IMPROVING THE OPERATIONAL EFFICIENCY OF PUBLIC TRANSPORT

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ABSTRACT

Improving the efficiency of public transport systems is a critical problem. In order to help implement strategies for improving efficiency, public transport managers and researchers need access to an up-to-date information system that fully describes these strategies including data on their quantitative benefits. This research outlines a proposal for developing such a database and how it might be organized. It recommends using travel time as a measure for evaluating the operational efficiency and categorizing efficiency improvement strategies based on trip processes. The categorization scheme would be used to organize a database of strategies and to help identify areas for additional research. Finally, the research suggests a structure for creating an internet-based strategy database and outlines how this database might be used.

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1. INTRODUCTION

Efficient public transportation is a fundamental building block for creating sustainable and livable urban areas. An efficient public transport system is fast, reliable and safe; all qualities that make it attractive to customers and improve its productivity – a win-win situation. Unfortunately public transport efficiency is decreasing just when rapid urban development makes it more crucial.

The project's objective is to encourage development and implementation of strategies designed to increase public transport efficiency. Efficiency strategies fall into one of the following categories:

- **Agency-wide** – These strategies address the organization and business practices of public transport agencies (e.g. contracting) as well as programs implemented throughout the network (e.g. GIS vehicle tracking).
- **Network Planning** – These strategies are used to design transit networks including line routing and modal choice decisions. They are often long-term changes such as constructing new rail lines.
- **Operations** – These strategies increase the efficiency of transit vehicles operating in revenue or non-revenue service. They include all techniques that reduce travel time without significantly changing the route/network.

This research focuses on operations level efficiency strategies because they can play a major role in making public transport more efficient and attractive to customers, and because they are often neglected in favor of larger, more visible projects, such as new rail lines. Moreover, these strategies form the building blocks for successful network planning projects. For example, many bus rapid transit (BRT) projects are based on systematically implementing a comprehensive set of operations level efficiency strategies. [1]

Many operations level efficiency improvement strategies have been developed, but they are not being implemented to the degree that they might be due to a lack of accessible information describing and quantifying their benefits. This research presents an approach for better communicating descriptive and quantitative information about operating efficiency strategies and their implementation. If the approach is successful, it could be expanded to include network planning and agency-wide efficiency strategies.

The following section defines public transport efficiency and measures used to quantify it. Section 3 describes operating efficiency strategies and outlines their importance. Section 4 describes a proposal for better communicating information about efficiency strategies. Section 5 presents conclusions and recommendations. This paper describes an on-going research project and comments/recommendations are welcome.

2. QUANTIFYING THE BENEFITS OF OPERATING EFFICIENCY STRATEGIES

A key problem hindering implementation of operations level operating efficiency improvement strategies is the lack of quantitative information about the benefits of individual strategies. Quantitative information is needed to justify implementing these strategies. This section outlines the general concepts of productivity and efficiency, describes their use in the public transport industry, and considers several variables for measuring the benefit of operations level efficiency improvement strategies.

2.1 Productivity and Efficiency

Productivity is the ratio of what is produced to what is required to produce it. Usually this ratio is in the form of an average, expressing the total output of some category of goods divided by the total input of, say, labor or raw materials. [2] This can be expressed as shown in equation 1:

$$\text{Productivity} = \text{Output} / \sum \text{Inputs} \qquad (1)$$

Often output is defined as the good or service produced, and the sum of inputs are defined in terms of cost. This leads to productivity measures of the form: public transport agency X produced 2.5 million trips at a cost of 5 million dollars last year.

Efficiency is how effective a given process is in converting inputs to outputs. In the example it would be $2 per trip (2.5 million trips divided by $5 million). This value would then be compared to the cost per trip for other companies to determine how 'efficient' public transport agency X is at producing transit trips compared to agency Y.

Equation (1) shows that there are three ways to improve productivity (and efficiency):

- increase output using the same inputs;
- produce the same output using fewer inputs; or
- increase output using fewer inputs.

