

SYSTEM DYNAMICS SIMULATION FOR PARK MANAGEMENT

A CASE STUDY OF GLACIER NATIONAL PARK, MONTANA

By

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To the Faculty of Washington State University:

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DISCLAIMER

Although the model in this research was constructed specifically for the case of Glacier National Park in Montana and the research in general has benefited from discussions with park staff, any views or opinions presented in this dissertation are solely those of the author and do not necessarily represent those of the National Park Service. The goal of this research is to illustrate System Dynamics methodology, not an analysis requested by anyone at Glacier National Park. The assumptions and results in this thesis are presented strictly for illustrative purposes. They do not represent official assumptions or approved results by the staff or management team at Glacier National Park.

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Abstract

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National park management encounters the challenge of conserving the park unimpaired for the enjoyment of future generations. Many national parks in the world are faced with resource degradation due to overcrowding on roads and trails. The Going-to-the-Sun Road of Glacier National Park in Montana has undergone the same situation, especially after the high increase in visitation over the years since its first completion in 1932. During the rehabilitation project of the road starting from 2007, a free shuttle system was introduced to reduce road congestion. The operation of the shuttle system has received contrasting feedbacks from users, park staff and researchers. The continuation of the shuttle is best considered within the larger context of planning for the Going to the Sun Road corridor. Planning issues, including questions on the shuttle, can be addressed through the use of System Dynamics simulation. In order to evaluate the effect of the shuttle system on road and trail use, a System Dynamics model was built for a typical busy day in July. The model helps reveal visitor behavior and explore possible policies to improve road and trail management. Three sub-models are linked together including the Traffic sub-model, Shuttle sub-model and Trail sub-model. Results suggest that the shuttle helps reduce traffic congestion but does not lessen parking lot congestion. The main reason is because a significant number of cars fail to park and the number highly exceeds parking lot capacity. The shuttle also puts more people on trails and the Logan Pass Visitor Center. The

increase ranges from 18 to 22%. Further analysis reveals that when there are more annual visitors, major parking lots will become full earlier and stay full longer during the day. Increased annual visitation will add more people on trails but the increase is minimal due to limited parking space at Logan Pass. In addition, making the Logan Pass Visitor Center more attractive to lengthen visiting time would indirectly reduce the number of car people on surrounding trails.

LIST OF ABBREVIATIONS

Modeling abbreviations

ABM	Agent-based modeling
iRAS	Intelligent Recreational Agent Simulator
MASOOR	Multi Agent Simulation of Outdoor Recreation
RBSim	Recreation Behavior Simulation
SDM	System Dynamics Modeling

Abbreviations for Glacier National Park

ATC	Apgar Transit Center
AV	Avalanche
AVC	Apgar Visitor Center
GNP	Glacier National Park
GTSR	Going-to-the-Sun Road
LP	Logan Pass
TL	The Loop

National Park and management framework abbreviations

IUCN	International Union for Conservation of Nature
LAC	Limits of Acceptable Change
NPS	National Park Service
ROS	Recreation Opportunity Spectrum
VERP	Visitor Experience and Resource Protection
VIM	Visitor Impact Management

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Dedication

This dissertation is dedicated to my mother and father for their unconditional love and emotional support

CHAPTER ONE

INTRODUCTION

1.1 A brief history of National Park management

The National Parks have been praised as “America’s Best Idea” (Duncan and Burns, 2009). Since the establishment in 1872 of Yellowstone National Park, the world’s first national park, there has been a rapid growth in public protected areas all over the world. By 2008, more than 120,000 protected areas were recorded which covered 12.2% of the Earth’s land area and 6.4% of the Earth’s seas (UNEP – WCMC, 2010). The International Union for Conservation of Nature (IUCN) describes national parks with the primary objective of protecting “natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation” (IUCN, 2009, n.p.).

