A System Dynamics Model for Bus Rapid Transit Corridor Planning and Ridership Forecasting

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ABSTRACT

Bus Rapid Transit (BRT) systems have many infrastructure and operational features that may be deployed in phases over several years. During the planning of a BRT system, important decisions need to be made on what features should be incorporated into the system and at what time. The decisions are made more complex by the fact that certain features need to have critical ridership (or revenue). On the other hand, the BRT ridership depends on attributes (such as accessibility, comfort, reduction in travel time) offered by these features. The interactions between the features and ridership are complex and consist of feedback loops. This paper presents the Systems Dynamics (SD) approach to model the complex inter-relationships between the system features and ridership of a BRT corridor. A case study using the Mesa Street in El Paso, Texas, is used to illustrate the applications of the SD model as a potential decision support tool in the BRT corridor planning.
INTRODUCTION

Bus Rapid Transit (BRT) systems may be described as “an enhanced bus system that operates on bus lanes or other transitways in order to combine the flexibility of buses with the efficiency of rail” (1), “a high-quality bus based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service” (2), “a complete rapid transit system that combines flexible service and new technologies to improve customer convenience and reduce delays” (3). There are many features (also known as elements or attributes) that can be combined to form a BRT system in order to deliver a fast, comfortable and cost effective transportation service. Galicia et al. (4) have identified and grouped all the possible BRT features that either contribute to (i) reduction in travel time or (ii) increase in ridership into infrastructure features and operational features.

BRT has been very popular in major cities in Latin America. This mode of transportation is gaining popularity in cities in U.S. Albuquerque, Boston, Las Vegas, Los Angeles, Miami, New York, Orlando, San Francisco are some of the U.S. cities that have BRT systems in operation. Compared to rail transit systems, BRT systems are relatively faster and cheaper to implement. However, the design of a BRT system involves a relatively more complex decision. Unlike rail transit systems, BRT projects rarely include the whole set of possible features when the systems are launched. A common practice is to start a BRT service with a few selected features within the initial budget and time frame. More features are added over time as ridership grows and when budget is available. Galicia et al. (4) have suggested market packages of possible infrastructure and operational features in three phases of implementation (limited, moderate and aggressive phases), each with an increasing budget. The phases of implementation need not be sequential and therefore planners still have the flexibility to select the features in each phase. With the many combinations of features over the project’s life cycle, common questions faced by BRT planners are: (i) What features should be selected for the initial system? (ii) What other features are to be added and at what time? (iii) How would the initial and added features help to increase ridership?

On the other hand, one of the most important and probably one of the most uncertain components in the BRT planning process is ridership forecast. The Federal Transit Administration (FTA) requests ridership forecasts for the base year, “opening” year, “maturity” year and horizon year (usually 20 years after the base year) for all New Start transit projects (1). However, FTA does not prescribe a standard methodology to estimate BRT ridership (5).

Bus rapid transit features and ridership are complex, inter-related and changing with time. At present, there is no simple methodology to model the BRT ridership that is linked to the system’s features, and capture their dynamic relationships over time. Such problem can be modeled by the Systems Dynamics (SD) approach.

System dynamics is a modeling approach for users to perform simulation of dynamic systems that involve many interlocking variables with feedback loops. In SD models, variables and their relationships are represented graphically by the so-called casual loop diagrams. Once a model has been constructed, users can simulate the effect of the change of one or more variables on the entire system over time. System dynamics has been used as a tool to study organization behavior due to policy changes (6).

This paper presents a SD model that captures the complex inter-relationships between a BRT corridor’s infrastructure and operational features and ridership. In the next two sections,
more detail discussions on the problems of BRT feature selection and ridership forecast are presented. This is followed by an overview of SD and a review of very limited applications of the SD approach in transportation-related topics. Having introduced the problem and the solution approach, the next section of this paper describes the development of the SD model for the modeling of BRT features and ridership forecasting problem. We then present a case study using the Mesa Street in El Paso, Texas, as a potential BRT corridor to illustrate the application of the SD model.

BUS RAPID TRANSIT FEATURES

Bus rapid transit systems consist of many features that are distinct from regular bus service. Some features are evolved or upgraded over time and with technological advancement. Many system designers adopt the features suitable for the local conditions, project budget, time frame of implementation and user needs. Therefore, there have been a variety of descriptions of what is a BRT system and what features can be used to characterize a BRT system.

