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A dynamic framework on travel mode choice focusing on utilitarian walking based on the integration of current knowledge

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Abstract

Recently, research on utilitarian walking has gained momentum due to its benefits on both health and the environment. However, our overall understanding of how built and social environments affect travel mode choice (walking or not) is still limited, and most existing frameworks on travel mode choice lack dynamic processes. After a review of several mainstream theories and a number of frameworks, we propose an integrated framework. The basic constructs in the travel mode choice function are utilities, constraints, attitudes, and habits. With a hierarchical structure and heuristic rules, the travel mode choice function is modified by individual characteristics and travel characteristics. The framework explicitly presents several dynamic processes, including the perception process on the environment, attitude formation process, habit formation process, interactions among an individual's own behaviors, interactions among travelers, feedback from travel to the built and social environments, and feedback from other behaviors to the built and social environments. For utilitarian walking, the framework may contribute to the study design, data collection, adoption of new research methods, and provide indications for policy interventions.

Keywords

Utilitarian Walking; Travel Mode Choice; Dynamic Framework; Built Environment; Feedback

1. Introduction

Recently, numerous empirical studies have been published on utilitarian walking as a travel mode due to benefits of walking on physical and mental health, as well as its potential to decrease air pollution and traffic congestion and to promote sustainable urban development and social cohesion in neighborhoods^{1–3}. Evidence shows that utilitarian walking is associated with individual characteristics, such as age, sex, socioeconomic status, race/ethnicity, auto ownership, and psychological properties including attitude and habits^{4,5}, and built and social environmental characteristics, such as the land-use density, land-use mix,

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street connectivity, street design, aesthetics, traffic safety, level of violence, social support, social network, social cohesion, and social norm⁶⁻⁹. Simultaneously, a number of conceptual frameworks have been proposed that focus on physical activity in general^{7,10}, active travel including walking and bicycling^{11,12}, or more specifically on children's travel to school^{13,14}. Most of these frameworks are extensions of theories, including utility theory^{15,16}, the theory of planned behavior (TPB)^{17,18}, or the social-ecological model^{7,19}. Substantial progress has been made towards the understanding of how a travel mode is chosen (by walking or not), especially the incorporation of psychological properties and multiple factors at multiple levels.

Utility theory is one of the core theories in the transportation field, stating that people make rational decisions to maximize their interests^{15,16,20}. The basic rationale of traditional travel mode choice models is that a person will select a travel mode that could maximize her/his benefits and minimize her/his costs. Although utility theory has been widely and consistently applied to travel behavior with substantial improvements over the past several decades²¹, utilitarian walking is not the focus. The utilities beyond travel cost and time may be more important to utilitarian walking compared with other travel modes^{7,19}. For example, for a walking trip, positive utilities may include the enjoyment of walking itself, the enjoyment of the interaction with the environment and other persons, and the satisfaction of the potential benefit to physical health. In addition, negative utilities may include physical fatigue, as well as exposure to heavy traffic, polluted air, unsafe environments, and severe weather. In the field of physical activity, the TPB may be the most widely applied theory²²⁻²⁶. According to TPB, attitude, subjective norms, and perceived behavioral control jointly determine the formation of the intention that is the direct determinant of behavior. At the same time, perceived behavioral control could influence behavior directly.

For frameworks related to walking, substantial progress has been the incorporation of psychological properties. Both utility theory and the TPB have been criticized for their assumption that people always behave rationally. In reality, a person may choose a satisfactory travel mode instead of the optimal one²⁷. A person's rationality is bounded by her/his cognitive limitations, the available information, limited amount of time available to make decisions, the cost of research and learning, and inaccurate memory²⁸⁻³¹. For example, a driver may select a different route to avoid heavy traffic if the traffic information could be accessed in real time or may even decide to choose an alternative travel mode. Some psychological properties are largely unexplored, for example, how people shape their perceptions to reduce dissonance³². Some psychological properties are challenging to capture, for example, habit, either by utility theory or the TPB^{33,34}. People are not constantly conscious of their behavior. When a behavior is repeatedly performed, it may become habitual^{35,36}. This is especially true for daily travel that is executed on a repetitive basis and that therefore may become routine or habitual. Evidence^{33,37-39} has shown that habit strongly influences travel mode choice. An attitude has a weaker influence on the corresponding behavior when the corresponding habit is strong and has a stronger influence when the habit is weaker⁴⁰⁻⁴².

