INTEGRATED URBAN SYSTEMS MODEL WITH MULTIPLE TRANSPORTATION SUPPLY AGENTS

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16. Abstract

This project demonstrates the feasibility of developing quantitative models that can forecast future networks under current and alternative transportation planning processes. The current transportation planning process is modeled based on empirical information collected from interviews with key transportation agencies and planning documents published by these agencies. The investment decision-makings rules of and interaction/negotiations among state and local transportation authorities are explicitly considered in the proposed agent-based model. Results on a test network show the current transportation planning process can be improved in several different ways. Either a more centralized or more decentralized planning process can improve investment decision-making and enhance the performance of future transportation networks.

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LIST OF ACRONYMS

BRTB – Baltimore Regional Transportation Board
DOT – Department of Transportation
HNI – Highway Needs Inventory
MAUTC – Mid-Atlantic Universities Transportation Center
MDOT – Maryland Department of Transportation
MPO – Metropolitan Planning Organization
MTA – Maryland Transit Administration
MWCOG – Metropolitan Washington Council of Governments
SHA – State Highway Administration
STIP – Statewide Transportation Improvement Program
TSO – Transportation Secretary Office
TTF – Transportation Trust Fund
U.S. DOT – United States Department of Transportation

1. INTRODUCTION

The growth and decline of transportation networks result from a series of temporally and spatially interdependent systems management decisions (e.g. operation, pricing, investment, ownership) in response to changing travel demand and technology. For instance, the total length of paved roads in the United States has increased from 240 kilometers in 1900 to 6.4 million kilometers by 2000 *(1)*, with the overall decline of certain other transportation modes such as rail and transit. Government agencies at federal, state, and local levels, as well as private road authorities, all make routine transportation supply decisions (e.g. taxation, tolling, maintenance, and capacity expansion) to achieve mobility, accessibility, welfare, and/or profitability objectives. These efforts make key contributions to the economy and quality of life.

State and federal governments have funded the construction of most major highways to carry intercity and city-suburb traffic. User fees directly charge those who travel for the services that they receive, and reinvest the revenue into the costs of building and maintaining the system. They come in a wide range of forms including toll and fare mechanisms, motor fuel taxes, vehicle registration fees, and truck weight fees. Revenues from motor fuel taxes are typically held in "trust funds," which, in turn, distribute revenues to state or local governments. The user fee model still accurately describes the major part of transportation funding in the US, but in many states it no longer describes how the largest and most significant new investments are financed. Gradual, but important, changes have been occurring in transportation finance over the last two decades. With the completion and maturation of the nation's vast highway network, the ongoing costs of system maintenance and repair have been steadily rising. And while fuel taxes and other user fees continue to provide a large proportion of funds, revenues from these sources have failed to keep pace with growing costs and expenditures. As a result, the availability of transportation trust fund revenues for major new initiatives has become pretty scarce. In such an environment the whole system is in need of coordinated work of responsible transportation agencies. This can be best achieved when transportation system in a study region is completely controlled by a centralized welfare-maximizing agency. However in the real world, as it was noted above there are many decision agencies that have dissimilar and sometimes competing objectives.

Currently, most efforts to advance the regional transportation investment procedures are based on the federal government's model of metropolitan planning, most recently embodied in the 1998 Transportation Equity Act for the 21st Century *(2)*. This framework encourages agencies "in charge" to consider multiple objectives (efficient system management, intermodal linkages, environmental protection, and local economic goals) in choosing the candidates for investment within the context of existing fiscal resources. However, in many cases the planning actions do not go beyond the simple allocation of transportation funds.

This research recognizes that the transportation planning process through which current and future investment decisions are made both shape future transportation networks and determine future network performance. The objective of this report is to develop quantitative models to forecasts future networks and their performance under existing and alternative transportation planning processes. Since transportation investment decisions combine finance with legislature, local and state governments are the major forces for innovation in regional transportation planning and investment. By examining alternative investment decision-making processes and revising existing ones, transportation agencies can identify and remove inefficiencies in the existing process and at least mitigate the impacts of less than optimal decisions.

2. LITERATURE REVIEW

The growth of transportation networks is a complicated and multidimensional process that lasts decades. It is determined by investment decisions as, if no support is provided for a particular roadway, whether it is construction or maintenance, no growth effects would occur. Therefore, many believe it is possible to predict and guide the process of network growth by influencing investment decision processes.

Back to the 1950s through 1980s state and local transportation agencies in the country were involved with the construction of the US Interstate Highway System, and all the transportation infrastructure funding sources were concentrated on highway construction projects. In the mid 1980s, the focus shifted to the management investments, whether maintenance or operational, and till today these type of projects absorb most of the federal and state funds. Since then, many efforts have been put into the modeling and analysis of transportation network growth. Previous research has been done by scholars of different fields. Xie and Levinson *(3)* provided comprehensive review of the previous studies that followed five main streams. Earliest studies date back to the 1960s, when for the first time models of network growth were developed. At that time researchers relied on heuristic and intuitive decision rules for network growth due to computational simplicity and no specific traffic data requirements. In particular, Taaffe et al. *(4)* studied the economic, political and social forces behind infrastructure expansion in underdeveloped countries. Their study found that initial roads were developed to link economically developed regions and rural roads were built around these initial roads. Later on, in 1970s, transportation planners and economists took over the forecasting process and started to use traffic demand models to model the changes to networks. Their assumption was that network growth was the result of rational decisions by jurisdictions, property owners, and developers in response to market conditions and policy initiatives. Statistical analyses of transportation data became popular in the later years as new transportation data management tools supported the techniques.

In the last two decades the dynamic traffic assignment tools became highly popular for analyzing complex transportation systems. The concepts of preference or self-organization have been introduced to interpret network dynamics as a spontaneous process. In the first strand of research the focus was on describing network growth in stages, in the second - researchers constructed models that would replicate observed developed network patterns. However, these studies, originated by the interest to replicate the observation of network topologies, had to deal with simple networks using heuristic and intuitive rules for network growth and transformation due to the lack of understanding on the inherent mechanisms with regard to why and how transportation networks evolve. In recent years, solution algorithms to user equilibrium have been widely incorporated to solve the network design problems (NDP). Typically the NDP is formulated as a bi-level framework in which the lower-level represents the demand-performance equilibrium for given investment while the upper level represents the investment decision-making of the transport planner to maximize social welfare based on the unique equilibrium flow pattern obtained from the lower-level problem. If the NDP were how decisions are made, network changes would be due to planners' rational behaviors to maximize the efficiency of a given network, measured according to some quantifiable objective, based on predicted traffic with budget and other constraints. Verhoef et al. *(5)* explored the interrelations between pricing, capacity choice, and financing in a small network model; Zhang and Levinson *(6)* proposed an analytic model discussing properties of long-run network equilibrium with regard to price and capacity with different small network layouts and ownership regimes. Levinson et al. *(7)* focused on understanding the conditions under which new links could be constructed on a highway network as opposed to existing links being improved, and developed a model to predict the location of new highway construction based on the surrounding conditions of the new link, the estimated cost of construction, and a budget constraint. Levinson et al. *(8)* incorporated jurisdictional planning processes to forecast network growth. In their attempts to predict the Twin-Cities seven-county road network 30 years from now, they developed network forecasting models with stated decision rules, processes encoded in flowcharts and weights developed from official documents or by discussion with agency staff. Montes de Oca and Levinson *(9)* have shown that different levels of jurisdictions including the state (the Minnesota Department of Transportation), region (the Metropolitan Council), and seven counties developed respective stated decision making processes in which federal or local funding are allocated to road projects prioritized according to their funding needs based on measured pavement quality, level of service, safety, and other conditions.