There are three types of inputs used in producing all goods and services: labor, capital and intermediate goods (equation 2). Labor is defined as the human effort that is used in the production process (often defined in hours), capital is defined as the machinery, equipment and buildings used in the production process, and intermediate goods are products purchased outside the firm used in the production process.

$$\sum \text{Inputs} = L + K + I \qquad (2)$$

Where:

L = labor inputs;
K = capital inputs;
I = intermediate goods used in production;

Equation (2) shows that there are two methods of reducing inputs: changing the proportion of inputs used in the production process to increase the share of more efficient inputs and reduce the share of less efficient inputs, or improving the productivity of individual inputs.

The first method, changing the proportion of inputs used in the production process, is used often in public transport industry. One example is reducing labor hours by increasing capital investments (e.g. replacing several bus lines with a single light rail line). However, this is only effective if the capital investment is more productive than the labor it replaces, which is not always true. [3] Another example is contracting out service (replacing capital and labor with purchased goods). Again, this is only effective if the contracted service is more productive than that provided internally by the agency (this is referred to as the 'make or buy' decision in management).

The second method for increasing efficiency, improving individual input productivity, is also used in the public transport industry. One example is increasing labor productivity (reducing the amount of labor needed to produce a given output) by designing bus routes so that the same operator could make three trips an hour rather than two (this would also improve capital productivity since one bus could be used for three rather than two trips).

2.2 Productivity and Efficiency in Public Transport

Productivity and efficiency are easy to understand and measure in the theoretical sense, but these are more difficult in practice. Productivity in the private sector can be measured in financial terms, since all inputs are purchased (for a price) and all outputs are sold (again for a price). For industries that provide social goods and/or which operate outside the market system, including public transport, prices are not always available.

For example, what is the proper value (price) for public transport's special "outputs" (e.g. reduction in air pollution, provision of mobility to those unable to drive, etc.) and for improved service quality? A large part of public transport productivity literature describes various input and output variables. [4] [5] [6]

A good variable for measuring efficiency will have the following qualities:

- it must be impacted by the types of strategies under consideration;
- it must be oriented to the analysis purpose; and,
- it should be relatively easy to measure.

As outlined above, there are three categories of public transport improvement strategies (agency-wide, network planning and operations-level). Measuring efficiency at each of these levels has different objectives and therefore different variables, and choosing the most appropriate measures of productivity is problematic at all levels.

Agency-wide

At the agency-wide level, productivity is measured based on data related to the entire system (e.g. all the routes, or total labor costs). One problem caused by the difficulty in finding an appropriate measure for agency productivity is the question of what measure to use to determine subsidies – since choosing the wrong measure can create inappropriate incentives. For example, providing subsidies based on vehicle kilometers of service supplied has led some agencies to focus on service expansion instead of maximizing the usage of existing services or redistributing service toward markets with greater potential demand. [7] This problem is compounded when public transport service is contracted out – selecting the correct measure for compensating the private operator is critical to program success.

Network Planning

Defining productivity at the network planning level is also problematic. A key question running through the public transport network design literature is identifying the best objective function to minimize (or maximize). There is a fundamental problem in network design: builders (operators) want to provide the smallest possible network (to minimize production costs) while users want to have the largest possible network (to minimize travel costs/time). Both solutions are optimal from one point of view but are clearly unsuitable from the other point of view. [8]

Most agree that there must be a compromise between service cost and passenger comfort. [9] The typical approach is to express user travel time financially and then minimize total (builder and user) costs. However, the problems involved in weighting different parts of user travel time make this a very complex and uncertain process. [10]

Operations Level

There are many possible measures for evaluating efficiency at the operations level including vehicle travel time, distance, speed and delay. Vehicle travel time is an attractive measure since the less time it takes to make a trip, all other things being equal (e.g. serves the same number of passengers, collects same amount of fares), the more efficient and productive the route. Furthermore, reducing travel time increases customer attractiveness (thereby increasing revenues). By increasing revenues and productivity, reducing travel time provides a double benefit.