The FTA (1) describes BRT as “an enhanced bus system that operates on bus lanes or other transitways in order to combine the flexibility of buses with the efficiency of rail”. In the BRT Planning Guide (2), BRT is “a high-quality bus based transit system that delivers fast, comfortable, and cost-effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations, and excellence in marketing and customer service”. The Transit Capacity and Quality of Service Manual (3) states that “BRT is a complete rapid transit system that combines flexible service and new technologies to improve customer convenience and reduce delays”. The above descriptions appear to summarize the general characteristics of BRT systems. Some other statements are more specific in spelling out what constitutes a BRT system. The U.S. General Accounting Office (7) states that BRT may include a set of features that include exclusive bus highways and lanes, High Occupancy Vehicle (HOV) lanes, technological and street design improvements, traffic signal prioritization, better stations and/or bus shelters, fewer stops, faster service, cleaner, quieter, and more attractive vehicles. The Transit Cooperative Research Program (TCRP) Report 90 (8) describes BRT as “a flexible, rubber-tired rapid-transit mode that combines stations, vehicles, services, running ways, and Intelligent Transportation System (ITS) elements into an integrated system with a strong positive identity that evokes a unique image”.

As can be noticed, without a common BRT definition, it is difficult for system designers, transportation engineers and planners to explain the characteristics of BRT systems to the policy makers and the public. It is also difficult for them to decide what features should be included in the design. In many cases, BRT systems are implemented with a few selected features that are deployed in a short project development period within the initial budget. More features are subsequently added as ridership grows and when more budget is available. A recent study by Galicia et al. (4) concluded that the common features of BRT systems are those that lead to (i) travel time reduction and/or (ii) ridership attraction relative to regular bus services. The features may be categorized as infrastructure features and operational features:

Infrastructure features
- Guideway and lane improvement
  (right of way improvement in whole or part of corridor)
• Shelter and Station  
  (station & shelter design, amenities, traveler information)  
• Park and ride facility  
  (include auto, taxi, bicycle, rail intermodal connections and covered walkway)  
• Surrounding land use  
  (transit oriented development, sidewalk improvement, safety & security in surrounding area)  

Operational features  
• Vehicles  
  (vehicle capacity, accessibility, fuel type and in-vehicle amenity)  
• Intelligent transportation systems  
  (transit signal priority, automatic vehicle location, in-vehicle and at-station real-time information, collision warning, driver assist systems, in-vehicle and station video monitoring)  
• Fare collection methods  
  (different types of systems from cash to smartcard)  
• Service and operation  
  (market identity, no. of stops, frequency, feeder service, on-schedule performance)  
• Operating speed  
  (<20 mph, between 20-30 mph, >30 mph)  

However, they noted that not all the features must be implemented for a BRT system to be successful. The same study has suggested possible infrastructure and operational features (also known as market packages) in three phases of BRT implementation. They called them limited, moderate and aggressive phases, in increasing order of features, technical complexity and budget. However, they also noted that (i) The phases need not be sequential. That is, one can upgrade from the limited phase to the aggressive phase, or directly implement the aggressive phase from scratch; and (ii) Planners have the flexibility of select the features to be included in each phase. With the many combinations of features over the project’s life cycle, common questions faced by BRT planners are: (i) With the initial budget and project implementation time frame, what infrastructure and operational features should be selected for the initial system? (2) What other features are to be added and at what time? (3) How would the initial and added features help to increase ridership? There is no simple answer to the above questions because the BRT features affect its ridership. On the other hand, the increase in ridership may necessitate the improvement of certain features (e.g., vehicle capacity, service frequency). There exist many feedback loops between the many features and ridership, with the ridership forming an important variable in the decision making process.

THE BUS RAPID TRANSIT RIDERSHIP FORECASTING PROBLEM

There are several national or international guidelines for implementing BRT systems in urban corridors (2, 5, 8, 9). These guidelines are used to identify corridor characteristics, BRT features, cost of implementation, financial and marketing opportunities, transit oriented development potential and other related issues. These guidelines presented several
methodologies for BRT ridership forecasting, which can be summarized into three approaches: (i) travel demand model (TDM); (ii) elasticity methods; and (iii) sketch planning.

