

Massachusetts Institute of Technology
Engineering Systems Division

Working Paper Series

ESD-WP-2008-08

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DESIGN AND MANAGEMENT OF FLEXIBLE
TRANSPORTATION NETWORKS THROUGH THE USE OF
INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

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February 2008

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ABSTRACT

Designing a flexible system with real options is a method for managing uncertainty. In this research, Intelligent Transportation System (ITS) capabilities were used to create a flexible transportation system, capable of coping with multiple uncertainties. Specifically, HOT, BRT and TOT managed lanes were examined in a case study centered in Houston, Tx, to determine the benefits of flexibility these capabilities provide. A qualitative analysis procedure utilizing regional traffic demand modeling and real options analysis was utilized to assess these benefits. It was found that ITS managed lanes can be configured in multiple ways to create flexibility in transportation systems, each of which provides value when dealing with uncertainty.

KEY WORDS

Real option, option, managed lanes, uncertainty, flexibility, flexible system, complex systems

INTRODUCTION

Complex systems exist in an uncertain environment and have behaviors that can be difficult to predict. These uncertainties can result in outcomes that have serious consequences for the users of the system. Making “good” decisions about the system under this uncertainty is non-trivial. This leads to the need to find some way of coping with this uncertainty. For this research, flexibility is the means with which uncertainty is addressed.

Designing flexibility in a physical system is one method for managing uncertainty. A case study was chosen to illustrate the ability to design flexibility into a system via design and operational decisions in the physical system. The case study considered in this research focuses on Intelligent Transportation System (ITS) capabilities applied to managed lanes in an

urban metropolitan setting and the various stakeholders involved in such a regional transportation system (1). The city of Houston, Texas, a major metropolitan city in the United States, was chosen as the specific site of the case study.

UNCERTAINTY AND FLEXIBILITY

Uncertainty appears in many forms, such as technical uncertainty, economic uncertainty, scheduling uncertainty and political uncertainty. These areas have been recognized and tools have been developed in the past to deal with each. For example, factors of safety are included in the technical design to accommodate technical uncertainty; management reserves are created to address financial uncertainty; and work in major government programs is spread over many congressional districts to reduce political uncertainty.

This research primarily studies flexibility as a means of transforming the physical system configuration or operation to deal with uncertainty, where flexibility is defined as a *property of a system that is capable of undergoing changes with relative ease* (2). The emphasis of the research is on designing real options “in” the physical system, as opposed to real options “on” a system, which deal less with the actual technology and more with the use of the technology, such as scheduling flexibility in program management (3).

Real options provide a decision maker the freedom to act in response to a changing environment, by creating flexibility in the system. The concept of real options can be used to help create flexibility in a system and tools such as real options analysis for valuation can be used to quantitatively evaluate the benefits associated with options.

The concept of real options is based on financial options. Financial options give the option holder the right, but not the obligation, to take some action now or in the future at a predetermined cost. Real options are similar in concept to financial options, but in reality, additional complexities may exist, such as the ability to actually exercise the option or uncertainty surrounding exercise costs.

FLEXIBILITY IN HOUSTON GROUND TRANSPORTATION SYSTEM

As the population of Texas has grown at a far faster pace than road capacity, the transportation network in Texas has become strained. With a growing realization that construction of sufficient freeway capacity to maintain free-flowing traffic in urban areas will be difficult due to costs, land use, neighborhood impacts and environmental concerns, the Texas Department of Transportation has been examining managed lanes as one method to fight the growing traffic congestion problem (4).

Houston has already deployed one of the largest networks of HOV lanes in the United State, with 112.5 lane miles of HOV and Diamond lanes on six different freeways serving eight counties. Houston’s HOV lanes are reserved for buses, vanpools, high occupancy vehicles and motorcycles and in most cases, single occupant vehicles and large trucks are not allowed on the HOV lanes.