Speed and delay are related to travel time, but cannot be used as easily to measure the effects of strategies. For example, using speed would probably be based on average speed for the whole route; this would be only slightly impacted by any given strategy and could be subject to other influences. Delay is also problematic since the concept of delay requires setting a baseline (how long it "should" take to complete an operation) and this baseline is difficult to define for public transport. However, all strategies designed to reduce travel time will increase speed and reduce delay.

Empirical data support the thesis that reducing travel time can make public transport more efficient and successful. Patronage increased by about 14% and costs were reduced by €4 million when travel times were reduced by about 21% on a series of routes in Munich. [11] Similarly, Los Angeles' Metro Rapid Program, which placed bus rapid transit (BRT) service in several of the Los Angeles area's busiest corridors, reduced travel times by up to 29% and increased bus ridership by 20% in the Wilshire-Whittier corridor and 50% in the Ventura Blvd. Corridor. [12]

Therefore, this research recommends using vehicle travel time to quantify the benefits of operations level efficiency improvement strategies since it is easily measured, easy to understand and appropriate for the research purpose. To the extent possible, this measure should be used to describe the benefits of specific efficiency strategies that are included in the project database.

3. OPERATIONS LEVEL PUBLIC TRANSPORT EFFICIENCY STRATEGIES

A second key problem hindering implementation of operations level efficiency improvement strategies is that since these strategies are often implemented as part of larger projects, it is difficult to understand how specific strategies operate and to identify their particular benefits. Understanding individual strategies better helps improve the quality of implementation, increase the number of strategies implemented, and foster the development of new strategies. One technique for increasing understanding of specific strategies is to develop a framework for categorizing these strategies; this section describes a categorization system for operations level efficiency improvement strategies.

3.1 Qualities for Selecting a Categorization Scheme

There are many possible schemes that could be used to categorize efficiency improvement strategies. The best categorization schemes will be those that are intuitive, easy to use, expandable, and meet the project objectives.

It is critical that the scheme meet the project objectives, therefore, the first step in selecting a categorization scheme is to understand how the categorization will be used. In this case the scheme will be used to communicate information about efficiency strategies (from a database) and to help guide further research.

Categorization schemes should be intuitive so users can easily find the information they seek. This means the scheme should be logically organized for the people who will be using it. In this case, the users are mainly researchers and transport managers, but also include decision-makers and the public.

Categorization schemes should be easy to use; complicated schemes will not be used. The qualities that make a scheme easy to use include simplicity and intuitiveness.

Finally, categorization schemes should be expandable; they should allow new information to be added while maintaining or improving the scheme's logicalness and ease of use. Expandability is important if the database is to remain current and serve as a long-term information source. A good technique for creating easily expandable schemes is using a branching structure that allows additional information to be added at more detailed levels.

3.2 Potential Categorization Schemes

Table 1 presents four possible categorization schemes and qualitative ratings of their intuitiveness, ease of use, expandability and ability to meet the project objectives. Each of these schemes is described below.

Trip Process

This categorization scheme would break each element of the public transport *vehicle* trip into a separate process and present efficiency improvement strategies for each process. There would be two basic types of process in this system: revenue service processes and non-revenue processes.

This scheme would be easy for transport managers and researchers to understand and use. It would be less intuitive for the public since they normally focus on their whole trip rather than on the vehicle trip. The scheme would be easily expandable as it would be possible to add processes and/or divide processes into smaller sub-processes. Since this scheme is based on the elements of the public transport vehicle trip, it fully meets the project objectives.

Passenger Process

This categorization scheme would break each element of the *passenger* trip into a separate process and present efficiency improvement strategies for each of these processes. Elements would include travel to station and riding transit vehicle.

This scheme would be easy for everyone to understand and use, but would not be as useful as the trip-based scheme in supporting the project objective. More specifically, the passenger process starts with the passenger's trip to the station/stop and ends with the passenger's trip from public transport to the destination. These two elements are critical to public transport, but belong to the larger network design process rather than operations level analysis.