The National Park Service (NPS) of the United States was founded in 1916 with the mission of preserving national parks unimpaired for posterity’s public education, enjoyment and appreciation (The National Park Service Organic Act 1916). Although the concept of unimpairedness seems reasonable to most people, due to its value-laden nature, its definition varies from person to person and context to context. According to IUCN, unimpairedness means managing “in as natural state as possible” the biodiversity, the viability of functional populations, the integrity and resilience of the ecosystem inherent to the region or a geographical unit over a long period of time (IUCN, 2009). The phrase “in as natural state as possible” leaves room for changing conditions evolving around ecological processes of a certain area such as natural disasters, climate change, population growth pressure and pollution, just to name a few. As public protected areas play an important role in maintaining biodiversity, striking a balance

between protecting natural resources and maintaining visitor's experience for education and enjoyment is the greatest challenge in park management. Looking forward to the second century, The National Parks Second Century Commission recommended the following actions to advance the national park idea: (1) improving educational opportunities within the park system, community conservation and local collaboration, (2) fortifying management, research and community assistance capacity, (3) strengthening NPS ability to prevent other federal agency actions that harmfully impact parks and (4) enhancing funding from existing federal programs as well as grants funded by public and private sources (National Parks Second Century Commission, 2009). The Commission also recommended the use of systems thinking in park management which will be discussed in chapter two.

Wilderness management shares many common characteristics with national park management with a great emphasis on maintaining visitor's solitude. As a result, park management also benefits from wilderness management approaches. Several frameworks have been used to aid wilderness management. The proponents describe these frameworks as methodologies for planning and managing resources and visitor use within the area of interest to meet both the objectives of tourism and conservation. Highlighted frameworks include Recreation Opportunity Spectrum (ROS) (Clark and Stankey, 1979), Limits of Acceptable Change (LAC) (Stankey et al., 1985) and Visitor Experience and Resource Protection (VERP) (National Park Services, 1997). These frameworks integrate monitoring into the process of making management decisions and use monitoring results as the basis for taking corrective actions. Hence, having proper techniques to conduct monitoring and obtaining useful data are essential to the success of management. However, monitoring is costly and time consuming. In addition, it is not easy to obtain and maintain high quality data for supporting decision making.

From this emerging need, other management supporting tools have been developed.

Simulation models are one of the commonly used tools to help interpret the trend of monitoring data, visualize management issues, unfold the relationship between different system components and understand system behavior through feedback loops. Good modeling has enabled the improvement of staff or stakeholder understanding, management practice and monitoring program design in a wide variety of systems.

There are two main types of dynamic models. The first type emphasizes visitor behavior within a recreational area. This type of model looks at visitor travel mode, arrival patterns and trail/road congestion. Due to the dynamics of visitor travel, the temporal scale is usually observed in days, with the time unit being in minutes or hours. Examples include models using Extend (Wang and Manning, 1999), agent-based models linked with GIS such as RBSim (Recreation Behavior Simulation) (Gimblett et al., 2001), iRAS (Intelligent Recreational Agent Simulator) (Loiterton and Bishop, 2008) and MASOOR (Multi Agent Simulation of Outdoor Recreation) (Jochem et al., 2008) designed to manage trails and campsites.

An exemplary study is the application of RBSim to the case of Twelve Apostles in Australia, a scenic but rugged coastal area. The popularity of the place keeps attracting an increasing number of visitors which leads to concern about parking facility, trail congestion and other safety issues. The model was built to explore two different scenarios of existing condition (Scenario 1) and a new master plan (Scenario 2) involving multiple travel modes (bus/car) and onsite pedestrian for a projected period of ten years from 2001 to 2011. An interesting feature of the RBSim is its ability to examine impacts of recreation infrastructure on visitor movement. In addition, its complex scenario setup assists managers in refining facility management plans (Cole, 2005).