In addition to HOV lanes for high occupancy vehicles and bus service, Houston operates two HOT lanes, called QuickRide; one on the Katy Freeway (I-10 W) and the other on the Northwest Freeway (US 290). Both of the HOT lanes utilized existing HOV lane facilities, which are still one-way reversible lanes, operated in the direction of peak traffic flow.

The QuickRide program operates the HOT lanes as a 3+ passenger facility during peak hours, but as a 2+ facility during non-peak hours. During peak hours, 2+ vehicles are allowed to use the lane for a flat \$2.00 fee. The lane was upgraded from a 3+ HOV lane to a HOT lane to help fill unused capacity (5).

ITS AS A REAL OPTION

Two uses of using ITS as a real option have been studied by the authors as potentially having value in the regional transportation network of Houston, described below

Managed Lanes as a Means to Delay Traditional Infrastructure Investment

Traditionally, when traffic demand approaches maximum roadway capacity and congestion becomes an issue, additional capacity is added by expanding the roadway or building another facility, increasing the capacity of the network. Typically, this involves the addition of new lanes in a variety of manners, such as widening the roadway, which can be prohibitively expensive, especially in urban areas. Or operational changes can also be used to increase capacity with strategies such as using shoulders or breakdown lanes as general purpose lanes during peak hours, effectively increasing the road capacity, at least during peak hours.

The use of managed lanes is another potential solution for increasing capacity or changing traveler's habits. By adding ITS equipment and changing the lane operating strategies, existing HOV lanes can be converted into HOT lanes or TOT lanes. The effect of including the ITS capabilities serves to increase the capacity carrying potential for a managed lane, increasing the overall capacity for the entire highway facility, as additional traffic is diverted from the general purpose lanes onto the managed lane. For example, on California's Orange County I-91 highway, two HOT lanes that operate during peak hours carry more than 40% of total traffic, even though the lane capacity is only 1/3 of total capacity, i.e. two out of six lanes (6).

Since the managed lane can only increase the utilization of the network, future demand increases may still require the addition of new traditional infrastructure or change in travel habits, such as increased use of transit or off-peak travel. In this case, the use of ITS technologies on managed lanes may only delay, as oppose to replace the need for, traditional infrastructure expansion.

This option to delay infrastructure is useful for a variety of reasons. First, future traffic demand is uncertain, both in terms of level of demand and the timing of the demand. Second, traditional infrastructure expansion is typically more expensive than the use of ITS on managed lanes. As many states and metro areas throughout the U.S. are facing budget shortfalls for transportation systems, it is uncertain when, or if, funding would become available for new infrastructure expansion. Third, increased environmental and stakeholder concerns have made it more difficult to build new or wider roads. The ability to add new

capacity in a timely manner, even if the funds were available, is uncertain, especially in metropolitan areas. Fourth, the level of political pressure for enacting a solution to growing congestion problems is uncertain. An increased level of political pressure for a solution for alleviating congestion in the near term may be great enough to threaten politicians who can not enact new road widening construction projects in enough time to placate constituents.

The use of ITS capabilities on managed lanes to create the option to delay infrastructure expansion can be configured in a variety of ways. The exact characteristics of the ITS managed lane and potential traditional infrastructure expansion will vary from facility to facility. For the purpose of this research, it is assumed decision makers can always add one or more lanes to a facility, though at a large construction cost. It is also assumed that either a HOT/BRT or TOT/BRT managed lane could be converted from an existing HOV lane. As transit ridership is not great enough in Houston to warrant a dedicated BRT lane, a dual HOT/BRT or TOT/BRT managed lane is instead considered.

The decision path of this option is presented in Figure 1.