To summarize, whether the new transportation infrastructure is built or the existing facilities and services are expanded, such activities can have positive or negative effects on urban economy. Overall, changes to the transportation networks are the results of numerous small decisions by different agents (state departments of transportation (DOTs), districts, metropolitan planning organizations (MPOs), transit agencies and other local governments) in response to market conditions and policy initiatives. Understanding how markets and policies translate into facilities is essential for scientific understanding and for improving forecasting, planning, policymaking, and system evaluation.

In terms of methodology for transportation planning and investment analysis, most previous studies employ methods based on assumptions of a single decision-maker with system optimization goals; to a less extent – examine two or three agents in the context of toll road competition with game theoretical models. And agent-based simulation is just on the rise of popularity because it is a powerful tool for considerations of multiple decision-makers that interact with each other (which is the case in the real-world transportation investment process).

Agent-based modeling represents an analytic approach to explain the choices of multiple agents in conflict with each other with scope for cooperation, where the payoffs are interdependent. The application of agent theory usually requires acceptance of certain assumptions about the behavior of agents (in this report – jurisdictions and transportation agencies) and their level of knowledge. Agent-based modeling techniques have found many applications in transportation demand analysis. Microscopic traffic simulation can be viewed as an example of agent-based models. Vehicles are agents in a simulator and they interact between each other, while the road network characteristics remain static. Zhang and Levinson *(10)*, for instance, have developed a prototype agent-based model for trip distribution and traffic assignment. Also, in a later work Zhang et al. *(11)* examined the unique feature of the agent-based model and its modeling techniques for the prediction of important macroscopic travel patterns.

3. CURRENT TRANSPORTATION INVESTMENT PROCESSES IN THE WASHINGTON DC-BALTIMORE REGION

Interviews with the transportation agencies in the Washington DC and Baltimore region have been conducted with staff members at the county, metropolitan, state and regional levels to learn about the processes and decision rules that drive their transportation investments. This section briefly summarizes the interview findings which provide the empirical information for our modeling work. A detailed description of the transportation planning and investment processes in various transportation agencies in the DC-Baltimore region is provided in a separate paper *(17)*.

Several interesting observations have been revealed through these interviews. Transportation investment in the Washington DC-Baltimore region involves three state DOTs, two large MPOs, six small MPOs, more than a dozen counties, and regional and state transit authorities. The existing investment process favors state DOTs. The large MPOs primarily provide technical assistance in projects' evaluation. The needs of local jurisdictions that may not be obvious at the regional and state levels are often not met. This creates tension between state DOTs and local jurisdictions, and between local jurisdictions as well. There exists the perception that transportation funds are not distributed fairly. The state-county priority letter process in the Region provides a platform for communication, coordination, and cooperation. However, in the end, it is the agency that has direct control over transportation revenue that makes the final decisions. Also, there are regions where MPOs or local jurisdictions have more influence in the project selection process.

Multimodal transportation investment in the Region is pretty well defined. Funding allocation between multiple transportation modes occurs at the highest level of the planning process. The interviews have revealed that in an era of needs-budget gap, all agencies have decided to give priority to system preservation needs, and allocate only the remaining revenue to capital expansion projects. This is relatively reasonable since life-cycle cost of postponing necessary system preservation activities can only get higher. Agencies have seen larger and larger share of their resources dedicated to system preservation needs due to aging transportation infrastructure, cost increase and stagnating revenue.

All the agencies value qualitative project prioritization since it is more flexible in considering policy initiative and political factors. Quantitative methods are also used but mainly for the technical evaluation of candidate projects (e.g. impact on safety and congestion). Several agencies indicated at the interviews that they would like to either introduce or strengthen objective quantitative procedures in their investment decision-making processes (e.g. Baltimore Regional Transportation Board (BRTB), Prince George's County, Washington Metropolitan Transit Authority), while other agencies do not see an imperative need in changing the current qualitative methods (e.g. SHA, Montgomery County). All agencies acknowledge that an exclusively quantitative procedure will not meet their needs and objectives. The BRTB process assigns explicit weights to policy/political consideration and technical evaluation scores, which represent a transparent way of balancing political and technical factors.

For capacity expansion and capital improvement, the following three investment criteria are adopted by most agencies in the DC-Baltimore region: improving safety, mitigating congestion, and supporting economic development. The actual performance measures corresponding to these investment criteria, however, differ from agency to agency. Other investment criteria mentioned include environmental preservation, project cost, cost sharing, community improvement, accessibility, intermodal connections, and freight mobility. In the existing investment process, project cost estimates influence the planning process at a very late budget allocation stage after projects are already prioritized. Environmental considerations only impact the decision-making process as conformity constraints that highlight the federal role in promoting environmental stewardship.

To summarize, the interviewed agencies have different objectives they try to achieve by investing into various facilities, but their investment procedures have similarities in performance measures they choose as a basis for technical and policy prioritization. For these reasons and for modeling simplicity in this study, to represent the transportation investment processes in the Region and to picture the agencies' interactions, relations and dependencies, the key investment players are presented as agents and the whole investment process is shown as a game imitating the investment process in which each agent brings its own decision rules to the game.

4. MODEL

An agent-based model is developed to simulate the investment decisions of and interactions among various state and local government agencies in the transportation planning process. Agents in the model are described in the following subsections. While transit agencies are interviewed in the empirical study, the model currently only considers highway investment. We expect to expand the model to consider multimodal transportation investment in the future. The specification of agent decision and interaction rules are based on empirical findings from the interviews described in Section 3.