The second type of models is System Dynamics. System Dynamics which was first developed in the 1960s by Jay Forrester (Forrester, 1961) is a method of analyzing system behavior over time and it helps understand “how a system reacts to dynamic forces and how those reactions shape its behavior as it moves into the future” (Coyle, 1977, p.1). System Dynamics models, usually built in Stella, Vensim or Powersim, look at the management issues from different stakeholders’ points of view on a larger scale and a longer time frame, generally in years. Their structures involve integrating socio-economic factors of the surrounding areas with management issues within the study areas. Highlighted case studies include Yucatán Peninsula (Kandelaars, 1997), Ria Formosa Natural Park of Portugal (Videira et al., 2003), Dominica (Patterson et al., 2004), Basque Country, Northern Spain (Bald et al., 2006), Ranthambhore National Park in India (Dayal, 2007), Jamaica (Ishutkina, 2009) and a typical island in Southern Europe (Xing and Dangerfield, 2010).

The case of the Southern European Island study is an exemplar of the System Dynamics method. The model included the interaction between tourist flow generation, tourism labor, hotel and public utilities (airports, energy, water and waste disposal). The interaction was described by a weighted attractiveness index which comprised tourism price, social stability, low density and infrastructure attractiveness indices. This study was successful in using economic tools to describe the connection between tourists, social and environmental conditions. The researchers tested three price-adjusting policies including: (1) changing charter flights, (2) applying tourist tax and (3) promoting luxury tourism by banning the building of new budget hotels. It is interesting that a high fraction of charter flights is associated with more packaged tours and cheaper accommodation. This approach which has been used by large tour operators results in a tourism market dominated by customers who prefer cheap holidays. Tourist tax involves the

complexity of collecting tax and redistributing to environmental projects. Tourists tend to be resistant to taxes so when the tax is too high, arrivals are reduced significantly. For the last policy, it turns out that luxury hotels seem to be a way to control the expansion of mass tourism. However, associated impacts to the environment need to be considered (Xing and Dangerfield, 2010).

1.2 The study area

Glacier National Park (GNP), Montana, was established in 1910 and has become part of Waterton-Glacier International Peace Park since 1932. The park encompasses over one million acres of scenic landscapes including mountains, glaciers and lakes (National Park Service, 1999). The Going-to-the-Sun Road (GTSR) is a 50 mile scenic road lying in the heart of GNP connecting the east and west park entrances (Figure 1-1). This road was completed in 1932 and has been considered one of the most important historical features in GNP. Every year, 2 million visitors enjoy the park which translates into roughly 475,000 vehicles traveling the road between June and October. In 1999, the National Park Service saw the need for rehabilitating the GTSR to preserve a National Historic Landmark. The Rehabilitation Plan/ Draft Environmental Impact Statement was created in 2002 to consider alternative rehabilitation schedules while taking into account cultural, natural and socio-economic factors. The Final Environmental Impact Statement was published in 2003 with four alternatives including the Preferred alternative (shared use), Priority rehabilitation alternative, Accelerated completion alternative and Repaired as needed alternative (no action) (National Park Service and Federal Highway Administration, 2003). The decision to repair the road was signed in 2003. The project started in 2007 and was expected to complete over 7 or 8 years (National Park Service, 2003). During the implementation of the project, a free shuttle system was introduced operating from the Apgar center at the west

entrance to the St. Mary Visitor Center at the east entrance to facilitate visitors throughout their visit and minimize their impacts on park resources.