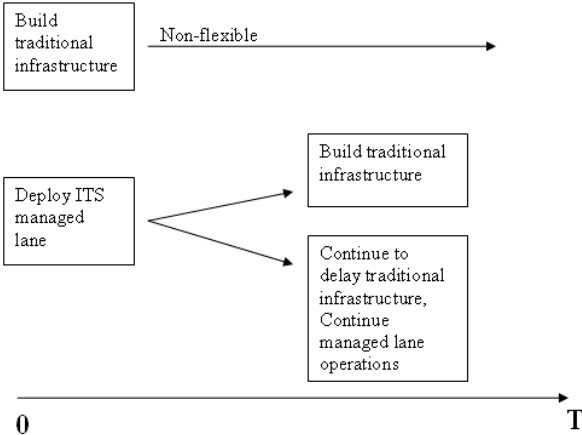


Figure 1 Decision path for ITS managed lane option to delay infrastructure

As shown in Figure 1, decision makers can chose between two alternatives at time = 0. The non-flexible solution is to build the traditional infrastructure immediately. The decision maker also has a choice of an option, which is to deploy the ITS managed lane at time = 0 and delays a build decision to some time in the future.

While the simple delay option creates flexibility benefits, the ITS managed lane option creates both flexibility benefits (from the possibility of construction delay) and inherent benefits (from the ITS managed lane itself). Additionally, there is the possibility that the ITS managed lane inherent benefits can influence the flexibility benefits; namely the more efficient utilization on the managed lane could further delay the need to build the traditional infrastructure.

Managed Lanes as Option to Switch Operations.

Current managed lane implementations have been of a single application variety to date, meaning that managed lanes have been of only one type, HOT, BRT, or TOT, or at most a combination of types, such as HOT/BRT or TOT/BRT. While the ability to switch a managed

lane from one type to another has been identified, such as switching from a HOT lane to a TOT lane, this has not been applied in practice.

The potential exists to switch the managed lane operations over multiple time-scales. For example, in the long-term, the lane could be switched from a HOT lane to a TOT lane if the growth in truck traffic outpaced the growth in auto traffic. The switch option could also be designed for use in the short-term. For example, during rush hour the lane could be a HOT lane and during mid-day could be switched to a TOT lane. To bound this research, only long-term switching is considered.

The primary benefit associated with the option to switch between managed lane operational states comes from coping with the uncertainty associated with relative growths in different traffic mode shares. While both passenger and commercial vehicle mode shares have been growing over time, the relative growth between these mode shares has been different. In general, commercial vehicle mode share has increased at a faster rate than passenger vehicle mode share. Compounding the uncertainty of relative growth rates, the location of the highest growth rates is often uncertain. Local changes, such as a new logistics facility, or national changes, such as increased international commercial traffic from treaties such as NAFTA, can both increase commercial traffic in unforeseen ways on various facilities. The ability to re-configure or change operational conditions on a managed lane to cope with changes in mode share is the benefit of using ITS as an option to switch between different managed lane configurations.

The decision path for this option is shown in Figure 2.

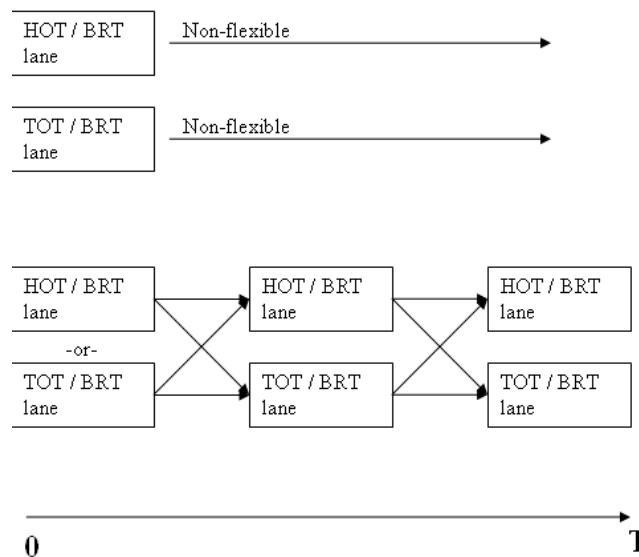


Figure 2 Decision path for ITS managed lane switch option

As shown in Figure 2, a decision maker has the choice of two non-flexible alternatives at time = 0, deploying either a HOT/BRT or TOT/BRT lane and keeping the chosen operating strategy in the future. The ITS managed lane option could also be chosen. This would entail choosing either the HOT/BRT or TOT/BRT lane operating strategy in time = 0 and the having the potential to maintain or switch strategies at some time in the future. The time frames considered for this research were measured in years, so switches can only occur at a minimum of one year apart from one another.