The issue of psychological properties has been acknowledged from the origin of utility theory, and continuous efforts have been initiated to incorporate psychological properties

especially attitude, preference, and perception^{32,43,44}. For example, experienced utility was distinguished from decision utility to capture better the properties that are related to travel satisfaction²⁸. Recent empirical research found travel satisfaction was influenced by travel mode and personal and environmental factors^{45,46}. Active travel such as walking, is likely to yield high travel satisfaction due to its benefits of autonomy, environmental mastery, social interaction, and involved physical activity⁴⁶, whereas private vehicle use is likely to be associated with symbolic and affective benefits (e.g., the car may be taken as symbol of status and success)⁴⁷.

Additional substantial progress has been to incorporate the effects of multiple factors at multiple levels and the interrelations among these factors^{11,19,48}. The social-ecological model^{7,19}, which has gained increasing attention over the past decade, is considered to be an improvement over the social cognitive theory^{49–51} because the latter is criticized as being focused on the social environment and does not represent the physical environment well¹⁹. The social-ecological models consider both the social and physical environments and are taken to be an essential guide to the design of effective multilevel interventions to increase physical activity, including utilitarian walking⁴⁸.

However, one major problem for most frameworks is the lack of dynamic processes by which the behavior (specifically, utilitarian walking), attitude and habit, and environment are directly or indirectly shaped. The dynamic processes are ubiquitous and continuously adapt to reduce the imbalance between current or expected needs and available opportunities⁴⁴. As criticized by Barff et al.³⁰ (page 378), "...Most models are cross-sectional in nature, trying to explain today's behavior by today's attitudes. However, today's attitudes are of limited help in learning how attitudes may change; we must know when and how the attitudes were originally formed". In addition, a habit may be broken by changes including both major life events and daily exposures²⁴. Major life events, such as moving one's residence, changing jobs, or getting married, may break habits because of the abrupt contextual change^{52–54}. On the other hand, people are constantly exposed to smaller changes every day from the environment and other people, and such daily exposure may cumulatively influence the travel mode. We need to account for the dynamic relationships among persons (e.g., the walking by one individual affects others' behaviors), between persons and their built and social environments (e.g., the environmental changes in response to persons' walking and vice versa), and among environmental characteristics (e.g., the change of residence distribution may initiate a corresponding change in the transport network)⁵.

Another problem is that most frameworks, especially those being based on social-ecological models, are not operation-oriented. Most of them simply demarcate boundaries between different levels and list a number of characteristics within each level but seldom provide the interactions among these features; therefore, they fail to indicate how an interaction may lead to behavioral and environmental changes¹².

Our understanding of how an empirical intervention may increase utilitarian walking (and overall physical activity) is limited⁵⁵, and research on health behaviors⁵⁰ has shown that interventions based on theoretical frameworks or theoretical constructs are more effective

than are those without them. Indeed, we need frameworks at both the conceptual and operational levels to provide indications for both theoretical research and policy interventions ¹².

Theories may be complementary to each other. As reviewed ¹⁹, the utility theory is operation-oriented, that is, it provides an operational mechanism by which the properties affect the travel mode choice, but it does not suggest how to delineate physical activity behavior as discrete mode choices or what properties might be relevant to those choices. On the contrary, the TPB and social-ecological model define specific properties influencing travel behavior and may provide causal mechanisms regarding how these properties work together. However, most mechanisms are presented in a qualitative term; thus, it is not clear to what extent and how fast one property could influence another property. With this consideration, we believe that the combination of various theories and frameworks, together with the accumulated evidence from empirical research, provide a knowledge foundation on which a more comprehensive framework could be based.