4.1. Multimodal MDOT Agent

The Maryland Department of Transportation (MDOT) is one of the State's largest agencies "committed to delivering a balanced and sustainable multimodal transportation system" for Maryland's residents and businesses. *(12)* MDOT handles partnerships across modes and with partner agencies to support statewide plans. MDOT retains responsibility for decisions on capital investments as well as operating and planning activities that reach across all modes of transportation and is responsible for distributing the state's transportation budget between the modes. At the same time the Transportation Secretary's Office (TSO) establishes transportation policy in the State. *(13)* MDOT represents the MDOT Agent in our model. MDOT Agent tries to achieve the most efficient use of the existing transportation system: maintenance and preservation are prioritized over other needs to extend the useful life of facilities and equipment in existing budget shortfalls. MDOT has a unified pot of money - Transportation Trust Fund

(TTF) - that provides flexibility to fund high-priority projects across the state regardless of transportation modes. Nowadays, system preservation accounts for 42% of MDOT Agent's expenditures. *(13)* It means that only about 39% of the MDOT's budget goes to capital programming (keeping in mind that about 19% of the budget usually goes to debt payments and to local governments and the state general fund). In the future, system preservation may require even greater portion of the budget if new sources of funding are not being identified for both maintenance and capital expansion needs. However, U.S. Department of Transportation will be awarding grants under the Interim Transportation Investments Generating Economic Recovery (TIGER) Guidelines for the projects meeting certain criteria. *(14)* These grants will be helpful in achieving a better state of the transportation system in Maryland. To qualify for the TIGER grants the projects should demonstrate significant long-term benefits (state of good repair, livability, sustainability, safety) and lead to creating new jobs and economic development in the Region. These criteria help to assume that the percentage of budget allocated to Maryland's system preservation and capital expansion activities will remain on about the same level as nowadays, as the TIGER program favors both types of expenditures. Also, this grant program will continue supporting the current transportation policy practices in Maryland, keeping safety, congestion mitigation and accessibility improvements as top priorities in project selection process. Of the 42% MDOT Agent allocates to system preservation where the Maryland SHA gets 14% and 52% goes to transit needs of Maryland Transit Administration (MTA) and WMATA. *(12)*

MDOT Agent's capital expenditures which, as was mentioned earlier, account for 39% of total expenditures, are also distributed among different state modes, where the SHA receives the biggest chunk - about 52% (according to current transportation program), and 33% goes to meet WMATA and MTA needs. (See Figure 1 for schematic representation of MDOT's budget allocations) Once funding is distributed to the mode administrations, then the process of budget allocation to different improvement activities and projects begins. Each mode administration, in particular the SHA, MTA and WMATA, has their own investment processes based on the policy priorities of the MDOT. These processes are explained in the subsequent sections.

4.2. State and Local Agents in Charge of Highway Investment Decision-Making

When the SHA, which represents State Agent in the model, receives funding from the MDOT for maintenance and preservation needs, it decides on its own how to use that money. The State Agent first ensures that the roads belonging to state system are properly maintained. Only after investing into structural deficiencies, State Agent can put money into capacity expansion activities. Usually State Agent relies on its Highway Needs Inventory that includes the list of all structural deficiencies in the system. As it is almost impossible to fund all of those deficiencies due to budget shortfalls, the projects from the Inventory are mostly selected based on 2 measures: road/pavement roughness and age of bridges in the system. It is important to mention here, that from the interview with the SHA staff it was found out that bridges usually require twice as much funding as pavements do. This leads to an assumption that two thirds of available operational funding is spent on bridges, and one third – on pavements. Road roughness quality is measured using the International Roughness Index (IRI). It is a measurement of the "bumpiness" of the road. Low values (0-94) indicate a very smooth riding quality, while higher values (above 220) indicate a rougher riding road. The range of IRI for each category of roads is based on limits set by the Federal Highway Administration. Assuming the State Agent inspects IRI on all state links, the first candidates for funding would be links with the highest IRI. The State Agent tries to maintain about 84% of pavements in the system in “acceptable” condition. As for bridges, the more time has past since its last maintenance, the higher the possibility the bridge requires improvement works. Therefore, bridge projects from the Inventory are assumed to be selected for funding based on their maintenance schedule. At the same time, all the bridges (about 2500 bridges) in the system should be in safe conditions. It is also worth mentioning here that while pavement and bridge maintenance consumes the majority of State’s system preservation budget, there are 24 special smaller funding categories dedicated to specific needs including drainage, traffic signs, and community improvement. As we do not know the percentage of funding going to these “small” needs, we assume that money for these activities comes from State Agent’s own budget. For capital projects State Agent is required to work in coordination with state counties and MPOs (they represent Local agents in the model). Local agents are responsible for generating their own revenues through various local taxes and fees and are required to perform regular evaluation of the roads within their jurisdictional boundaries. Some of the roads in local jurisdictions may qualify for State agent’s funding, which is determined through the policy and technical prioritization process.

Each local jurisdiction (e.g. counties and cities; referred to as Local Agents in the model) may propose a project for state funding for a variety of reasons, such as being very important for local needs as well as state development, but still it can not be guaranteed to be sponsored due to the State agent’s policy considerations, limited financial resources and technical evaluation. In reality, some projects move forward when the SHA selects them as preferred alternatives in studies, in other cases - projects are delayed or dropped because funding is unavailable, because other “more important” projects emerge, or simply because there is controversy from policy point of view whether the State benefits from a particular project or not. Sometimes locally proposed transportation improvements are listed for years in local or state plans before any action is taken to get them funded. This is largely due to the lack of financial resources and the “black box” of political decisions that produce unpredictable decisions on funding.

In the model the State Agent considers 2 factors when selecting capital projects for funding (whether they are state or local): policy factor and technical evaluation. For each factor a project gets a score. For policy factor a score can be as high as 60 points, and for technical evaluation – a maximum of 40 points. A score for policy factor depends on who is promoting a project: the State Agent or a Local Agent. If State Agent proposes a project, than that project always gets 60 points for policy factor. If a Local Agent – then a score will depend on how important a project is for local needs (policy score given by a Local Agent), its score obtained from State Agent technical evaluation and the amount of contribution a Local Agent is willing to pay if the State agent fails to identify enough resources for that project.

The State agent’s technical evaluation is based on three performance measures, which are safety, congestion and accessibility improvements. A project can get up to 15 points for safety performance, 15 points – for congestion and 10 points – for the need of accessibility improvements in particular zone. Capital projects submitted by Local Agents and projects in the State agent inventory undergo the same technical evaluation. Technical evaluation of projects’ safety performance and point assignment are performed in the following manner: first, the accident rates for each link in the system are calculated, and then the rates of all the links are compared between each other and scaled in descending order. That said, after comparing various accident prediction models used in the literature and application of those models to the data, the Poison models for arterial and freeway links from the study done by Chen et al. *(15)* are used in this research for safety evaluation (local links are treated as arterials and freeways are treated as state links in this model). Local links in the network are ranked based on the following estimated Poisson model for arterial links *(15):*

$$Y = 4.61215 - 0.085300X_1 + 0.327695X_2 + 0.027944X_3; \qquad (4.1)$$

Where:
Y- Accident rate in peak or off-peak hours;
X_1 - Annual average volume per hour during peak and off-peak periods;
X_2 - Median type (divided or not);
X_3 - Intersection density (defined as the ratio of number of intersections to Link length).