ANALYSIS OF FLEXIBILITY

To better analyze the value of the flexibility associated with the option, an analysis procedure combining transportation demand modeling and real options analysis was used. As shown in Figure 3, the quantitative evaluation process that was used for the research consisted of three main parts; generation of inputs, the travel demand model, and the quantification of option value. An overview of the activities and purpose of these three main parts are described below.

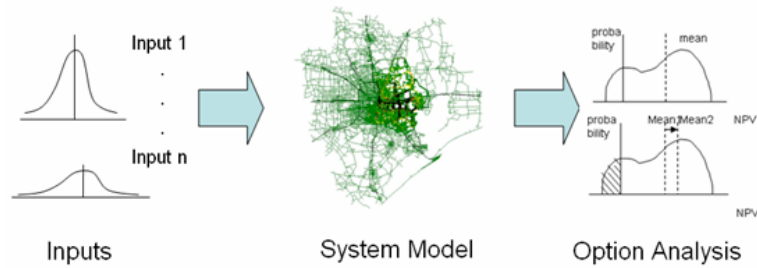


Figure 3 Quantitative analysis process for ITS case study, using Transcad traffic demand model as system model.

- **Inputs** – The inputs can describe network characteristics (such as numbers of lanes for facilities), traffic characteristics (such as modes and mode split), and environmental characteristics (such as travel demand growth). A few of these inputs whose uncertainty may affect systems decisions are then identified, and assigned a probability distribution. The input uncertainties of interest are: traffic demand growth, mode split, decision rules for building new infrastructure, and type of operator for any managed lane, i.e. a public or private operator.
- **Traffic Demand Model** – A traffic demand model, using the Transcad travel demand modeling software package, was created to allow facility and network level analysis of traffic flows and speeds, with and without ITS capabilities. The Houston area transportation network used for the research is a detailed representation of all the roads in the Houston area, including freeways, arterials, frontage roads, local roads and toll roads. Figure 3 shows the network obtained from the local Houston area metropolitan planning organization and used in analysis.
- **Real Options Analysis** – Results from the traffic demand model with the input uncertainty are used to create probability distributions of the benefits associated with specific choices of ITS and traditional infrastructure. Benefits of interest for this research are value of time savings and toll revenues.

Comparing the probability distribution function averages for systems with flexibility and without flexibility yields the value of flexibility. For example, the NPV distribution for addressing congestion problems with non-flexible and flexible solutions are generated. A non-flexible solution could be building traditional infrastructure capacity in year zero, while a flexible solution could be building ITS managed lane capabilities that would delay construction of additional traditional infrastructure until it was needed in the future. Comparing the average of the two NPV distributions would provide the value of flexibility.

RESULTS

Option to Delay Capacity Expansion – The option to delay capacity expansion construction on a congested facility is always present and has value, assuming that some alternative investment that provides comparable returns is available. The use of ITS on a managed lane facility does not create flexibility in this context, as this option already exists, but it does increase the value of the option. Using ITS on the managed lane to enable a congestion pricing operating strategy allows all of the remaining capacity to be utilized. By utilizing the existing capacity, additional vehicles can be removed from the GP lanes, which creates value not only for the vehicles using the HOT lane, but for the vehicles on the GP lanes as well, in the form of time savings. As seen from this analysis, using ITS in a more limited way, such as charging a static toll, as is being done with the QuickRide program, creates benefits, but not as much as a HOT lane using congestion pricing does. This is because the existing capacity is not being fully utilized.

