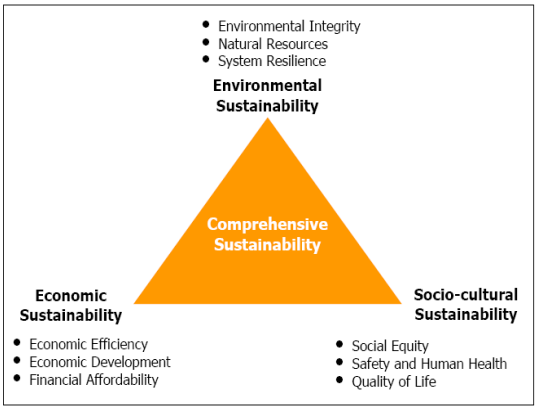

Figure 3. Three dimensions of sustainable transportation system(Source: Jeon, 2007)

It should be noted that there are two different approaches to conceptualizing sustainable transportation: holistic and transportation-centered approaches. The former mainly considers the transportation sector as one of many components consisting of more comprehensive agenda of sustainability. Another view, on the other hand, focuses on transportation sector itself, addressing the goals and principles specific to transportation. Neither one is easy to put into practice; rather, it relies upon what is more helpful to settle the problems.

Ⅳ. Issues and Challenges

Sustainable transportation reflects a number of related issues as described in the previous section. Three issues among them are raised in this section: performance measurement and assessment, the role of land use in transportation sustainability and land use impacts on travel behavior.

Litman and Burwell (2006) proposed some policy directions from a comprehensive perspective. They suggested: 1) technological innovation such as fuel-efficient vehicles, and Intelligent Transportation System; 2) transportation demand management for improving traffic flow and increasing choices; 3) economic reform including full-cost and congestion pricing; 4) alternative modes such as transit and non-motorized modes; and 5) land use changes to decrease trip distance and auto choice. Wachs (2005) addressed seven issues in the future transportation: sustainable transportation indicators, changes in technology, the effect of government regulation, direct control of individual travel behavior, the effect of pricing policy, public education, and regional planning.

Schipper (2002) placed emphasis on governance sustainability in addition to three elements of sustainable transportation. Key issues are to make an agreement and balance among stakeholders, and to develop effective policy measures for addressing transportation problems. Zietsman and Rilett (2002) reviewed institutional and policy frameworks in the U.S. including pricing, technology, regulation, traffic management, non-motorized transportation, behavior and education, and land use and transportation.

Table 3 summarizes the issues and challenges in this regard (STI, 2008).

1. Performance Measurement and Assessment

Sustainability in transportation can be assessed using a combination of indicators or measures useful for setting up baselines, tracking changing patterns, evaluating alternatives, evaluating and comparing particular regions or organizations, and establishing future performance objectives (CST, 2000; Litman and Burwell, 2006; Litman, 2008a). Litman and Burwell (2006) argued that conventional and simple performance measures might not be helpful for achieving the goals and objectives of sustainable transportation because they did not take into consideration a variety of related issues and concerns.

Zietsman and Rilett (2002) claimed that little research on sustainable transportation has been done so far mainly due to lack of understanding its concept and idea and quantifying performance measures. It was found that the final decision on project selection could be varied by introducing and applying sustainable transportation concept and measures instead of economic feasibility analysis. However, this study only paid attention to mobility and environmental measures, which is not consistent with the idea of sustainable transportation.

Zietsman et al. (2003) have applied similar methodology to the previous research into two corridors: one in South Africa and another in the U.S. They maintained that the goals of sustainable transportation should be appropriately defined, measured, and employed into the decision-making process. Five measures were identified based on the goals of each regional strategic planning. Then, performance measures were developed, and used to make comparison among links. It was claimed that the same method could be employed to decide transportation project priorities, and to compare different corridors regardless of their classification, goals, mode, time and spatial boundary.

Jeon and Amekudzi (2005) examined the characteristics of definitions, measurements and indicators of sustainable transportation system. They analyzed the mission statements of all State Department of Transportation in the U.S.