This research aims to create a dynamic framework for travel mode choice focusing on utilitarian walking. First, we review the current knowledge on travel mode choices, focus on a number of published frameworks. Next, we propose an integrated framework and describe its key features. Finally, we discuss the framework's values, utilities, limitations, and challenges.

2. A brief review of the current frameworks on travel mode choices

We have identified 22 frameworks ^{7,10–14,32,43,56–70} related to travel mode choice/utilitarian walking through the combination of manual pick-up, peer recommendation, and a non-comprehensive search with keywords including walking, travel, physical activity, theory, and framework, and in major databases including MEDLINE, Web of Science, and ScienceDirect (see Table 1). We reviewed these frameworks using three major criteria: (1) psychological properties (here, a psychological property needs to be explicitly included in the framework; for example, a framework that simply lists attitude, preference or habit as an individual's properties is not considered to have psychological properties), (2) multiple factors at multiple levels, and (3) dynamic processes.

Sixteen frameworks ^{12–14,32,43,56–59,61,63–68,70} explicitly include psychological properties, such as attitude, preference, and habit. Pikora's framework ⁵⁶ integrates the TPB and adds habit. Van Acker's framework ⁵⁷ considers psychological properties not only for travel behavior but also for location and activity. Ogilvie ¹² presents the process of how the strength of habit may be changed by previous travel experiences. Idris ⁵⁸ proposes an equation to quantitatively describe the formation of habit. Most frameworks ^{13,14,70} regarding children's travel to school acknowledge that the attitudes of both the parents and children jointly influence children's travel mode choice.

Thirteen frameworks ^{7,10–13,32,56,59–62,65,68,70} explicitly include multiple levels of characteristics. Most frameworks have at least three levels, as follows: (1) the individual level, (2) the level of the "hard" environment, such as physical, built, natural, spatial,

geographical, and sometimes climate (or weather), and (3) the level of the “soft” environment, which may include two sub-levels: the interpersonal level (family, friends, and the social network) and the social, cultural, information, and policy levels. Some have a broader context than others by definition; for example, the physical environment consists of the built and natural environments and some are synonymous but could be used for different scales, such as spatial and geographical.

Twelve frameworks ^{7,11,12,14,32,43,57–59,64–67} include dynamic processes, such as feedback, by which the characteristics of an individual and her/his environment together decide the travel behavior; afterward, the travel behavior influences the individual or/and environment. The feedback mechanism varies significantly among the twelve frameworks. The first pathway is how travel behavior influences individuals. Three frameworks ^{7,14,32,43} simply state that an individual’s travel behavior (or physical activity) could influence the individual. Six frameworks ^{57–59,65–67} go further by claiming that an individual’s travel behavior influences her/his psychosocial variables, and then the psychosocial variables influence her/his perception of the environment, and eventually the perception of the environment influences travel behavior. Interestingly, Schneider’s framework ⁶⁴ elaborates a five-step loop in travel mode choice: awareness and availability, basic safety and security, convenience and cost, enjoyment, and habit. Habit, as the final step of this loop, influences the first step (i.e., awareness of travel modes). The second pathway is the so-called “land use transport feedback cycle,” ^{71,72} that is, an individual’s travel behavior (together with other activities) not only influences her/his perception of the environment but also could influence the environment over time. One example is Ogilvie’s framework¹². Another example ¹¹ goes further and proposes that travel behavior also influences long-term choices, such as auto ownership and residence, and these long-term choices could also influence the environment over time.

In addition to the three features that we summarized, several frameworks have certain interesting features. For example, the environment’s influence on medium-term choices, such as auto ownership, and long-term choices, such as residence ⁷; the influences among short-, medium-, and long-term behaviors ⁵⁷; and the integration of utility maximization and learning processes ⁵⁸. Some frameworks explicitly include a module for imputed impacts, including health benefits, carbon impacts, environmental impact, and injury risk ^{12,65}. Four frameworks ^{13,14,69,70} specific for children’s travel to school highlight the role of parents in choosing the school travel mode, and Mitra’s framework ⁷⁰ notes that as children grow, they take greater control over their travel mode choice.