Travel demand model is essentially the traditional four-step Urban Transportation Planning System (UTPS) process. The four steps are trip generation, trip distribution, mode choice, and traffic assignment. The BRT ridership is usually one of the outputs of the mode choice step. The TRCP Report 118 (9) recommends that regional TDMs should be used if “major investments are anticipated”. The four-step process, although widely accepted by transportation planning agencies, has one potential shortcoming. The regional TDM usually has a set of calibrated utility functions (for the logit model in the mode choice step). For a new BRT corridor without BRT service attributes and ridership data, the utility function and its coefficient values, calibrated for other modes along the same corridor, have to be directly applied to the BRT mode, or “borrowed” from another corridor that has BRT service.

The elasticity methods estimate the percent change in mode share with respect to a percent change in the service attribute. The TCRP Report 118 (9) defines elasticity as the change in ridership corresponding to a 1% change in: (i) fare; (ii) travel time; or (iii) service frequency. The elasticity methods can also be applied if there is a change in other attributes as well. This method is especially suitable when a change is to be made to a feature in an existing BRT route. The TCRP Report 118 (9) presents three elasticity methods: shrinkage factor, midpoint arc elasticity and log arc elasticity. Each method still needs elasticity value as input, plus base BRT ridership. This elasticity value can either be obtained from historical data, state preference survey or from other BRT corridors that have similar characteristics.

The sketch planning method makes use of land-use, demographic, residential and employment data, street configuration, transit routes and stop locations within the transit analysis zones to estimate transit trips generated. These methods are easier to implement than the TDM and elasticity methods. However, it also involves the estimation of mode share, growth and other factors. This method is recommended only for cases where the corridor does not have an existing regular bus service.

The above three forecasting approaches assume that BRT features and the resulting service attributes have been pre-determined. The forecasts are performed in a “one-shot” fashion. That is, given the BRT features and service attributes, the models produce ridership forecasts. In reality, some service attributes (e.g., service frequency, vehicle capacity) depends on the estimated ridership. The change in features, attributes, or level of service in response to ridership is not captured by these models. The SD approach can overcome this shortcoming by nature of its feedback loops in the model structure.

Another deficiency of the above forecasting approaches is their inability to simulate the change in system features and ridership over multiple time intervals (e.g., at every year for the next 15 years). The elasticity methods can predict the ridership in a future year along with a change in a service attribute. For multiple time periods, the forecast needs to be repeated in a chained fashion. The TDM and sketch planning method only apply to a fixed time scenario. For every time instant in the future years, the TDM and sketch planning method need to start with the demographic forecast of that year. The SD approach can simulate the changes in all the variables in the system simultaneously on-the-fly as the simulation clock advances.
FUNDEMTALS OF SYSTEM DYNAMICS

System dynamics is a modeling approach for users to perform simulation of dynamic systems that involve many variables with feedback loops, some of which the relationship may not be well defined (6). The System Dynamics Society describes SD as a “methodology for studying and managing complex feedback systems, such as one finds in business and other social systems” (10). The field of SD was introduced by Forrester in 1956 and since it has been applied to corporate planning and policy design, public management and policy, biological and medical modeling, energy and the environment modeling, system modeling in natural and social sciences, and etc (11).

System dynamics is an approach well suited for the modeling of complex dynamical systems. A complex dynamical system consists of many variables interlocked by feedback loops. The state of the system changes with time. A change in value of one of the variables affects its related variables. Such changes propagate to other variables in the system and feedback to some of the variables. A feedback is a situation in which one variable affects the other and vice versa. If there are two variables \( X \) and \( Y \), feedback refers to the situation when \( X \) affects \( Y \) (may be with a time delay) and in return \( Y \) affects \( X \) (may be with a time delay). Therefore, the link of \( X \) and \( Y \) and the link between \( Y \) and \( X \) should be analyzed as a feedback system in order to more accurately predict the final outcome.