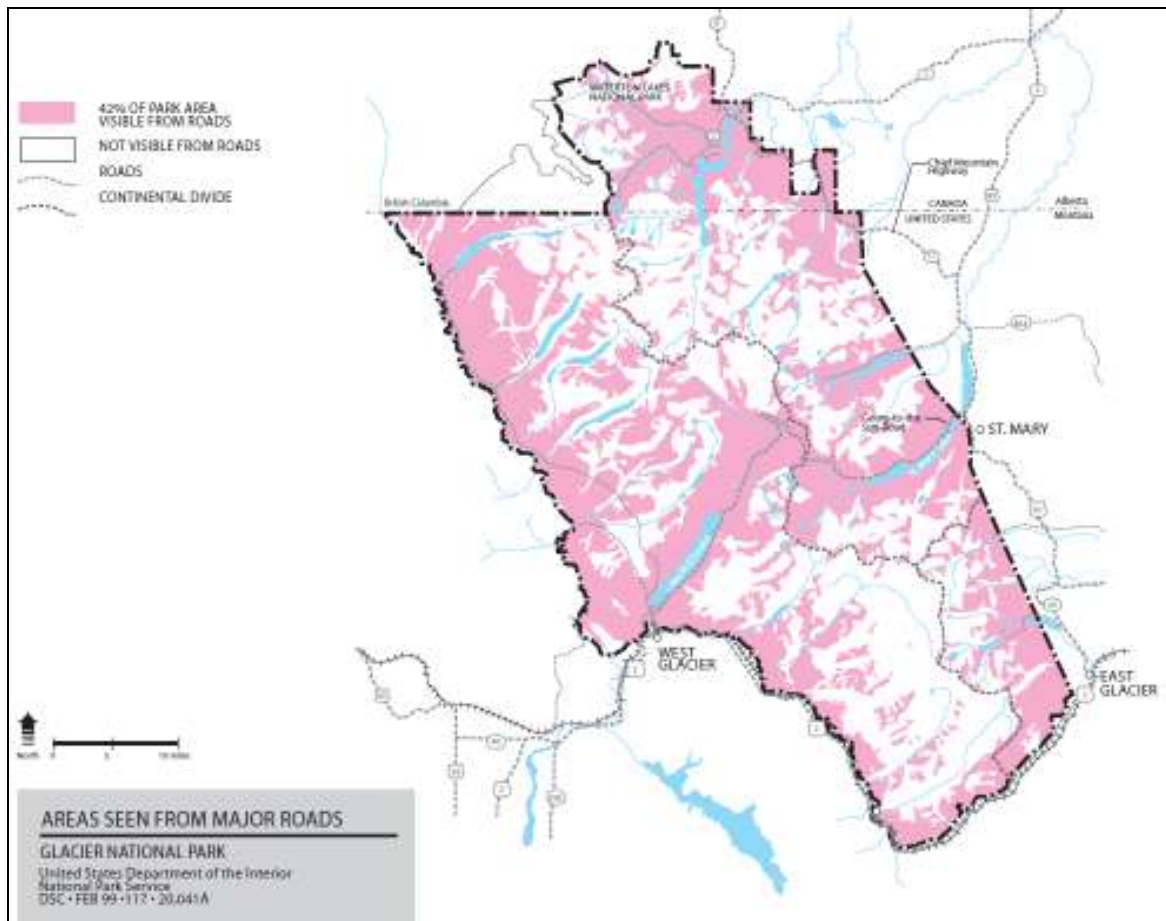


Figure 1-1: Map of Glacier National Park with GTSR connecting the east and west sides (NPS, 1999)

Research on visitor use of the GTSR and different parking lots along the road before and after the introduction of the shuttle system was conducted from 2005 to 2010 by researchers from the University of Montana (Johnson et al., 2010). The five year research reported that about 10% of the visitors used the shuttle system between 2007 and 2009. The use of the shuttle system brought multiple effects including a reduction in car traffic and encouraging more visitors to take one-way hikes which were previously impossible. With the shuttle, hikers drove to one of the trailheads and took the bus to the other trailhead to start their hike. This fact increased

backcountry hiking and shuttle use, caused vegetation trampling and created more social trails at bus stops without reducing much congestion at busy parking lots (Johnson et al., 2010). As the GTSR continues to be an important feature in GNP to visitors, park managers and local businesses, managing the corridor to meet different interests continues to be a pressing concern.

1.3 Objectives of the study

This research models the traffic on GTSR, shuttle operation along the road and trail use at Logan Pass area using the System Dynamics methodology. The three sub-models of traffic, shuttle and trail use are interconnected in one synthesis model to: (1) give an overview of parking lot congestion at Apgar Visitor Center, Avalanche, The Loop and Logan Pass for a typical busy day in July; (2) describe visitor use of highlighted trails around the Logan Pass area such as Overlook, Highline, Hidden Lake and The Loop during the same time period; and (3) evaluate the effect of the shuttle operation on trail use. The most important objective is that (emphasis added) the model can provide a learning environment for park managers to test potential policies before considering implementation. Several illustrative tests are presented. They include parking capacity change, change in annual visitation, visiting time and shuttle capacity. These tests will reveal the effects of visitors on the road and parking lot without the shuttle system and how the shuttle system affects trail use with its higher capacity.