TABLE 1: Potential Operations Level Efficiency Strategy Categorization Schemes

Potential Schemes	Intuitive	Ease of Use	Expandable	Meets Project Objective	Description
Trip Process	++	++	++	++	Categorization based on vehicle trip processes (e.g. stopping at station)
Passenger Process	++	+	++	–	Categorization based on passenger trip elements (e.g. travel to bus stop)
Hardware	+	++	+	–	Categorization based on physical devices or equipment (e.g. traffic signal)
Organizational Responsibility	–	–	+	–	Categorization based on organizational responsibilities (e.g. roadway administration)

Note: + = positive and – = negative.

Hardware

This categorization scheme would be based on the physical elements used for the public transport trip and would present efficiency improvement strategies for each of these elements. Elements include vehicles, control systems (e.g. traffic signals), and stations.

This scheme would be easy for managers and researchers to use, but less so for the public who are not likely to think in terms of the physical elements involved in a public transport trip. The scheme has the further disadvantage of dividing elements that might be more advantageously considered together. For example, under the trip-based scheme, the element "stopping at station" would include several strategies each based on a different physical element for making this process more efficient. Considering these physical elements together could help managers decide how best to reduce time spent stopping at stations; a hardware-based scheme might encourage managers to focus on a single physical element (e.g. the vehicle) and thus miss the opportunity to achieve the objective more cost effectively.

Organizational Responsibility

This categorization scheme would be based on the organizational unit responsible for implementing particular efficiency improvement strategies. In other words, improvements to the roadway would be categorized under the roadway department.

This approach has several problems. First, while this scheme makes implementation responsibilities clear, it diffuses implementation incentive. While some departments would have a strong interest in improving public transport, for others public transport may be of little interest (e.g. roadway administration). Second, since organizational responsibilities are also frequently divided along hardware lines, this scheme shares the disadvantage of limiting the scope of improvements considered. Finally, there is no standard assignment of responsibilities to departments; in other words road maintenance may be part of the public works department in one city and part of the building department in another. Thus any scheme based on organizational responsibility would not be consistent for all cities.

Recommended Categorization Scheme

Of the four categorization schemes considered, the trip-based scheme is intuitive, easy to use, can be expanded easily and is the best suited to meeting the needs of this project. Therefore, it is recommended for use in the research. The trip-based categorization scheme is presented in Table 2.

TABLE 2: Public Transport Trip-Based Processes

Type	Process	Description
Non-Revenue Service	Travel to Layover Point	Time required to travel from the end of one trip (or garage) to the location where vehicles wait before starting their trip (layover point).
	Operator break	Time required for operator to rest before starting a new trip (often a subject of labor agreements).
	Recovery	Time provided to enable a late arriving vehicle to start the next trip on time.
	Travel to Terminal Point	Time required to travel from the layover point to the route starting point (first stop).
Revenue Service	Time in Motion	Time the vehicle spends in motion between stations.
	Time at Traffic Signals	Time spent decelerating to stop at a traffic signal, stopped at a traffic signal, and accelerating from a traffic signal.
	Station Acceleration/ Deceleration	Time spent decelerating to stop at a station and time spent accelerating back into the traffic stream from a station stop.
	Door Opening	Time it takes for the doors to become completely open.
	Passenger Alighting	Time it takes for passengers to alight the vehicle.
	Passenger Boarding	Time it takes for passengers to board the vehicle.
	Door Closing	Time it takes for the doors to become completely closed.
	Return to Traffic	Time between closing doors and beginning acceleration back into traffic stream.

4. PUBLIC TRANSPORTATION EFFICIENCY PROJECT DATABASE

The project objective is to encourage development and implementation of strategies designed to increase public transport efficiency at the operations level. The research proposes to achieve this objective by creating an easily accessible (via Internet) database of strategies organized using the trip-based process structure including quantitative strategy effectiveness data. This section describes the proposed Internet database.

4.1 Database Users

The database will have four types of users: transport managers, researchers, decision-makers, and interested members of the public.