An integrated framework covering all the three features is of distinguishing value, especially the dynamic processes that are crucial not only to understanding utilitarian walking behavior but also, more importantly, to create a policy intervention aimed at triggering a behavioral change. However, we do not indicate that these three features are the sole criteria to judge the above 22 frameworks because a framework aiming to answer a specific question does not need to be comprehensive; in addition, the same feature may be integrated into a framework in diverse ways. For example, three frameworks ^{12,59,65} have included all the three features. However, two of them ^{59,65} do not include the dynamic processes of the aforementioned “land use transport feedback cycle.” All the three frameworks ^{12,59,65}, like

most frameworks based on social-ecological models, define and list a set of variables influencing travel mode choice but do not suggest an operational function of how these variables are working together.

3. An integrated framework for travel mode choice

We propose an integrated conceptual framework for travel mode choice focusing on utilitarian walking (Fig. 1). The basic constructs in the travel mode choice functions are utilities, constraints, attitude, and habit. Utilities include “hard” utilities, such as cost and time, and “soft” utilities (perceived utilities²⁸) are related to travel satisfaction, such as enjoyment, health benefits, and exposure to traffic⁷³. Some utilities pertain solely to active travel, such as health benefits due to physical activity. Constraints here refer to objective constraints, including three types of spatial and temporal constraints identified by Hägerstrand^{57,74}. Capability constraint is that a travel behavior is limited by the distance a person can reach in a certain time. For example, driving provides a larger range of activity space compared with active travel due to the higher speed. Coupling constraint defines the limitation due to the interaction with other persons. For example, a father may jointly determine his travel mode travel to work and his child’s travel to school. Authority constraint refers the limit access due to “control” areas or domains. For example, public transportation is not an option during its closing period at night or over holidays. Attitude in this framework could be defined as “positive or negative evaluations or beliefs held about something that in turn may affect one’s behavior.”⁷⁵ Habit may be formed if a routine travel mode is regularly repeated, and it tends to occur unconsciously.

The travel mode choice function follows a hierarchical structure and heuristics rules. By hierarchical structure, we mean that utilities, constraints, attitude, and habit are not considered simultaneously, and some constructs need to be satisfied before other constructs are considered. Alfonzo’s framework⁶¹ of the hierarchy of walking needs and Schneider’s framework⁶⁴ propose that the environmental characteristics are not necessarily considered simultaneously and that the decision process is more likely a tree structure, that is, some characteristics need to be satisfied before other characteristics are considered. Specifically, Alfonzo’s⁶¹ five levels of walking needs include feasibility, accessibility, safety, comfort, and pleasurability. For example, a person may not walk to work if she/he feels the safety level along the route is lower than her/his threshold value, regardless of the other characteristics, such as sidewalks and aesthetics. By heuristics rules, we mean a person may not consider all utilities and may seek a satisfactory travel mode instead of the optimal one. The decision process is boundedly rational and subject to heuristics and cognitive biases⁷⁶. For example, laboratory evidence indicates that choice of travel mode is significantly affected by heuristics and biases, and both lead to deviations from rational behavior⁷⁷. People may have different forms of decision rule (for example, dominance, satisfaction, and lexicographic rules⁷⁸), and the function is modified by individual characteristics and travel characteristics. The boundary and weights of the basic constructs and hierarchical structure and heuristics rules vary by individual characteristics. For example, concerning utilitarian walking, traffic safety may be more important for children than for adults⁷⁹. The function also varies by travel purpose. For example, people walk a shorter distance for shopping than for work⁸⁰, perhaps due to the burden of carrying purchases.

The travel mode choice function is influenced directly or indirectly by a number of dynamic processes, including perception of the environment, attitude formation processes, habit formation process, interaction among an individual's own behaviors, interaction among travelers, feedback from travel to the built and social environments (i.e., interaction between individuals and the environment), and feedback from other behaviors (e.g., change of residence and auto ownership) to the built and social environments.