With these objectives in mind, this dissertation is organized in the following order. Chapter 2 provides more in-depth background on park management framework and simulation approaches. Chapter 3 describes the detailed structure of the model. Results of the base case including comparisons between “No shuttle” and “Current shuttle” scenarios are presented in Chapter 4. Sensitivity analysis and illustrative policy tests follow in Chapter 5. Suggestions for future research and conclusions are presented in Chapter 6.

CHAPTER TWO

BACKGROUND ON FRAMEWORKS AND MODELS FOR PARK MANAGEMENT

2.1 Carrying capacity in park management

Since the management of a national park concerns managing a common resource for multiple purposes such as conservation, education and enjoyment, this task encounters many challenges. The fundamental challenge is to avoid the “tragedy of the commons” which is the unacceptable degradation of resources due to overuse motivated by self-interest of related stakeholders (Hardin, 1968). Simply put, park managers have to strike a balance between conserving the natural and cultural resources while still meeting the increased demand of the public for education and recreation. The difficult part is ensuring that not only current generations but also future generations can enjoy the same benefits from the parks.

It is conceivable from the tragedy of the commons that “there are environmental limits to population and related economic growth” (Manning, 2007). As a result, the concept of carrying capacity which has been applied widely to wildlife and range management has become the focus of the National Park Service:

In fact, it was first suggested in the mid-1930s as a park management concept in the context of the national park system. However, the first rigorous application of carrying capacity to park planning and management did not occur until the 1960s. (National Park Service, 1997, p. 4)

The original idea of carrying capacity is that a given habitat can only support a limited number of a certain species. In line with this, a certain park can be open to a limited number of visitors to remain unimpaired. The logistic growth model has often been used to describe how growth is

slowed and the population comes into accommodation with its limits (Ford, 2009, p.80). This

growth model has the equation $P_t = \frac{KP_0 e^{rt}}{K + P_0(e^{rt} - 1)}$ where P_0 is the initial population/system size,

K is the carrying capacity and r is the growth rate. Statistical data on park annual visitation in the first century of operation gives the impression that some parks have reached their carrying capacity (NPS stats, 2011).