Transport managers would use the database to learn the latest information about individual strategies for improving public transport efficiency including results of both academic and practical studies. Managers could also add information to the database about strategies they have implemented or tested.

Researchers would use the database to publicize their research results and to help keep abreast of research and implementation. This will help make research more relevant – publicizing research ideas could help them be implemented. It will also help researchers identify areas where additional research would be useful, thus helping develop new strategies for improving public transport efficiency.

Decision-makers and members of the public would use the database to learn about strategies. If these groups better understood the importance of efficiency strategies they would be more supportive of implementation.

The database would be accessible from a Public Transport Efficiency Improvement website. This website would also allow users to communicate with one another. For example, transport managers could contact researchers to find out more information or researchers could contact managers to solicit their help on field research (e.g. surveys, field trials, case studies). In the long term, this website could foster development of a user community to support implementation of public transport efficiency strategies.

4.2 Website Structure

The Internet website would present information from the database to users. It would be organized in four levels as shown in Figure 1.

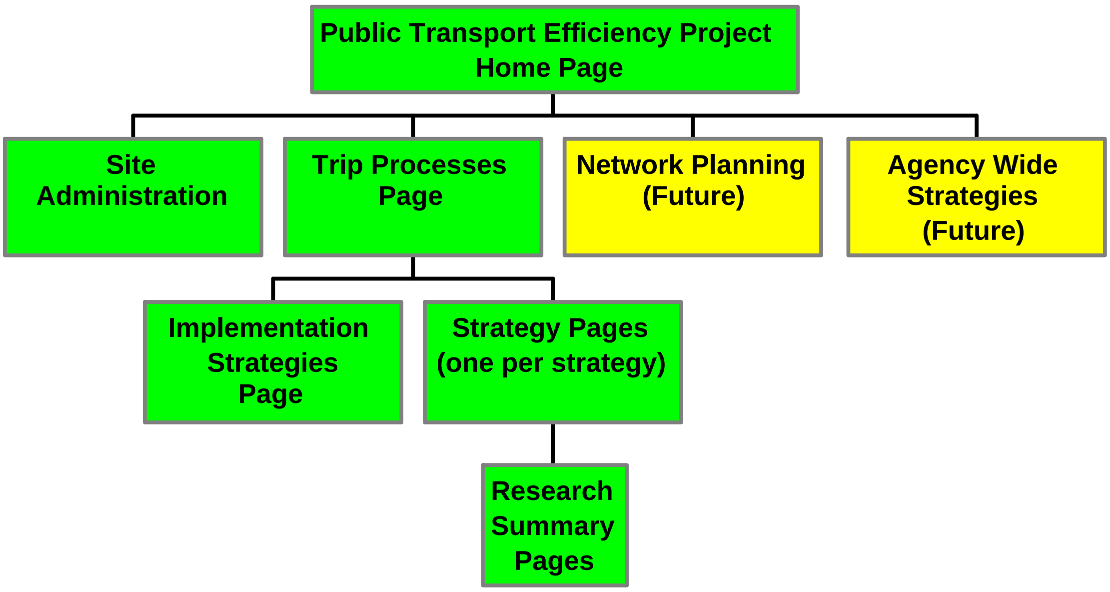

Figure 1: Schematic diagram of proposed public transport efficiency project Internet site.

The initial website would include the following pages: home page, trip process page, strategy pages, research summary pages. These pages would include the following information:

- **Home Page** - The home page would present general information about public transport efficiency, the project, and website administration. It would include links to the trip processes pages, an implementation programs page, and several administration pages.
- **Trip Processes Page** – The trip processes page would include a table listing the different trip processes and potential strategies for improving the efficiency of that process. Each strategy would be linked to a "strategy page."
- **Strategy Page** – Each strategy page would describe a strategy that can be used to increase operating efficiency. Each page would consist of a research summary in WIKI format and a research summary table that presents information from the database.
- **Research Summary Page** – Each research summary page would present detailed information about a particular research study from the database.