State agent links are ranked based on the following estimated Poisson model *(15):*

$$Y = 5.81252 + 0.1140E\text{-}03X_1 - 1.358E\text{-}02X_2 + 0.142474X_3 - 0.064002X_4; \qquad (4.2)$$

Where:
Y - Accident rate during peak or off-peak hours,
X_1 - Volume per lane;
X_2 - Median width;
X_3 - Auxiliary lane ratio (the total length of auxiliary lanes on a link to the length of the link);
X_4 - Number of through lanes.

Evaluation of projects' congestion performance and point assignment are performed as follows: first, the volume/capacity ratios for all the links in the system are calculated, and then those links are scaled in descending order based on determined ratios. For the purposes of this study the traditional determination of capacity is used:

$$X_i = V_i/C_i; \qquad (4.3)$$

Where:
V_i – volume on a link i,
C_i – capacity on a link i.

Accessibility is usually referenced as the measure by which travel costs are determined (e.g. the impedance function from gravity models applied to the travel time between two zones) and, also a spatial element reflecting the distribution of the activities in a region. In this model two standard measures of job and residential accessibility are adopted to convert travel time changes into accessibility shifts as was done in the P.I's previous studies. Accessibility changes due to changing travel costs between origins and destinations, jobs and houses located in a specific zone may become more (or less) accessible relative to other zones in the region, which leads to

increased (or decreased) level of future jobs and houses in that zone. The models for residential and employment distributions are adopted from Zhang *(16)* and as follows:
The population of the zone i after accessibility changes:

$$P_i^2 = P\frac{P_i^1 \exp[b(A_{i,E}^2 - A_{i,E}^1))}{\sum_i P_i^1 \exp[b(A_{i,E}^2 - A_{i,E}^1))} \tag{4.4}$$

Where:
P - Total study area population,
P_i^1 - Initial population of the zone i,
b – Calibrated sensitivity coefficient of accessibility measure,
$A_{i,E}^1$ – Initial accessibility to work of zone i,
$A_{i,E}^2$ – New accessibility to work of zone i.

Employment in the zone i after accessibility changes:

$$E_i^2 = E\frac{E_i^1 \exp(A_{i,P}^2 / A_{i,P}^1)^b}{\sum_i E_i^1 \exp(A_{i,P}^2 / A_{i,P}^1)^b} \tag{4.5}$$

Where:
E – The fixed total study area employment,
E_i^1 - Initial employment of the zone i,
$A_{i,P}^1$ – Initial accessibility to house of zone i,
$A_{i,P}^2$ – New accessibility to house of zone i.

In the model population and employment growth are evaluated for each zone, and then zones are scaled in descending order based on their future estimated populations and employments. The links connected to zones with highest growth are prioritized for funding.

Whenever the SHA performs investment procedures based on the above described measures, which in their own turn depend on the performance of each individual link, the transportation network grows and expands in places where links score the highest for policy and technical factors. Policy factor has higher weight than technical evaluation (60 points versus 40 points), which explains why in some cases there no action is taken for technically “needed” projects. A link with the highest combined policy and technical score is funded first, then next “in line” link is funded, and so on. The investment process continues till the point when the budget is exhausted. In case, if there is still money left after previous links’ investments, but that amount is not sufficient to fund the next link “in line”, then that link is dismissed by its successor link and the cost of improvement for successor link is compared against available funding. If the cost is matched, then the link is financed, otherwise – a new link down the scale is selected.

From interview observations, it can be stated that the performance measures of the Local Agents are the same with the State, but the point distributions are different as they are determined through the processes of Local Agents’ budget allocations. When selecting state links that might qualify for the State funding, Local agents perform not only the technical evaluation, but also the policy evaluation. And again, policy factor has higher weight than technical factor (60 points versus 40 points). Local agent's policy evaluation is also some kind of "black box" of decisions, which means that this process is very subjective. Projects from which a Local Agent benefits the most are given the highest scores, but it is difficult to predict which project a Local Agent will consider beneficial and which – not. However, each Local Agent can not submit unlimited number of projects with high scores and neglect projects with low policy scores. To remind, the final decision on funding is after the SHA, and Local Agent's low policy score may turn out to be high score when the SHA re-evaluates locally proposed projects. Therefore, to closely reflect reality, in our model we assume that every Local Agent submits 5 projects with policy score 60, 4 projects with policy score 40 and 3 projects with policy score 20. When performing technical evaluation, a Local Agent considers the same three measures as the State agent does, but the point assignment is different. The total number of scores a particular project can get for overall performance is 40.

Link scores obtained from Local agents' technical evaluation are summed with the corresponding policy scores given by each Local Agent. After that Local agents submit a list of qualified links. To remind, each agent can submit 12 projects (5 projects with policy score 60, 4 – projects with policy score 40, and 3 – with score 20). Combined with the technical score, these 12 projects will need to have the following number of scores:

- 5 projects with scores greater than 80, where 60 points would come from policy factor,
- 4 projects with scores 61 – 80, where 40 points would come from policy score,
- 3 projects – with scores 41 – 60, where 20 points would be from Local Agent's policy evaluation.

4.3. State–Local Agency Interactions in the Highway Transportation Planning Process

Multi-agent planning is when multiple agents coordinate their activities. It involves:1) agents' planning for a common goal – the future state of the transportation network, 2) the State agent's coordinating and compiling the plans of others into the general merged plan, and 3) a Local agent refining its own plan while negotiating priorities or resources with the SHA agent in the general merged plan. The general idea of multi-agent planning is to combine a planning method for each agent with an auction for delegating investment priorities in the shared transportation system.

In this research model the agents are making their investment plans independently of what the other agent is planning but they have to coordinate their efforts in creating one merged plan based on those independent plans. The performance measures valued by each individual agent determine which links in the network qualify for funding and therefore are included into their plans.

In the multi-agent planning process the agents' primarily characteristics are:

1. Each agent does not have the accurate abilities to solve the whole problem, i.e. each agent cannot determine all the links in the system that require investment.
2. Data about links is not centralized, so it must be shared by all agents.

3. Each agent has his own ranking system for determining candidates for investment.
4. All agents in the system are designed to be self-interested and myopic. That is, in making a decision, such as selecting a particular link into a plan, the agents are only concerned with their own needs. Agents have no way to estimate other agent's needs but have an idea of what would benefit to the global welfare of the system. The main goal of the Local agent is to prioritize links based on performance measures, and the main goal of the State agent is to reevaluate that prioritization and assign funding.