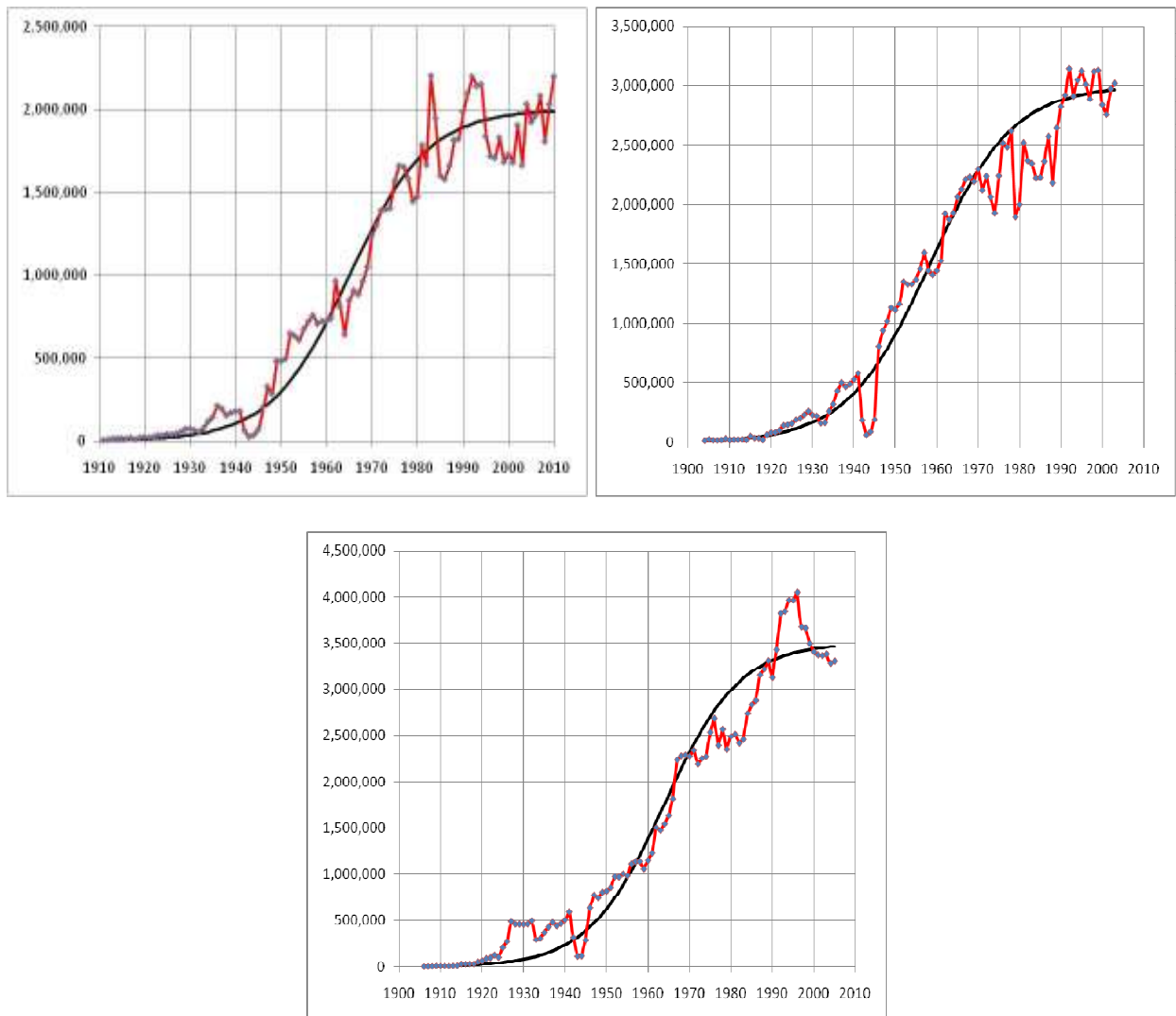


Figure 2-1: Annual visitation of Glacier National Park (top left), Yellowstone (top right) and Yosemite (bottom): red – data, black –logistic growth model

The annual visitation of Glacier, Yellowstone and Yosemite National Parks from early 1900s

until 2010 is shown in Figure 2-1. In these graphs, the red line indicates the actual data and the black line indicates the logistic model. Annual visitation of Glacier National Park seems to fit well with a logistic model having a K of 2 million and r of 11.5% per year. For Yellowstone, K is 3 million and r equals 10% per year. Yosemite appears to have a K of 3.5 million and growth rate of 11% per year.

Initial applications of carrying capacity in park management focused on visitor impacts on natural resources. However, park managers soon realized that the social dimension of visitor experience should also be included in the carrying capacity concept (National Park Service, 1997). The reason is because when there are more people visiting the same site, the quality of recreation experience of each visitor often decreases. In Manning's book about Parks and Carrying Capacity, his work in visitor social norms reveals that there are three groups of visitors: solitude oriented, access oriented and tradeoff oriented (a middle ground group). When the site becomes crowded, the solitude oriented group will be displaced either spatially or temporally (Manning, 2007). This research topic involves system feedback which sparks the interest of Washington State University researchers and will be planned for future studies.

Manning stated that "carrying capacity as applied to humans is less rigid, positivist, mechanistic and deterministic than traditional models such as the logistic growth equation might suggest" (p. 14). To do so, there should be a shift from defining maximum visitor number to defining the level and type of recreation use that can be accommodated, and human carrying capacity now becomes social carrying capacity. In addition, since "the amount and type of management" such as redistribution of visitors, enforcement of rules and regulations, and site-hardening have a great impact on the carrying capacity, this concept has expanded to three dimensions of resource condition, experiential quality and managerial actions (Manning, 2007).