Perception process on the environment

Discrepancies were reported between perceptions (i.e., subjective measures) and objective measures of the neighborhoods' environmental characteristics^{81,82}. Evidence suggests that positive perceptions of the neighborhood environment are associated with more walking^{83,84}. One study shows that objective measures of the built environment have stronger associations with walking than perceptions⁸⁵. However, it may be plausible that objective measures of a neighborhood environment influence an individual's utilitarian walking (or general health behavior) both directly and indirectly (through perception)⁸². In essence, both perceptions and objective measures of the neighborhood environment are necessary when examining the relationship between the environment and walking^{86,87}. Thus, understanding the mechanism of how an individual's perception is formed and why persons living in the same neighborhood have different perceptions (e.g., how perceptions are modified by the individual's characteristics) is crucial to the travel mode choice function. However, few studies examining these issues exist. One study found that the changes in some but not all perceptions were associated with changes in travel behavior⁸⁸, and another study reported that positive changes in the perceptions of aesthetics and convenience were associated with more walking⁸⁹. Further studies are needed to determine the causal relationships among the environment, perceptions, and behavior.

Attitude formation process

The attitude formation process in this framework is defined as the process for an individual to update her/his attitude toward each travel mode, including utilitarian walking through daily exposures, such as travel experiences, information that is required, interactions with other people, the built and social environment, and other behaviors (both long term and short term), over time. The basic assumption is that a positive exposure for travel by a certain mode will improve the attitude towards this mode. Therefore, this mode will be more likely to be chosen for future travel⁹⁰. In addition, people's attitudes can be influenced by their social network⁹¹. Although attitudes may not be directly observable by other individuals and hence cannot themselves be sources of social influence⁹², a person will update his attitude based on observations of the travel mode of her/his friends (rather than directly from their attitudes). Thus, a walking-friendly environment may provide a reinforced mechanism by which more positive attitudes towards walking and walking trips are shaped over time. On the contrary, if the environment is not conducive to walking, a higher level of attitude towards walking promoted by an education campaign may diminish over time⁹³.

Habit formation process

Travel for a particular purpose repeatedly performed by the same mode may become habitual. Habit is formed due to the reinforcement of the learning process⁹⁴. With

accumulated positive feedback for a certain travel mode, this travel mode will be more favorable than others. Then, a decision process is less likely to be involved again, and thus, the habit for this mode is formed. A habit may be broken by major life changes. For example, the life stage of having children was shown to affect travel mode choice: households with children are more like to drive than those without children⁹⁵, and entry into the labor market is associated with an increase in driving for both men and women⁹⁶.

Interactions among an individual's own behaviors (Interaction A)

This includes the interactions among an individual's own travel behavior and the interactions between travel behaviors and other behaviors. For a single trip, travel modes obviously compete with each other to be chosen. Different transportation modes may also affect each other in complex ways. For example, those who regularly walk long distances to work may not be inclined to walk for recreation. Conversely, it is plausible that traveling by car to work or shopping may leave more free time to walk for other purposes⁹³. Travel mode choice in short-term decision-making interacts with other behaviors, both medium and short term^{97,98,99}. For example, if a person selects driving as the mode of daily travel to work, then maintaining her/his auto ownership will become a requirement. Afterward, owning a car will allow this person to select a residence further away from her/his workplace (or select a workplace further away from her/his residence) when she/he considers relocating her/his residence or changing employment. Eventually, the increased distance from the residence to the workplace may make utilitarian walking modes impossible. Another example is the so-called "self-selection,"^{6,100–102} that is, a person who prefers walking may select a neighborhood that is more amenable to walking, and therefore, their residence relocation decision makes more utilitarian walking possible.

Interactions among travelers (Interaction B)

The interaction here is from two aspects. First, it refers to joint accessibility^{103,104} or coupling constraint⁷⁴ aforementioned, that is, to conduct certain face-to-face activities together, a participant may adjust her/his travel behavior depending on the other participants. Second, it refers the dynamic interactions among travelers through their sharing of transport facilities. Because of the exclusive nature of various travel modes, utilitarian walking is at odds with other travel modes, especially the use of a car¹⁰⁵. When more people begin to drive and quit walking, there are more cars in the neighborhood, and it becomes more dangerous for walking; therefore, fewer people walk. At the same time, if there are more pedestrians, the cars may drive slower than before,¹⁰⁶ which will encourage more people to walk. Competition for travelers using the same mode may be more prominent for driving and using public transportation. For example, traffic congestion and crowded public transit systems may make travel experiences less comfortable and convenient¹⁰⁷.