Because a complex dynamically system consists of a web of interlocking variables with feedbacks, linear and nonlinear relationships and time delays, the system cannot be easily represented by a set of equations (as in control theory) and solved analytically. It is, at the current state of practice, modeled and solved by the time-stepping simulation approach. In SD models, variables and their relationships are represented by the so-called casual loop diagrams. Figure 1 shows an example of a simple SD model. In Figure 1, the variables are classified into level, rate or auxiliary variables. A level variable (a rectangle) accumulates or integrates a value over consecutive time periods. A rate variable (next to two triangles that represent a valve), as its name suggest, controls the rate of change of a level variable. The auxiliary variables are used as intermediate, input or output variables. The relationships between the variables are represented by arrows. The direction of an arrow symbolizes the influence one variable has towards the other. A positive sign (+) indicates a positive relationship while a negative sign (-) indicates a negative relationship. A “=” symbol denotes a time delay switch. It means that the positive or negative effect of one variable towards another will only take place with a specified time delay. Each variable has a constant value or equation attached to it. The level variable has all its associated rate variables as its dependent variables in the equation. The equations for the rate and auxiliary variables can only consist of variables that are pointing to it by the arrows. A feedback loop occurs when two or more variables are linked by a series of arrows in the clockwise or anti-clockwise direction. Depending on number of positive and negative relationships in a loop, the feedback loop can be either “positive” (self-reinforcing) or “negative” (equilibrating or self-correcting).

Currently, there are several software programs that can facilitate the building and use of SD models. Examples of such tools are VENSIM (12) and STELLA (13). System dynamics models can also be developed by using spreadsheets and programming languages.
There have been a few SD models developed to forecast urban growth, land use and effect of transportation policy. The limited and recent studies are reviewed in this section.

Haghani et al. (14, 15) presented a SD model to predict the simultaneous changes in land use and transportation system. The model, implemented in the DYNAMO simulation language, consisted of seven sub-models, namely population, migration of population, household, job growth-employment-and availability, housing development, travel demand and traffic congestion level sub-models. Each sub-model consisted of several level and auxiliary variables linked by casual loops. Selected variables in the sub-models were then linked to form the overall SD model. This model is the most complex and probably the first SD model reported in transportation literature. The model was calibrated and tested with data from Montgomery County, MD. During calibration, unknown parameters in the equations in the sub-models were individually estimated by the least-square regression technique using data from 1970 to 1980. Once all the parameters had been calibrated, the entire model was validated with system behavioral data from 1980 to 1990. The authors illustrated one application of the model by using it to forecast the effects of highway capacity expansions.

Pena and Fuentes (16) developed a SD model to simulate lane use changes in Ciudad Juarez, Chihuahua, Mexico. This model is relatively simple compared to the one developed by Haghani et al. (14, 15). The SD model developed by Pena and Fuentes consisted of three sectors: demographics, economic and land use growth sectors. The demographic sector had a population sub-model. The economic sector had an employment sub-model. The land use growth sector had three sub-models: industrial land use, commercial land use and residential land use sub-models. The SD model was implemented in STELLA. The developed model was validated with the annual population, employment, industrial, commercial and residential land use data from 1980 to 2000. A forecast of the above five level variables was then made from 2000 to 2020. This SD model had input variables such as employment elasticity and land use
elasticities to allow users to study the effect of the shift in overall industry’s labor intensiveness and land use densities for industrial, commercial and residential uses.

Wang et al. (17) constructed a SD model using VENSIM to model the effect of vehicle ownership policy on economic growth and environmental sustainability. The SD model has seven sub-models: population, economy, number of vehicles, environment, travel demand, transport supply and traffic congestion sub-models. The economic performance was represented by the gross national product (GDP). The environmental impact was measured by the NOx emitted by vehicles. The transport supply was measured by the lane-km of highways. The travel demand was taken as the vehicle-km traveled. The congestion is indicated by a so-called congestion factor. The SD model was calibrated using data collected from Dalian, China from 2000 to 2005. The model was then applied to study the effect of different vehicle ownership policies on the economic growth and the environment in the same region. The simulation time step was one year, from 2006 to 2050. An important input to the model was the vehicle ownership policy intervention factors (PIF). Five levels of PIF values had been used in the simulation (0.5, 0.8, 1.0, 1.2 and 1.5) to represent a range of policies, from “strict restriction” to “emphasized encouragement”.

DEVELOPMENT OF SYSTEM DYNAMICS MODEL FOR BUS RAPID TRANSIT

This section describes the development of the SD model for BRT corridor planning and ridership forecasting. From the SD models reviewed in the previous section, none of them has provided a detailed description of the model development process. In this section, the authors wish to share some insights into the model development process. The SD model described in this paper has been developed in VENSIM (12). For the rest of this paper, the variable names in the SD model all start with an upper case alphabet.