2.2 Management framework aiding park management

Embracing the social carrying capacity, many frameworks have been proposed since the 1970s; examples include: Recreation Opportunity Spectrum (ROS), Limits of Acceptable Change (LAC) and Visitor Experience and Resource Protection (VERP). LAC and VERP frameworks share three common features: (1) they emphasize maintaining desired future conditions of resources and experience, (2) they allow monitoring to qualitatively evaluate the effectiveness of the management system and (3) management strategies are implemented to achieve desired conditions (Hof and Lime, 1997).

Recreation Opportunity Spectrum (ROS) is the first framework concerning “both the allocation and management of opportunities for recreation” (Clark and Stankey, 1979). Opportunity factors are defined based on criteria such as accessibility, non-recreational resource uses, onsite management, social interaction, acceptability of visitor impacts and acceptable regimentation. There are four steps in using ROS: (1) allocating and planning recreational resources, (2) inventorying recreational opportunities, (3) identifying the consequences of management actions and (4) matching desired experiences with available opportunities (Clark and Stankey, 1979). In brief, ROS involves setting goals, standards and specifying indicators to measure standard compliance (Hammitt and Symmonds, 2001).

A later framework developed from ROS is the Limits of Acceptable Change (LAC) proposed by Stankey et al. (1985). As the name suggests, managers set the standards for resource indicators representing the minimum resource condition or LAC. When indicators show that resources are degrading more than the expected LAC, pre-proposed management actions are implemented to restore resources to the desired state. A LAC planning system involves nine steps as shown in Figure 2-2.

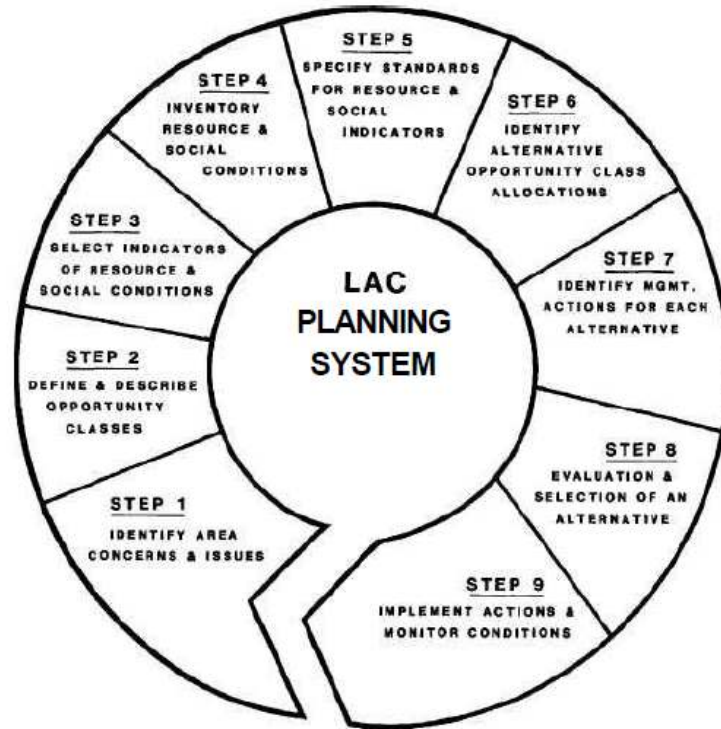


Figure 2-2: The LAC planning system (Stankey et al, 1985)

These nine steps embrace the four steps of ROS (define and describe opportunity class, select indicators and resource and social conditions, inventory and specify standards) and also add the proactive approach of searching for alternatives and proposing management actions for each alternative. Monitoring and revision make the planning system a continual process which ensures resource and social conditions comply with park's mission. Following LAC, other frameworks have been developed such as National Parks and Conservation Association Visitor Impact Management (VIM), the Parks Canada Management Process for Visitor Activities (VAMP) and the Park Service Visitor Experience and Resource Protection (VERP) (National Park Service, 1997).