Table 3. Issues of Sustainable Transportation

Economic	Social	Environmental
Accessibility quality	Equity and fairness	Air pollution
Traffic congestion	Mobility disadvantaged	Climate change
Infrastructure costs	Affordability	Noise pollution
Consumer costs	Human health impacts	Water pollution
Mobility barriers	Community cohesion	Hydrologic impacts
Accident damages	Community livability	Habitat/ecological degradation
Depletion of Non-Renewable Resources	Aesthetics	Depletion of Non-Renewable Resources

Source: STI(2008: 5)

Table 4. Goals, Objectives and Performance Measures of Sustainable Transportation for TxDOT's Strategic Plan

Goal	Sustainability-related Objective	Performance Measure
Reduce congestion	Improve mobility on highways	Travel time index
	Improve reliability of highway travel	Buffer index
Enhance safety	Reduce crash rates and crash risk	Annual severe crashes per mile
	Improve traffic incident detection and response	Percentage land-miles under traffic monitoring/surveillance
Expand economic opportunity	Optimize land-use mix for development potential	Land-use balance
	Improve road-based freight movement	Truck throughput efficiency
Increase the value of transportation	Maintain existing highway system quality	Average pavement condition score
	Reduce cost and impact of highway capacity expansion	Capacity addition within available right of way
	Leverage non-traditional funding sources for highways	Cost recovery from alternative sources
	Increase use of alternatives to single-occupant automobile travel	Proportion of non-single-occupant travel
Improve air quality	Reduce adverse human health impacts	Daily NOx, CO, and VOC emissions per mile of roadway
	Reduce greenhouse gas emissions	Daily CO2 emissions per mile of roadway
	Conform to emissions exposure standards	Attainment of ambient air quality standards

Note: The goals, objectives and performance measures only focus on highway mode.
Source: Ramani et al.(2009: 3)

and a number of initiatives in North America, Europe and Oceania. Three frameworks were determined for measuring sustainability in transportation using indicator systems: frameworks based on linkages or causality between transport system and environment, impacts of transport system on main elements of sustainability, and the level of influence of agencies on sustainability factors.

Jeon et al. (2006) criticized that sustainability concepts have not been fully incorporated into the regional planning process including long-range regional plans and transportation improvement projects. The multi-criteria decision making approach was employed to evaluate a current and two future transportation and land use plans in terms of sustainable transportation in Atlanta Metropolitan Region. They maintained that the method was useful for integrating sustainability measures into transportation planning and decision-making process, and assessing transportation plans with regard to sustainability goals.

More recently, there was an effort to integrate sustainable transportation concerns into the strategic plan of Texas Department of Transportation (TxDOT). The research constructed a framework and a methodology for

using performance measures consistent with goals and objectives of the plan. A user-friendly analysis tool was developed and several pilot studies were conducted. Table 4 presented goals, objectives and performance indicators. They maintained that using performance measures consistent with sustainability goals and objectives enables scientific comparisons among different locations and among various alternative planning scenarios for a specific area (Zietsman et al., 2008; Ramani et al., 2009).

2. The Role of Land Use in Transportation Sustainability

Compared with many recent studies of engineering and technology, and performance measures and decision-making system in the field of sustainable transportation, few research on the role of land use policies for transportation sustainability has been conducted. Rather, the impacts of land use measures on both individual and collective travel behavior patterns have been mainly studied. Discussions in this stream of research have primarily been concentrated on the issues and ideas of Smart Growth, New Urbanism, traditional neighborhood development (TND) and transit-oriented development (TOD) which have in common with the objectives of sustainability in transportation field. It is reasonable, therefore, to assert that the goals of sustainable transportation are closely connected with land use policies and strategies in most American regions (Litman and Burwell, 2006).

Litman and Burwell (2006) summarized transportation objectives and solutions consistent with the goals and objectives of sustainability. Many solutions related to land use and development were proposed in the objectives of economic and social welfare, equity and human health. They included efficient land use for freight mobility; neotraditional street planning and mixed land use for mobility for non-drivers; multi-modal community and land use; and pedestrian planning and livable community design.