The links in the system are organized in a priority queue, sorted by the performance measures of Local agents, and then the links are sorted again by the State agent. In detail, the negotiation process between agents can be described as follows:

1. First, each agent, whether State or Local, ensures that all the links in the system are properly maintained. Each agent uses its own budget for maintenance needs.
2. After maintenance, each agent selects candidate projects for capital expansion. Each Local agent observes all the links under his supervision, ranks links based on performance measures as was described earlier and submits links to the State agent for further consideration. State Agent performs technical evaluation for his own links as well.
3. Each Local agent submits 5 "high priority" projects, 4 – "medium priority", and 3 – "low priority" projects for State's evaluation.
4. The State agent evaluates the condition of Local links again but based on his own performance measures. During this process, links can get higher scores than was assigned to them earlier, or can get much lower scores even if a link was originally claimed to be "high priority". Therefore, some of a Local agent's links get funded and some of them not. If a particular link is not funded, it is sent back to a Local agent. In this case, a Local agent funds this link if it was high priority and budget still allows after maintaining links within local system. Otherwise, this link may be left for next year investment process.

It is important to note, that all the agents are subjectively rational when making decisions. And in many cases they make preferences based on their policy considerations, rather than technical assessment.

5. RESUTLS

Although the proposed model structure can evaluate most investment scenarios in real world networks, this report considers a hypothetical city with grid network for ease of interpretation, and focuses on the comparison between current investment regime and alternative centralized state regime, where all roads are controlled by state government, and decentralized local regime, where each local jurisdiction controls investments into its own roads. The hypothetical city network consists of 10 by 10 grid road way links of 2-mile in length and an initial capacity of 775.5 vehicles/hour on each link. In the city a uniform initial land use pattern is assumed, and each node has 100 residents and 100 jobs. Each network link is assigned to either the State Agent or one of the five Local Agents. Based on the existing planning process, the State Agent controls all major state highways, represented by two north-south corridors, two west-east corridors, and a beltway system in the stylized network. All other links are assigned to the five Local Agents with one local agent in the city center and each of the four other local agents occupying one of the four corner areas in this stylized network.

When the agent-based simulation is executed, the travel demand model first predicts link-level flows. Based on the demand forecasts, revenues available to state and local agents are computed respectively based on the existing revenue policies (i.e. fuel tax, registration fees, and some general funds). After that the investment model, developed in Section 4, operates and forecasts investment decisions based on the current planning processes adopted by state and local agents. After each round of investment decisions, the network is updated with improved capacities for links selected for investment. Network performance measures are also computed for each investment cycle (one cycle per year), including total travel time, total distance traveled, average speed, total revenue collected, user benefits/consumer surplus, and net total social benefits. A time horizon of 50 years was chosen for the simulation experiments to observe the effects of current and alternative investment processes on future network performance.

Three transportation planning and investment processes are considered:

1. **Base Case**: This scenario represents the existing transportation planning and investment process in the DC-Baltimore Area as described in Section 3 and modeled in Section 4;
2. **State Control Case**: The State agent has centralized control over all links in the system and makes decisions for the entire budgeting and investment process. And
3. **Local Control Case**: State agent has no influence in the transportation planning process at all. Each of the five local Agent monitors and budgets the links within its jurisdictional boundaries.

Figure 6a illustrates the transportation network changes and capacity increases over a 50-year period when transportation investment decisions are made according to the current planning process in the DC-Baltimore region wherein state and local agencies share power and engage in negotiations. This planning process has resulted in a hierarchical network with two major north-south freeways, two major west-east freeways, and a beltway system also with higher capacities. This network topology is consistent with that in many U.S. urban areas.

Figure 6b presents the transportation network changes under complete State Control where the state agent makes all investment decisions only based on technical considerations such as safety, congestion and accessibility. Overall, the future network under State Control is similar to that under the current planning process, which is consistent with our empirical observations that state DOT and State Highway Administration are the dominate decision makers in the current planning process and controls most of the resources. Further examination reveals that under complete State Control, there are fewer investment projects on the periphery of the network compared to the existing planning process. Clearly, state agent invests in peripheral roads under the existing planning process only because these projects are high-priority projects for the individual local agents (the state-local negotiation procedure is at work).

Figure 6c plots the transportation network changes under decentralized Local Control. Recall that in this case the state agent has no power at all and each local agent controls the resource from its own jurisdiction and makes investment decisions solely based on the interests of its own jurisdiction. Unsurprisingly, the resulting future network is much less hierarchical and capacities are much more evenly distributed in all areas of the region. Local agents apparently have no incentives to building major high-capacity freeways that primarily serve through traffic. Under this type of decentralized local control, the future network most likely consists of many major arterial roads with moderately high capacity. It should be pointed out that this network topology under Local Control has a lot more redundancy (i.e. good alternative routes) than that under the current planning process or under State Control, and therefore should be more resilient to traffic accidents, disasters, and targeted attacks.

Numerical results summarizing the performance the future networks are provided in Table 1. Compared to the two alternative planning processes, the current transportation planning process will produce a future network that is inferior by all performance measures: higher total vehicle hours traveled, lower vehicle kilometers traveled, lower average speed, lower total revenue, lower user benefits, and lower net social benefits. These finding based on the stylized grid network suggests reform of the current transportation investment process. Before any actual recommendations are made, analysis on a real-world network should be conducted. We are currently testing the effectiveness of several alternative planning and investment processes on the Maryland statewide highway network. It is to our surprise that the Local Control scenario is shown to be the most effective based on user benefits and net social benefits. This implies that the current investment strategy by state agencies that focuses on expanding the capacity of the most congested bottlenecks may not be a very good long-term policy. It is probably more effective to address the congestion problem on a particular road by expanding the capacity of its parallel roads, which in the long run produces a transportation network with a more balanced capacity distribution, not a very hierarchical one.

6. CONCLUSIONS

This project demonstrates the feasibility of developing quantitative models that can forecast future networks under current and alternative transportation planning processes. The current transportation planning process is modeled based on empirical information collected from interviews with key transportation agencies and planning documents published by these agencies. The investment decision-makings rules of and interaction/negotiations among state and local transportation authorities are explicitly considered in the proposed agent-based model. Results on a test network show the current transportation planning process can be improved in several different ways. Either a more centralized or more decentralized planning process can improve investment decision-making and enhance the performance of future transportation networks.

It would be naïve to believe a major reform of the current transportation planning process will happen anytime soon. After all, it is a process driven by political considerations, air quality concerns, economic development, safety, and engineering efficiency. While it is certainly feasible to employ the proposed model to evaluate alternative planning processes out of intellectual interests, the most likely practical application of this type of models is probably the evaluation of the impact of a particular group of investment projects on future network performance. Another application is to forecast future networks for long-range transportation planning and policy scenario analysis. Currently, there is not a general method for generating future transportation networks 30 or 50 years from now, though this kind of planning horizon is often required for land use, green house gas, and sustainability policy analysis. The model developed in this project can fill this methodological gap.