Population Sub-model

From the review of the developed SD models and BRT planning documents, the most fundamental variable that influences the transportation demand is population. Thus, the population sub-model as shown in Figure 2 was first coded to project the population within walking distance from the stations (typically 400 m) that lives along a BRT corridor. From the initial trials with VENSIM, in order to simulate the growth of population over the years, the Total Population Along Corridor was coded as a level variable. Its value from one year to the next is adjusted by the number of annual births, deaths and net migrations. The number of birth, deaths and net migrations in a year are the products of the corridor population at the beginning of that year and the respective rates. These equations are coded into the rate variables of Births, Deaths and Net Migration, respectively. The Birth Rate, Death Rate and Net Migration Rate are coded as auxiliary variables. These user inputs may be obtained from demographic data in a city or region. The Total Population Along Corridor in the base year is a necessary input and may be obtained from a GIS. Once coded and executed in VENSIM, this sub-model is able to simulate the growth of population along the BRT corridor every year from the base year. Obviously, the simulation time step is set to one year.
Ridership Sub-Model

The Total Population Along Corridor is multiplied by a mode share factor (named BRT Share) to obtain the base BRT ridership (named Potential Ridership) in a given day. Figure 3 shows the estimation of Potential Ridership from the population sub-model. Note that all variables outside the population sub-model are coded as auxiliary variables.

One of the outcomes of BRT implementation is ridership attraction. That is, because of the distinctive service features and market identity, an operational BRT system is able to attract up to 25% more trips (9). The level of attraction depends on the combination of BRT features. Thus, the Additional Ridership is added to the Potential Ridership to form the Total Ridership. All the ridership variables have a time unit of a day.

The Additional Ridership depends on seven features and their synergistic combination as modeled in Figure 3. The seven features are Branding, Shelter and Station, Guideway, ITS Applications, Fare Collection Method, Service Pattern and Vehicle Design. Branding accounts for the uniqueness of the stations and vehicles. Shelter and Station account for the physical design of boarding and alighting places. Guideway considers the bus guideway. ITS Applications deals with any type of transit technology. Service Pattern takes into account the line coverage, frequency and hours of service. These six features were taken from TCRP Report 118 (9) because this report lists the percentage increases in ridership attraction due to each of these features (in Exhibits 3-21, 3-22 & 3-23) for “minimal” and “high level” of BRT implementations. The Fare Collection Method was deemed important enough by the authors and was singled out as the seventh feature. Each of the seven features contributes a certain percent of additional ridership depending on the phase of implementation (limited, moderate or aggressive phase) of the BRT system. For example, Shelter and Station contributes 2, 9 and 15 points in the limited, moderate and aggressive phases, respectively. The points programmed into the SD model were adapted from (9) and factored by the features listed in Table 1 (for the complete list of features, see (4)). The limited, moderate or aggressive phase of implementation is entered via a variable named Initial Phase. The Initial Phase helps to select the points contributed by each of the seven features. The summation of the points from the seven features forms the Feature Implementation. According to (9), if the sum exceeds 60 points, an additional 15 bonus points should be added to reflect the synergy of combining the different features. Hence a variable named Synergy was added to increase the ridership forecast. The maximum output of Synergy is 100 points, which correspond to 25% of the Potential Daily Ridership. Thus, the maximum Additional Daily Ridership is 25% of the Potential Daily Ridership. Figure 2 shows the interconnectivity of all the above mentioned variables. The part of the SD model, other than the population sub-model, that computes the Total Daily Ridership is termed ridership sub-model.
So far, the population and ridership sub-models predict the total ridership in a given day along the corridor. The total ridership (demand) is used by planners and transit agencies to design the service pattern (supply). The interaction between the demand and supply results in BRT level of service. The level of service in return affects the total ridership. To illustrate these relationships, and to enable the SD model to produce some indicators to assist planners in designing the service pattern, a relatively simple service sub-model was hence constructed.

The first input variable in the service sub-model is the corridor’s Total Daily Ridership. The Total Ridership is scaled by the Hourly Factor to form the Design Hourly Ridership (which may be peak hour or any hour of a day). The Design Hourly Ridership divided by the Vehicle Capacity gives the desired service Frequency. With the Frequency and an estimated Roundtrip BRT Travel Time, the Fleet Size can then be estimated. Once the Fleet Size is obtained, the actual service Headway is then determined. All relationships are calculated following the
recommendations given by the Transit Capacity and Quality of Service Manual (3). The completed model is shown in Figure 3.