STI (2008) listed potential indicators for achieving sustainable transportation goals within a number of categories and subcategories of sustainability concerns. Two main categories linked to the role of land use were overall accessibility and land use impacts. The former included land use accessibility; the latter consisted of three subcategories: sprawl, transport land consumption, and ecological and cultural degradation. Litman (2008a) also identified sustainable transportation measures within three main dimensions in a comprehensive way. Land use and development plays an important role in a set of economic, social and environmental indicators. They cover employment accessibility, land use mix, land use planning, non-motorized transport, and land use impact indicators.

The role of land use in transportation sustainability cannot be overstated. Therefore, it is important to coordinate land use and transportation planning and projects, and encourage experts to collaborate on research and

practice in the areas to make them compatible (Litman, 2008b). The impacts of land use on travel behavior will be reviewed in more detail in the following section.

3. Land Use Impacts on Travel Behavior

Land use or urban form[3] and transportation are closely connected with each other in two major and more minor ways (Handy, 2002). Transportation investments and policies influence land use and development patterns; land use and development also affect transportation and travel behavior patterns. Separated land uses with low-density, for example, require more vehicle ownership and uses than does mixed land use in highly dense areas. This research only concentrates on the latter part of the connections: the impacts of land use on travel behavior. It should be noted that some studies did not find enough evidence in this regard. They contended land use effects on travel patterns are so limited that they hardly meet what we expected (van Wee, 2002; Maat et al., 2005).

A number of studies examining the effects of land use and development on travel behavior outcomes have been mainly conducted with regard to theoretical framework and methods, and practical analyses and applications (Badoe and Miller, 2000; Crane, 2000; Cervero, 2002). The research started from the late 1980s in response to the public interest in how and to what extent land use and development measures can reduce automobile dependence. Considerable amount of research has been performed to investigate their relationship in greater details. Badoe and Miller (2000), Crane (2000), and Ewing and Cervero (2001) provide great summaries and reviews from various perspectives.

Academic investigations of this specific discipline germinated from a pivotal research conducted by Newman and Kenworthy in 1989. They analyzed the simple relationship between transportation and land use in 32 major international cities as of 1980. An important contribution has been made to enhancing our understanding of how land use could systematize automobile dependence.

In addition, they opened a ground for policy debates among the experts of planning and development fields. During the early 1990s, an interest has been greatly increased in land use policies to manage transportation demand, which resulted in policy debates on the effectiveness of land use policies in this regard (Zhang, 2004; Lee, 2006). The arguments have originally been made from two different viewpoints: “get the price right” based on price-based and economic policies and measures in the transportation markets (Gomez-Ibanez, 1991; Giuliano and

3) Urban form is often recognized as more comprehensive than land use pattern in a spatial boundary. However, this study does not distinguish them as already did in many studies. The term built environment introduced in some studies is also considered to be same.

Table 5. An Example of Hypothesized Relationships among Land Use Measures and Travel Patterns

Travel behavior	Core dimensions of land use			Travel patterns
	Density	Diversity	Design	
Driving choice	-	-	-	Modal split
Driving frequency	+/-	+	+	Total trips
Driving length and duration	-	+/-	?	VMT/VHT
Departure time	?	?	?	Peaking
Route choice	+/-	+/-	+/-	Road congestion
Trip chaining	-	+	+/-	Trip rate and distance
Tele-travel	+/-	?	?	All

Note: The symbols +, -, and ? indicate positive, negative, and unknown, respectively
Source: Zhang(2004: 346)

Small, 1993; Giuliano, 1995), and "get the land use right" mainly relying upon physical planning and design strategies and regulations (Cervero, 1991; Jacobs, 1992; Cervero and Landis, 1995; Newman et al., 1995).

A group of professionals supporting the former point of view argued that the connection between land use and transportation has consistently diminished in the U.S. and other developed countries. It was, they maintained, because travel costs have consistently decreased thanks to technological advances in transportation planning and engineering; transportation system, e.g. highway network system has been well developed and steadily upgraded; and structural shifts to an information-based economy have increasingly speeded up (Giuliano, 1995).