The implementation programs page would be similar to a strategy page. It would present information at the general, detailed, and specific levels for implementation programs (in other words, evaluations of the “success” of programs for implementing operational level public transport efficiency improvement strategies).

4.3 Website Administration and Maintenance

The Internet website would be designed and maintained by a single research institute, but its contents (the database) would be developed by a wider community of researchers, professionals and others interested in public transport efficiency.

The administrator would be responsible for creating and revising the home page, trip processes pages, and strategies pages. The administrator would also be responsible for providing initial content, quality control, and normal administrative functions (e.g. registering users, maintenance, responding to questions).

Users would be able to add content to the site in two ways. First, the general and detailed descriptions on all pages would be created using WIKI format which allows users to add or edit text, images, and links. Registered users could add or edit information such as new research results and ideas. Thus, the descriptions would serve as an updated “state of the research”. This will help identify fruitful areas of new research.

The second way users could add content is by submitting results of their research to the website’s database. This research results database forms the foundation for the project – it contains the information needed to help increase implementation of public transport efficiency strategies. This information would be used to provide the data that is presented to users on the appropriate strategy page and research summary page. Researchers could add data to the database by filling in the website data entry form. This form would request information including: title, abstract, relevant strategy/strategies (from a checklist), contacts, and links to full study.

Once the website becomes established, administrative functions would be distributed to the user community. For example, one user could take responsibility for monitoring and quality control of one particular strategy. This is a common procedure for WIKI format websites.

4.4 Examples

This section presents an example of a Strategy Page and a Research Summary Page from the website. The intention is to provide an idea of the type of information that would be provided and the proposed format. The example is in text format and includes written descriptions of internet-related page elements. The example describes optimal public transport stop spacing. The same example can be viewed on the Internet at: http://www.andynash.com/pte-project2/PTEhome.html.

4.4.1 Example: Strategy Page

Strategy: Optimize Public Transport Station/Stop Spacing

(WIKI) **Introduction:** The spacing between public transport stations (stops) must be carefully considered to balance the need for passenger access and transit vehicle speed.

The more often a public transport vehicle must stop the slower its average speed. Slower speed means less attractive service to passengers and increases the cost of providing service. On the other hand, transit vehicles must stop to pick-up and drop-off passengers so stops cannot be totally eliminated. The key is to balance the need for passenger access to public transit stops with the benefits of increasing transit vehicle speed.

(WIKI) **Detailed Description:** Research supports the conclusion that station spacing for most public transport systems is too short (i.e. stations/stops are too close together). Ideal spacing of 600 – 700 meters for bus stops and about 800 meters for tram lines appears to be appropriate.

(Table from Database)

Strategy Summary Table: Optimize Public Transport Station/Stop Spacing			
Research Study	Performance Measure	Findings	Comments
VanNes (2000) *(link)*	Stop Spacing	Spacing generally too close; optimal spacing 600-700 meters (bus) and 800 meters (tram).	Spacing values are approximate and should be based on specific conditions. Research describes methodology in detail.
TCRP 26 (1997)	Bus Trip Time	Buses spend 9-26% of time at passenger stops.	Data is from US (1982). Report describes effectiveness of many techniques for speeding up buses on arterials.
Another Study (date) *(link)*	xxx	xxx	xxx

Note on sources: VanNes [13], TCRP [14]

4.4.1 Example: Research Summary Page

The research summary page will present summary information about the research studies that address the particular strategy. The database can present the results of a single study or multiple studies. This page is returned when users click on the link in the Strategy Summary Table (above) or when users query the database using the site's search engine.