Figure 3 Complete model structure.
APPLICATION

This section presents the application of the developed SD model to a potential BRT corridor. The selected corridor was the Mesa Street (State Route 20) in El Paso, Texas. The proposed BRT service runs between the downtown transit terminal and the intersection of Mesa Street and Doniphan Drive. The proposed BRT route was approximately 10 miles (each direction) with 10 stations (excluding the terminals at both ends). Figure 4 shows the proposed route and stations. There are several regular bus services along segments of the Mesa Street, but the proposed BRT will be the only route that runs along the entire corridor. It was assumed that once the BRT is put into service, the regular bus services would be reconfigured to serve as feeder routes.

Figure 4  Proposed Mest Street BRT corridor.

An analysis on the corridor population, existing bus ridership patterns, BRT guideway, shelter and station designs had been made and reported in (18). This analysis produced important inputs such as total population along the corridor (in 2007), number of stations and guideway which affect the travel time, for input into the SD model. The important input variables are:

- Total Population Along Corridor = 72,550 (in 2007, based on GIS data provided by the City of El Paso)
- Birth Rate = 2.2% (calculated from data provided by (19))
• Death Rate = 0.558% (calculated from data provided by (19))
• Net Migration Rate = 0.18% (calculated from data provided by (19))
• BRT Share = 0.0183 (based on 2007 actual transit ridership survey, reported in (18))
• Roundtrip BRT Travel Time = 95 minutes (estimated with guideway improvement and transit signal priority)

Once the necessary data are entered, simulation runs were performed from year 2007 (the base year) to year 2035. Three different simulation runs, for limited, moderate and aggressive initial phases of implementation, were made separately. The Total Ridership curves were superimposed in one plot in VENSIM. Figure 5(a) shows the curves of Total Daily Ridership for the three phases of implementation from 2007 to 2035. Note that, while performing the simulations, it was assumed that the features, once implemented, remain unchanged from 2007 to 2035. It should also be noted that (i) the population sub-model generated only one curve that predicted the population growth from 2007 to 2035; (2) the Total Ridership has three curves in Figure 6 due to the different Additional Daily Ridership caused the three phases of feature implementation.

As ridership grows, more vehicles of the same capacity need to be put into service to cater for the demand. Figure 5(b) below shows the fleet size that should be used to accommodate the increase in ridership. This figure also shows that VENSIM is able to cater for discrete integer variables. Although the limited BRT phase has a relatively smaller total ridership (as evident in Figure 5(a)), more vehicles are needed because the vehicles are of smaller capacity. The aggressive BRT implementation has articulated vehicles and hence fewer vehicles are able to accommodate the demand.

An advantage of using VENSIM is that users do not need to have programming knowledge or a VENSIM license to use the developed SD model. The SD model, once developed in VENSIM, can be compiled into an executable file that is easily installed and run on a Window-based personal computer. The modeler can even develop a user-friendly Graphical...
User Interface (GUI) for users to enter or vary the necessary input data. Figure 6 shows a prototype GUI developed for the BRT feature planning and ridership forecast SD model. This GUI provides slide bars for users to select the values of Birth Rate, Death Rate, Net Migration Rate, BRT Share and Initial Phase. As the user adjust the value of an input variable along a slide bar, the curves on the screens will be updated instantaneously.

Figure 6  Graphical user interface of the system dynamic model.

SUMMARY AND ON-GOING EFFORTS

The above sections have described a SD model developed for the BRT feature selection and ridership forecasting, and a case study in El Paso, Texas. The model presented is relatively simple and is by no means complete. Many improvements are being made to the SD model. The major on-going effort is to add more “arrows” that depict the influence of Headway, Vehicle Capacity, Operating Speed on Level of Service. The feedback of Level of Service on ridership also needs to be modeled. The authors have found that biggest challenge in the model development is the lack of clearly documented equation or heuristic that describes the
relationship between these variables. In the SD model presented in Figure 3, the sophistication of all the features remains unchanged during the planning horizon and is controlled by Initial Phase. A future improvement of the model is to code the level of implementation of each of the seven key features as user inputs. In this way, users of the SD model can mix and match any of the 3^7 combinations of the level of features. For each feature, the users can even specify in the model input the time of upgrade from one level the next.

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