Several aspects of the proposed agent-based model should and can be improved in future research. Model demonstration on a real-world network is clearly in order, and this work is underway for the statewide highway network in Maryland. The planning process model needs to be validated, possibly through comparisons between observed investment decisions and model estimated investment decisions. The current transportation planning process in other regions may also be studied and modeled.

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LIST OF TABLES AND FIGURES

Table 1. Future Network Performance under Alternative Transportation Planning Processes

Performance Measures	Base Case	State Control Case	Local Control Case
VHT (Million hours/year)	0.322	0.316	0.310
VKT (Million km/year)	12.7	13.2	13.0
Average Speed (km/hour)	39.2	41.8	42
Revenue ($Million/year)	46.5	48.5	47.7
User Benefits/Consumer Surplus ($Million/year)	201.7	274.7	293.8
Net Social Benefit ($Million/year)	248.2	323.2	341.5

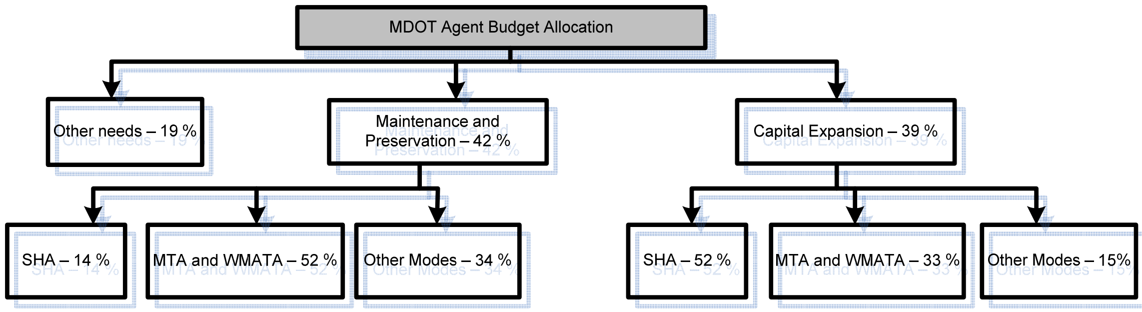


Figure 1. MDOT Agent Budget Allocation between Highways and Transit

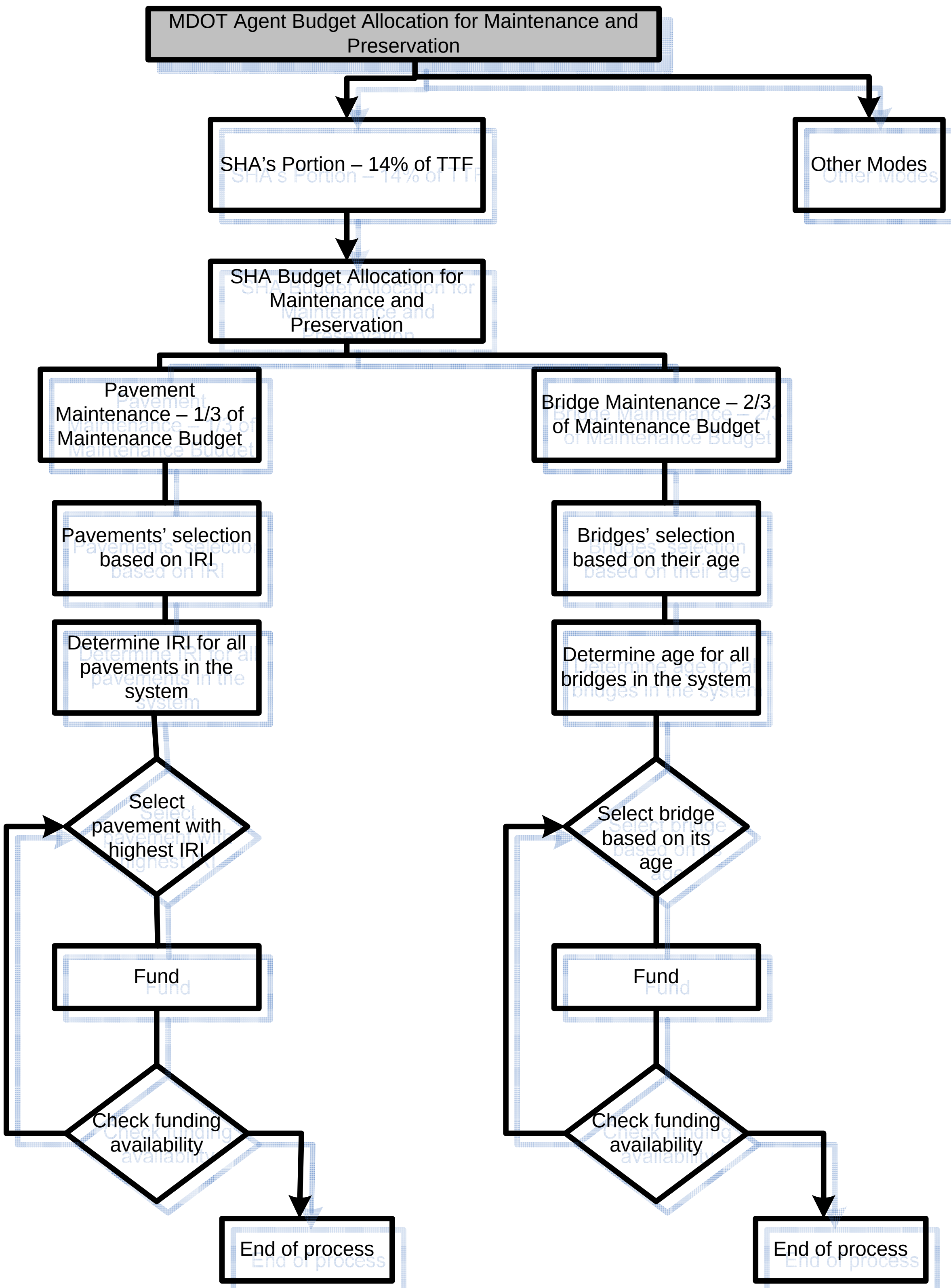


Figure 2. State Agent (SHA) Maintenance Budget Allocation

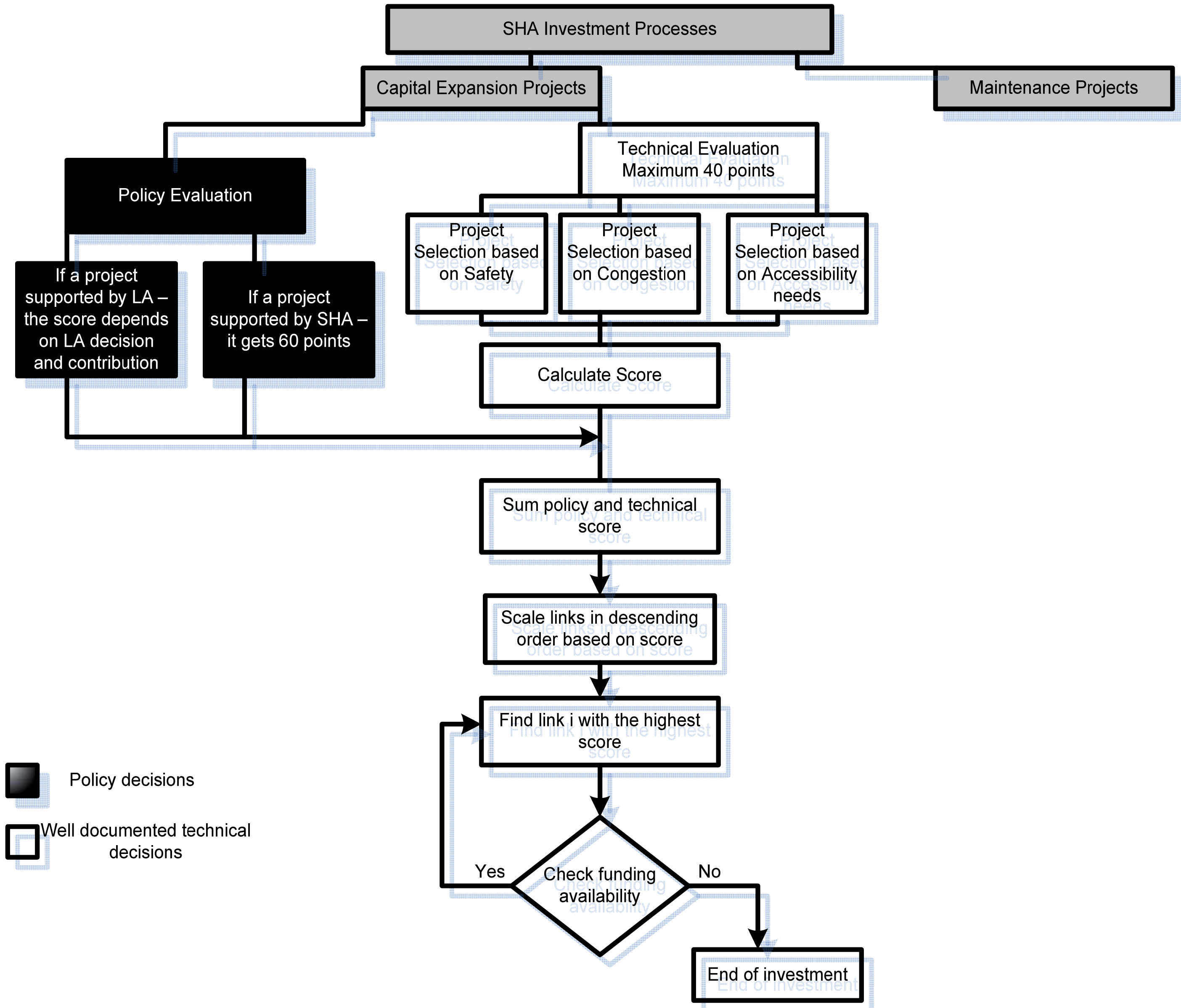