In response to the arguments, another group of research scientists and engineers claimed that the connection should be still considered a significant matter (Cervero and Landis, 1995). They agreed with diminishing transportation costs and growing accessibility. However, there has been strong theoretical and empirical evidence that land use patterns significantly affected travel demand. Litman (2000) also stated that transportation market has been distorted with violated free and competitive market principles. Feasible and cost-effective market reforms should be prepared and implemented.

A great advance has been made in land use measurement and methodology until late 1990s. Land use measures related to density, diversity or land use mix, and accessibility were significantly increased. They enlarged the capacity to evaluate land use and built environment efficiently and effectively in both quantitative and qualitative ways. In addition, many studies examined the relationship between transportation and land use using the regression analysis method by employing various dimensions of land use variables, while controlling other socioeconomic, individual and household characteristics (Cervero and Gorham, 1995;

Cervero, 1996; Handy, 1996; Cervero and Kockelman, 1997; Kockelman, 1997; Levinson and Kumar, 1997; Boarnet and Sarmiento, 1998; Handy et al., 1998; Crane, 2000).

Academic efforts have been also made to establish an analytical framework and methodology based on consumer behavior theory for utility maximization that originated from the work of Domencich and McFadden (1975). The travel demand models have been elaborated to incorporate the full set of variables such as travel time and/or cost variables, individual and household socioeconomic factors, and land use measures (Crane and Crepeau, 1998; Boarnet and Greenwald, 2000; Boarnet and Crane, 2001; Cervero, 2002; Zhang, 2004; Lee, 2006). Table 5 presents an example of the connections among land use and travel behavior.

Both academic and practical investigations are still conducted in this field. Recently, some issues have been raised. They include theory and modeling framework that deal with lack of a conceptual framework and theory to explain the linkage of land use and travel behavior outcomes; land use measurement and unit of analysis that enhance explanatory and forecasting power and lower spatial aggregation bias; causal relationship that primarily addresses the causal connections between land use measures and travel outcomes and causal notion for other variables beyond conventional correlations between them; self-selection which concerns about whether residents with specific travel attitudes and preferences are self-selective in the type of neighborhood in which they live; substitution effect which tackles if automobile mode can be replaced by other modes including transit and non-motorized modes; automobile captivity that explains how transportation system factors, socioeconomic attributes and land use characteristics cause excessive automobile dependence; and application of empirical results into the real world.

To sum up, it is evident that land use and development is linked to transportation in several ways. Land use policies are thus effective to manage transportation demand and achieve some goals of sustainable transportation despite the debates over the role of land use in the U.S. It should be noted that both land use policies and economic measures are considered complementary.

Ⅴ. Conclusion

Consistently growing automobile dependence over past decades has resulted in a number of malign impacts on our economic, social and environmental system. It has been a robust obstacle to our efforts for achieving the goals of sustainable transportation. As it was generally agreed that land use and development is one of main causes of automobile dependence, the policies and strategies of land use and development have been proposed to reduce automobile dependence as well as to accomplish the goals of transportation sustainability.

This study suggests some policy implications in this regard. First, comprehensive framework of sustainability is required to address the issues

of land use and transportation interaction. Typically, the issues related to land use and development have been dealt with by urban and regional planners; on the other hand, transportation issues have been tackled by transportation engineers and planners. Sustainable transportation as an applied concept of sustainable development into transportation should be an alternative to the conventional dichotomy. It addresses extensive topics in three dimensions, i.e. economic development, environmental preservation and social welfare. Land use and transportation integration in Korea should be tackled in this broad context.

Many studies and projects as they relate to performance measurement and assessment and decision-making system for transportation sustainability are applicable to various spatial levels: corridor, local, regional and national locations. They can also be employed in different strategies and plans, i.e. long-range urban and regional plans, different land use and development plans and strategies, and transportation improvement projects. It is, therefore, necessary to establish the systems and methods for evaluating performance measures and supporting decision-making system for a variety of plans and strategies at different spatial levels. They are effective for establishing baselines, monitoring changing patterns, assessing alternatives, evaluating and comparing areas or organizations, and setting up future performance goals.