As shown in Figure 1, three loops through Feedbacks A, B, and C emerge among the dynamic processes. In the first loop, a person's attitude and habit determine the travel mode together with other constructs; next, the travel behavior will feed back to influence the habit and attitude through habit formation and the attitude formation process, respectively (Feedback A).

In the second loop, the characteristics of the built and social environments, after being perceived as utilities and constraints, determine the travel mode, and then the corresponding travel behavior will feed back to influence the characteristics of the built and social environments (Feedback B). It is well accepted that behavior also influences the environment⁴⁹. Utilitarian walking could influence the environment from various perspectives. For example, just as mixed land use may promote walking, greater walking is likely to promote greater mixed uses, as businesses locate in areas with heavy foot traffic. Private developers may be encouraged to invest in walkable and compact areas, the so-called “infill development” and “smart growth”¹⁰⁸. In addition, the urban design and transportation network may be changed by the pressure of existing utilitarian walking. For example, the past two decades have seen a growing interest in modifying the built environment to promote healthy lifestyles, indicating by establishing of a number of organizations and movements, such as the National Complete Streets Coalition¹⁰⁹ and Smart Growth America¹¹⁰. Accordingly, 54% of states and 52% of cities now have Complete Streets policies or legislation, as of 2014¹¹¹. For the social environment, walking may increase the safety status, social capital, and social cohesion in the neighborhood¹¹² and change the social norm towards walking at the regional and national levels¹¹³.

In the third loop, travel behavior influences other behaviors, and then, other behaviors influence the built and social environments (Feedback C), and eventually the environment influences the travel mode choice. Behaviors, such as relocating residence and auto ownership, are not only influenced by the environment but also influence the environment. One example is urban sprawl. Cities have been walkable for most of human history, with higher-density and mixed land use. In the United States, urban sprawl began with the expansion of cities into rural areas and accelerated during the second half of the last century¹¹⁴. When people relocated to suburban areas, changes followed for their lifestyles and the built environment. Today, urban sprawl, as a dominant development pattern in the United States, features low-density and segregated land use and reliance on private vehicles for travel^{114–116}. This makes utilitarian walking very challenging.

Feedbacks A, B, and C work at different scales and may result in different time delays. Feedback A depicts a relatively direct process at the individual level. Although the durations of attitude formation and habit formation may vary among persons, generally behavior changes are short-term processes compared with Feedbacks B and C. Feedbacks B and C are more likely indirect and at the population level, that is, the built and social environments are influenced by aggregated behaviors from a group of individuals. It may take a much longer duration to observe their effects. For example, just as the low-density and segregated land-use pattern of the United States is the result of the long-term urban sprawl process driven by a combination of economic, social, and political determinants (e.g., federal mortgage insurance programs, and the expansion of the Interstate highway system), attracting investment back to inner-city neighborhoods and creating walking-friendly environments are long-term processes as well^{7,117}.

4. Discussion

This framework has two unique values. First, this framework is based on the integration of utility theory, the TPB, and the social-ecological model. The utility maximization mechanism is maintained in the framework with improvements, including (1) the scope of utilities is extended to “soft” factors, such as travel experience, which may be particularly important for utilitarian walking; (2) psychological properties, such as attitude and habit, join with utilities to determine travel mode; and (3) different from most traditional utility maximization models, which differentiate the importance of each category of utility by assigning weights, we assume that the travel mode choice functions within a hierarchical structure and heuristics rules and that the function is modified by individual characteristics and travel characteristics. Our framework maintains the key constructs of the TPB: the attitude towards the behavior is unchanged, perceived behavior control in the TPB is substituted by the utilities and constraints through perception, and the subjective norm in the TPB is remodeled as a factor in the attitude formation process, which shapes the attitude over time. By integrating utility theory, the TPB, and the social-ecological model, this framework is operation oriented, and incorporates multiple characteristics from multiple levels.