Figure 3. Summary of the State Agent (SHA) Investment Processes

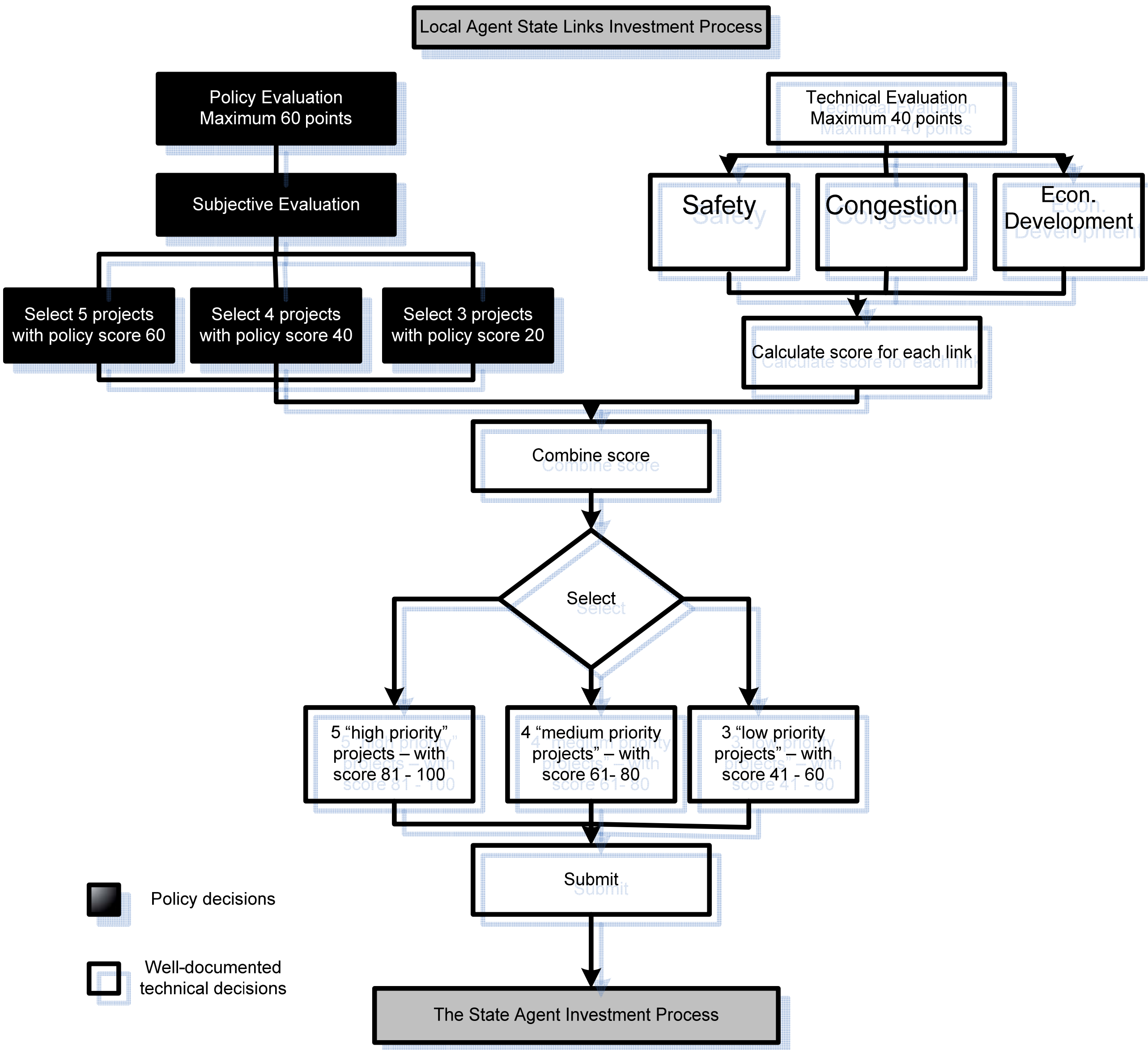


Figure 4. Local Agent (Counties) Project Prioritization for State Agent Funding

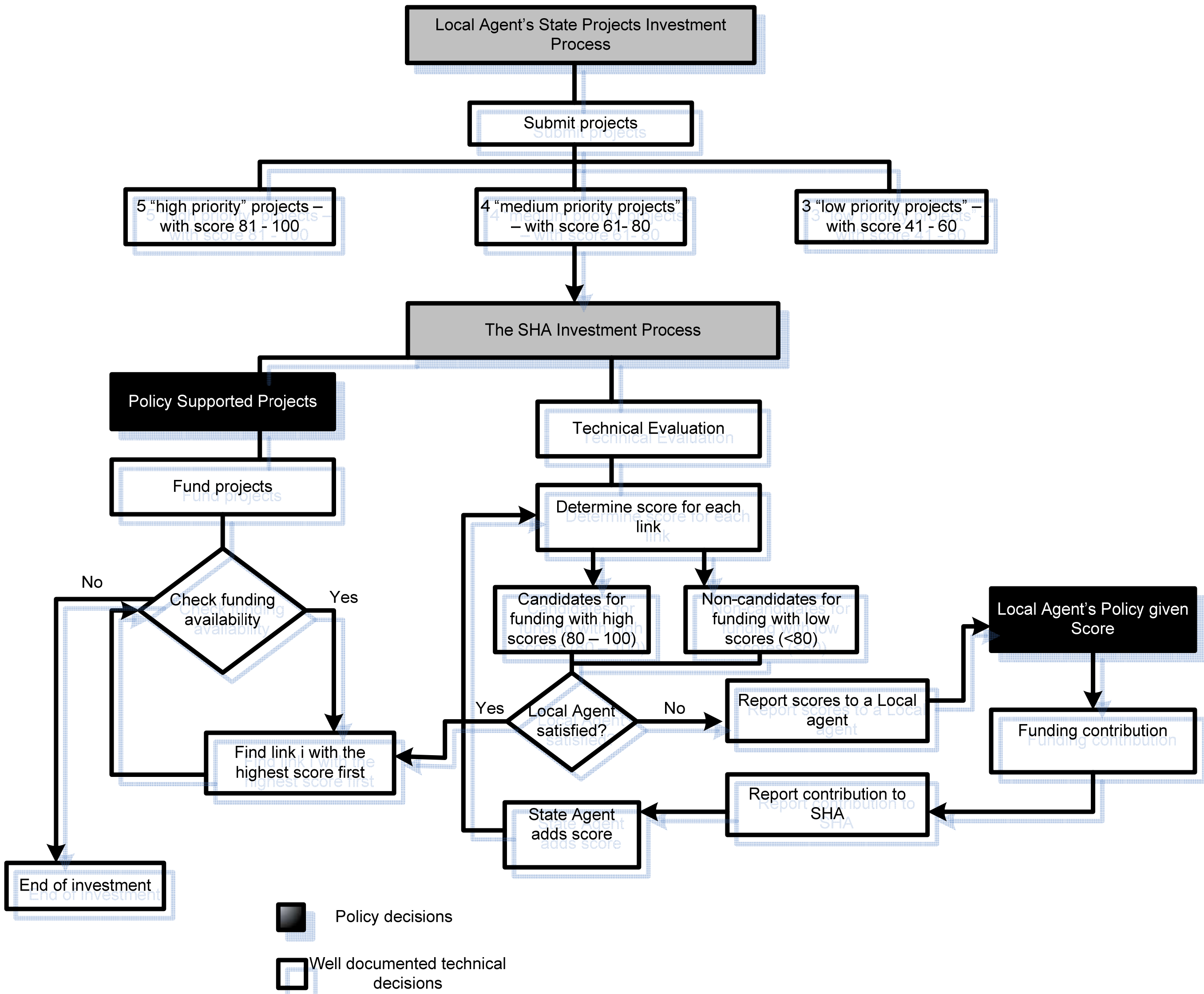
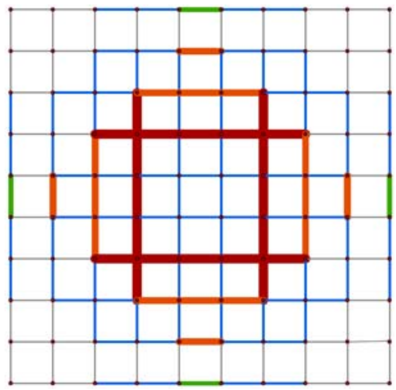
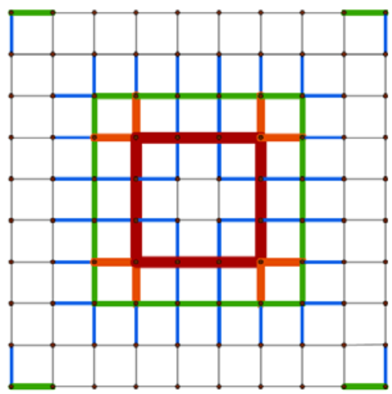


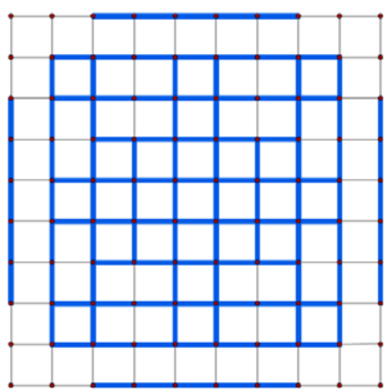
Figure 5. The Complete Existing Highway Investment Decision-Making Process with State and Local Agents



a: Base Case Scenario



b: State Control Scenario



c: Local Control Scenario

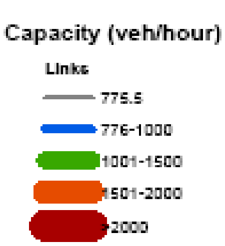


Figure 6. Future Networks under Alternative Transportation Planning Processes