It has been argued that conventional zoning and other local government land use regulations in the U.S. did not counter sprawling land use and automobile dependent travel patterns. New planning movements to tackle the effects of land use on travel behavior broke out: smart growth and new urbanism. Although they are different in some ways, they have common objectives for integrating land use and transportation: increase the share of non-automobile modes, decrease the number of auto trips, and reduce vehicle miles of travel and increase vehicle occupancy. Specific land use policies that they suggested include mixed-use zoning, form-based zoning code, cluster and infill development, brownfield development, transit-oriented development, and bicycle and pedestrian network. They should be fully considered for integrating land use and development and transportation under the goals of sustainability.

Land use measures and policies have long-term effect on changing both travel pattern. There are also numerous agencies, governments and interest groups relating to land use and development. Therefore, land use and development strategies should be established in a consistent manner to accomplish desirable long-term outcomes. Also, well-organized coordination and collaboration among stakeholders and among public entities are essential to control travel demand by introducing land use measures and strategies.

Much more attention needs be concentrated upon theoretical foundations, fundamental and practical issues and comprehensive approaches for sustainable transportation in Korea. Based on the research on land use and transportation

connections, it is also vital to develop a modeling system for integrating land use and transportation that is well suited for metropolitan areas in Korea.

In practice, it is important to establish detailed and well-organized database of land use and travel in the first step to have credible results. For example, household travel survey conducted on a regular basis should include detailed real-time vehicle and travel information, i.e. using global positioning system (GPS). Well-established database has great potential of extending the research to environmental issues, implying that the relationship between land use, transportation and air quality can be further investigated as transportation significantly affects air quality such as greenhouse gases, NOx and particulate matters. Through this process, academic and practical efforts for integrating land use and transportation can help not only create urban spatial structure for lowering emissions and saving energy, but also propose useful policies and strategies to keep them interconnected.

In addition, recent issues raised from both academic and practical investigations in the U.S. need to be considered in Korea in terms of land use impacts on travel behavior: theory and modeling framework, land use measurement and unit of analysis, causal connections, substitution effect of automobile mode, automobile captivity and application of empirical studies.

First, many studies suffered from lack of theory and modeling framework. They often have failed to consider transportation cost and system factors in the modeling process, which led to biased estimates. Full array of explanatory variables should be incorporated including travel price, individual and household characteristics and various land use measures.

Second, empirical models can be specified in this regard based on either disaggregate or aggregate travel data. In general, a model estimated with disaggregate rather than aggregate data were well consistent with the theory of economic behavior as long as they are available and informative. In addition, land use measures computed in any spatial extents, i.e. traffic analysis zone, census tract, zip-code area inevitably cause spatial aggregation bias. To minimize the bias and reflect traveler's surrounding built environment, certain level of geographical unit of analysis should be at least maintained such as one-quarter mile boundary or census block of both trip ends. It needs detailed land use information and advanced tools such as geographic information system.

Third, most studies have only investigated the correlations rather than causal connections between land use and travel behavior. Academic interests have increased in the causal connections between them and causal notion for explanatory variables in terms of land use effects on transportation. It can be addressed by introducing new methodologies and research design and modeling framework, which requires to collaborate with other academic fields.

Fourth, some studies examine whether and how people living in much dense, mixed-use and pedestrian-friendly communities are likely to

substitute public and non-motorized mode trips for driving trips. It is important because many land use policies and strategies are implemented to achieve the substitution effect in this academic field. It is quite hard, however, to explore how driving-alone travel can be replaced by shared-ride, transit, and walking and cycling in a specific built environment. For the regional level, the simulation method based on estimated models, while considering travel mode and trip rates, can be helpful to understand the substitution effect.

Fifth, automobile captivity is an outcome caused by excessive automobile dependence. An automobile-captive traveler do not use other modes except automobile mode due to some reasons including transportation system factors, socioeconomic characteristics and land use attributes. It is necessary to examine how and to what extent automobile-captive behavior takes place in Korea; some policies and strategies then need to be established to properly address it.

Last issue of importance is related to the application of empirical studies of land use impacts on travel behavior into the real situation of transportation market. In order to incorporate full array of land use measures in the travel demand modeling, either direct modeling or post-processing method can be considered as suggested by Cervero (2006). The former directly specified travel model; the latter, on the other hand, incorporates elasticity estimates into the existing travel demand model.

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