The value of the option to delay capacity expansion construction is increased compared with an option to delay capacity expansion construction without using ITS because the increased capacity utilization on the HOT lane delays the onset of irregular traffic flow conditions on the GP lanes, possibly by years. This delay in investing in the capacity expansion construction allows other opportunities to be pursued, which otherwise may not have been possible as the funds would be used in the construction of additional capacity.

The operational strategy of the managed lane not only affects the benefits generated, but also helps determine the feasible enterprise architectures that could pursue deployment and operation of a managed lane facility. In all cases studied, the managed lane facility produced positive benefits that exceeded costs, making it a worthwhile investment for a government agency. However, when differentiating the benefits into societal and toll revenues, the benefit stream showed that deployment and operation of a managed lane facility would not be worthwhile for a private company acting alone. However, public-private partnerships seemed feasible from the analysis, with multiple strategies being apparent. For example, shadow tolls from societal time savings gains could be paid to a private operator from a public agency. Or, a public agency could fund the deployment of the managed lane facility and grant a concession to a private company to operate the HOT lane, as revenues exceeded operating expenses.

Option to Switch Operating Strategies – The option to switch operating strategies between HOT and TOT lanes was examined and found to have value. Further, ITS capabilities are needed to create this option. The manner in which the lane would be operated over time, either as a HOT lane or as a TOT lane, was found to depend on the benefit metric chosen. Considering just societal time savings benefits or considering both societal time savings benefits and toll revenues changed the relative value of the lane when operating as a HOT or TOT lane. In general, for the ten year period of interest, the managed lane facility is most valuable when used as a HOT lane, if just considering societal time savings benefits. However, when considering toll revenue as well as time savings benefits, the managed lane facility becomes more valuable when operated as a TOT lane.

Similar to the above discussion of the delay option, the choice of benefit metrics affects the enterprise architecture of the organization that would deploy and operate the managed lane facility. Additionally, the enterprise architecture affects the benefits that are of interest. Which perspective to use depends on the specific situation. The difference in perceived benefits and the resulting desire to operate the managed lane with different strategies could

create conflict in a public-private partnership. Further, the conflict stemming from a public-private partnership would not need to be limited to the managed lane facility only. Instead, because the demand for the managed lane facility is partially dependant on the state of other nearby facilities, an operator of a managed lane facility interested primarily in toll revenues would maximize revenues when surrounding facilities were continuously congested. This creates externalities, as a private operator may seek, through political means, constraints on public agency investment in the transportation network that could negatively affect the managed lane revenues, even if it benefits society as a whole.

ACKNOWLEDGEMENTS

Thanks to Mikel Murga at MIT for help in utilizing Transcad for the technical analysis. Thanks to the Houston-Galveston Area Council for providing the network and data for the traffic analysis.

REFERENCES

- (1) McConnell, J. A Life-Cycle Flexibility Framework for Designing, Evaluating and Managing "Complex" Real Options: Case Studies in Urban Transportation and Aircraft Systems, MIT PhD Dissertation, June 2007.
- (2) Allen, T. et. al. ESD Terms and Definitions, Version 12. ESD Working Paper Series, ESD-WP-2002-01, esd.mit.edu, 2001.
- (3) de Neufville, R. Uncertainty Management for Engineering Systems Planning and Design, Monograph draft for Engineering Systems Division, 2004.
- (4) TTI. Current State of the Practice for Managed Lanes, Appendix A in Year 1 Annual Report of Progress: Operating Freeways with Managed Lanes, Report 4160-2, Texas, 2001.
- (5) Goodin, G. Managed Lanes: The Future of Freeway Travel, Institute of Transportation Engineers. ITE Journal, Feb. 2005.
- (6) Poole, R. and C. Orski. HOT Networks: A New Plan for Congestion Relief and Better Transit, Reason Foundation, Los Angeles, 2003.