Research Summary Page

Research Study 1

> Van Nes 2000 [13] – Van Nes completed a research study on the question of optimal stop and line spacing for public transportation networks including a substantial review of the literature (van Nes, Rob; Optimal stop and line spacing for urban public transport networks, Analysis of objectives and implications for planning practice; TRAIL Studies in Transportation Science No. S2000/01; Delft University Press, Delft; 2000; www.TRAIL.tudelft.nl).
>
> The study describes the problem background and analytical techniques used in optimizing passenger access time and transport agency costs (with various objective functions). It also considers how bicycle access to stations could reduce passenger access time and what impact this has on stop and line spacing. The study summary (page v) concludes:
>
> Based on the research study "clear recommendations for planning practice emerge. Current network design focuses too much on short trips and on access distance only, while ignoring in-vehicle time, waiting time, and operational costs. As a result, existing urban public transport networks are too expensive. Opting for a balance between traveler costs and operator costs and focusing on longer trip lengths, will result in twice the traditional stop spacing for bus and tram networks, and in twice the traditional line spacing for bus networks. Implementing these changes will lead to a significant reduction of operational costs, while service quality is maintained or improved and thus ridership is maintained or increased. Improving cycling facilities at and around stops will further enhance these favorable shifts."

Research Study 2

TCRP Project 26 (Operational Analysis of Bus Lanes on Arterials) [14] – This report summarizes many research projects on various strategies for improving the speed of buses. Of particular interest is information it reports on the share of time typical buses spend on various elements of its trip. It states that the typical bus spends about 48-75% of its time moving, 9-26% at passenger stops, and 12-26% in traffic delays. Cars are consistently 1.4 to 1.6 times faster than buses. (This information was reported by: Levinson, H. S. INET Transit Travel Time Analysis. Prepared for UMTA, U.S. Department of Transportation, 1982; and, Levinson, H. S. Analyzing Transit Travel Time Performance. In Transportation Research Record 915, TRB, National Research Council, Washington, DC, 1983.) The information is from US sources and was collected in 1982. The significant variability of the data, a difference of 17% for time spent at passenger stops shows that the stop time can vary substantially and therefore bears investigation. The variability also suggests that completing a simple study comprising of collecting these times for routes could provide valuable information for improving productivity (it would show the most worthwhile areas to focus on).

4.5 Using the Website

This section outlines how perspective users might use the website.

Assume that a manager wants to learn more about strategies to reduce the time a bus spends stopping at bus stops. By clicking on the operating efficiency strategies link (from homepage), the manager could see a list of various strategies for reducing stop time. If one of the strategies were of particular interest, the manager could click on its link to view the appropriate strategy page, for example "Door Opening Process." This page would describe how door opening time impacts travel time and research related to opening vehicle doors as well as a research summary table with links to more detailed information about the particular research studies (clicking the link would return a Research Summary Page for the study/studies).

A second way to use the site would be to use its search function to identify and view summaries of all research in the database on a given topic. For example, a user could enter the term "door closing systems" into the website's search function to view summaries of all the studies addressing this topic in the database. The search could be organized around keywords as well as a full document search.

In addition to simply providing information, the website could help create a network of actors interested in implementing public transport efficiency strategies. These actors would mainly interact using the website. Researchers would use it to publicize their research, make contacts with practitioners, and quickly assess the state of the research. Those responsible for planning and operating public transport networks would use it to identify techniques for improving operations and for contacting researchers. Decision-makers and the public would use the website's general summaries to better understand public transport efficiency strategies, thereby encouraging the implementation of strategies. All users would also be able to contact each other to learn details, ask questions and make suggestions.

5. CONCLUSIONS AND RECOMMENDATIONS

Improving the efficiency of public transport systems is a critical problem. In order to help implement strategies for improving efficiency, public transport managers and researchers need access to an up-to-date information system that fully describes individual strategies for improving efficiency including data on their quantitative benefits.

This research recommends developing a database that provides detailed information about individual public transport efficiency improvement strategies at the operations level and describes how such a database might be created. The research recommends focusing on travel time as a measure for evaluating the efficiency of public transport at the operations level. It further recommends categorizing strategies based on the main processes of the public transport trip. This categorization scheme would be used to organize the database of strategies and to help identify areas for additional research. Finally, the research suggests a structure for organizing an internet-based efficiency strategy database and how it might be used.

The author welcomes comments on all aspects of the project.

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