Second, the framework is dynamic and includes a number of feedback loops. The causal pathways between factors are seldom presented in most of the existing social-ecological frameworks. Our framework explicitly incorporates several casual pathways as dynamic processes upon which three loops are formed. Different from most social-ecological models, which often simply demarcate boundaries between different levels and list a number of characteristics within each level, our framework represents the causal relations and interaction explicitly but the multiple levels implicitly, because we believe that the causal relations and interactions among characteristics both from various levels and within a single level are more important and that having explicit boundaries between levels may not help.

Our framework may contribute to the study design and data collection for utilitarian walking. Our framework highlights the importance of dynamic processes. However, most of the existing research on active travel has been cross-sectional, and we need longitudinal study designs using time-series data to investigate causal relationships. Recently, a small but growing number of longitudinal studies has emerged to study the influence of the environment on walking¹¹⁸, between the change of environment and the change of walking^{119–121}, and between residential relocation and walking¹²². Particularly, following their framework on how active travel is influenced by environmental change¹², Ogilvie and his colleagues conducted several longitudinal empirical studies to test their framework^{88,121,123}. Longitudinal study designs also have the potential to address the “self-selection” bias¹²⁴. At the same time, our framework validates the necessities of well-defined concepts and operational measurements for a number characteristics that remain vague or controversial. For example, attitude towards walking, as a psychological characteristic, is not well defined in walking-related studies¹²⁵. Further development is also needed for both built and social environmental measures^{126,127}.

Our framework may promote the adoption of novel research methods. Dynamic processes, including feedback, time delay, heterogeneity in mode choice function, interactions among individuals, and influence from multiple factors at multiple levels, all are the properties of systems science methods especially agent-based modeling^{128,129}. Agent-based models (ABM), as a bottom-up approach, can be used complementarily with statistical analysis at the operational level. Dynamic processes and causal relationships could be explicitly implemented in an ABM to test hypotheses, make predictions, or explore policy interventions^{130,131}. For example, an ABM has been developed to examine the influence of spatial segregation and travel cost influences on utilitarian walking¹³². In this model, travel mode choice is based on a utility function that incorporates travel cost and attitude towards each travel mode. The model has a feedback mechanism implemented through updates to each person's attitude towards each travel mode, which vary with a person's experience with that mode. Attitude towards a given mode, in turn, affects the likelihood that a person will choose that mode subsequently. A person's experience includes influences of the social network, interactions with other travelers, and neighborhood safety.

Our framework may provide indications for policy interventions aiming to promote active travel. A number of testable hypotheses could be generated from our framework and be examined separately through empirical studies¹². For example, the travel mode choice function in our framework is with a hierarchical structure and heuristics rules and is modified by individual characteristics and travel characteristics. We may postulate that for certain groups (e.g., elderly), the crime in their neighborhood may prevent them from active travel even though the built environment is walking-friendly. Another example is that, due to the interactions among an individual's own behaviors, it is plausible that the change of long or medium term behaviors (e.g., residential relocation) provides an opportunity for individuals to reconsider their travel mode choice; thus, these individuals may be more effective targets for intervention program of active travel.

The framework needs to be further tested by designing empirical research. Fundamentally, most evidence to date is cross-sectional, and we lack longitudinal data on both the changes of behavior and the environment that are necessary to identify the dynamic interactions and causal relationships among various factors¹³³. According to a systematic review examining the causality between the built environmental and physical activity, from 1996 to 2010, only one quasi-experimental study investigated utilitarian walking. We need longitudinal evidence to support theories and frameworks, to eventually better inform policy interventions.

To work towards an operational framework is especially challenging. The seemingly relatively simple process of travel mode choice is far more complex than what has been presented in this framework. Numerous unanswered questions remain. For example, how do attitudes and habits interact with utilities and constraints to determine the travel mode? How can we generate the hierarchical structure and heuristics rules in the travel mode choice function? How is the travel mode choice function modified by other characteristics and travel purpose? For the study of utilitarian walking, existing knowledge is not enough to build a framework with both a holistic picture and all of the required operational details. Our framework is a relative synoptical framework and does not include details for every aspect. For example, we propose that mode choice function is in a hierarchical structure but do not

aim to provide a detailed description of the structure it should be like. Nonetheless, this is the value of our framework: to provide a skeleton for future studies to fill in the knowledge gap.

In summary, we propose a framework that integrates the key features of several mainstream theories, a number of frameworks proposed recently, and empirical evidence. It is a dynamic framework that includes a number of feedback loops, and the framework has potential towards the operational direction. More important, although this framework is for the travel mode choice, with considerable modifications it may be applied to other health behaviors involving decision-making and interactions with the environment.

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- We have identified and reviewed 22 frameworks related to mode choice for utilitarian walking.
- We propose an integrated conceptual framework for travel mode choice focusing on utilitarian walking.
- The framework is based on the integration of the utility theory, TPB, and social-ecological model.
- The framework is dynamic and includes a number of feedback loops.
- The framework may contribute to the study design, data collection, new research methods, and provide indications for policy interventions.

Figure 1.
Conceptual framework of travel mode choice

Table 1

Characteristics of frameworks on utilitarian walking.

Study	Psychological properties	Multiple levels	Dynamic processes	Other characteristics
Alfonzo 2005	*	*		A hierarchy of walking needs with five levels: feasibility, accessibility, safety, comfort, and pleasurability
Ben-Akiva et al. 1999; McFadden 2001	*		The results of current travel mode choice influences future choice	
Burbidge and Goulias 2009	*		Learning process between experience/information and attitude	Integration of TPB and Decision Field Theory
Corti 1998; Pikora, Giles-Corti et al. 2003	*	*		Integration of theory of planning behavior
Elias and Shifftan 2012	*			Integration of theory of planning behavior
Giles-Corti, Timperio et al. 2005		*		Environment's influence varies by walking purposes such as for recreation and transport
Götschi et al. 2015	*	*	A feedback loop to habit	Health benefits
Hodgson, Namdeo et al. 2012		*		
Idris, Shalaby et al. 2012	*		Travel behavior updates perceptions on environment	Integration of utility maximization and learning process
Krizek, Handy et al. 2009		*	Travel behavior influences long-term choices such as auto ownership and residence, and long-term choices influence environment	
McMillan 2005				Parents and children jointly decide travel mode
Mitra 2013	*	*		As children grow, they take greater control over travel mode choice
Ogilvie, Bull et al. 2011	*	*	Travel behavior influences psychological variables and environment	
Panter, Jones et al. 2008	*	*		Parents and children jointly decide travel mode
Pont, Ziviani et al. 2011	*		Travel behavior influences individual characteristics.	Parents and children jointly decide travel mode
Saelens, Sallis et al. 2003	*	*		
Sallis, Cervero et al. 2006		*		
Schneider 2013	*		Five steps in the travel mode choice: awareness and availability, basic safety and security, convenience and cost, enjoyment, and habit. Habit, as the final step of this loop, influences the awareness of travel modes	

Study	Psychological properties	Multiple levels	Dynamic processes	Other characteristics
Singleton 2013	*		(1) Feedback loop to habit and attitudes; (2) Perception process	(1) Alternative decision rules; (2) Hierarchy walking needs
Sirard and Slater 2008	*	*	Travel behavior influences psychosocial variables, and psychosocial variables influence on the perception on environment	
Transportation Research Board 2005		*	Physical activity goes back to influence individual	(1) Environment influences middle-term choice such as car-ownership and long-term choice such as residence; (2) Trade-off among various physical activities
Van Acker, Van Wee et al. 2010	*		Travel behavior and other behaviors influence psychological variables and perception on environment	(1) Reasoned and unreasoned behaviors; (2) Short-, middle-and long-term behavior influence each other

Note: In this table, a characteristic needs to be explicitly included in the framework (with indication of an asterisk for both psychological properties and multiple levels). For example, a framework that simply lists attitude, preference or habit as an individual's properties is not considered as for having psychological properties.