The VERP framework is adapted from LAC for national park planning so it covers the same content but is more specific for national parks and quite handy to use. There are nine

elements in VERP which include: (1) forming an interdisciplinary team, (2) developing a public involvement strategy, (3) developing statements of park purpose, significance, primary interpretive themes and identifying planning constraints; (4) analyzing park resources and existing visitor use; (5) describing a potential range of visitor experiences and resource condition; (6) allocating the potential zones to specific locations in the park; (7) selecting indicators and specifying standards for each zone, and developing a monitoring plan; (8) monitoring resource and social indicators, and (9) taking management actions (National Park Service, 1997). VERP has been applied in several national parks, highlighted are Arches National Park and Yosemite National Park (Belnap, 1998; NPS, 2007).

Since the aforementioned frameworks evolve around desired conditions of natural resources, social interactions and management actions, determining the right indicators and setting the appropriate standards are instrumental to the success of framework implementation. In addition to ecological research, inventorying and monitoring approaches, social science research methods such as qualitative interviews, quantitative surveys, normative methods, stated choice surveys, visual research methods and related statistical methods have been employed to elicit visitor acceptability to different social and resource conditions (Manning, 2007). In recent years, computer simulation models have shown rigorous applications in park management by providing a learning environment for managers to envision future scenarios and test tentative policies before conducting real-world management actions (Cole, 2005; Manning, 2007; Gimblett and Skov-Petersen, 2008). The merging of different fields and research methods in park management has shown that not only ecological sciences but also social sciences have become useful in guiding managers to make more informed decisions regarding balancing the varied interests of different stakeholders.

2.3 A review of computer simulations for park management

Since the 1970s computer-based models have been developed to aid management and research in the backcountry and wilderness (Cole, 2005). Agent-based modeling (ABM) and System Dynamics modeling (SDM) are the common approaches. Both approaches are dynamic and can be combined with GIS for visual presentation. The ABM approach involves designing the agents, the environment and the rules for the agents to interact with one another and with the environment. The SDM approach involves building stocks and flows and adding the feedbacks to control the flows. The following sections will give a brief overview, highlighted case studies and usefulness of each methodology.

a. Short-term visitor travel behavior models (agent-based models)

An early model known as Wilderness Use Simulation Model was jointly developed by IBM, Resources for the Future and the U.S. Forest Service to estimate the number of encounters in an area. The model is based on Stankey's hypothesis of the inverse relationship between visitor experience and number of encounters in the wilderness. The required inputs included the network of trail segments, overnight campsites, travel routes and times, arrival patterns of each group and their travel mode. Numbers and type of encounters, location, trip length and total use levels were model outputs. This model and its modified versions were applied in several wilderness areas (Spanish Peaks Primitive Areas, Adirondack Forest Reserve, Desolation Wilderness, Yosemite National Park); river recreation (Green and Yampa Rivers in Dinosaur National Monument, Colorado River in Grand Canyon National Park) and the Appalachian National Scenic Trail (Cole, 2005). The model was successful in showing the correlation between trail/camp encounters with total use level. It also helped assess spatial and temporal effects of trailhead distribution patterns which led to the establishment of

trailhead quotas in the case of Yosemite. However, due to computer-limited accessibility and calculation capabilities, this model was not applied extensively until the late 1990s.

Wang and Manning (1999) started a new trend of modeling for visitor use on the carriage roads in Acadia National Park using the object-oriented dynamic simulation package Extend. The main indicator of the VERP framework of Acadia that they looked at was people per viewscape. Later modeling efforts include frontcountry hiking, backcountry camping and public transportation in the park, and indicators used include people at one time (number of visitors at a location at a certain time) (Cole, 2005). Starting in 2001, Gimblett et al. developed the RBSim simulator, a specialized tool to build simulations of recreation behavior. They also integrated RBSim with GIS to allow both probabilistic simulations and agent-based simulations. RBSim was applied to the Sierra Nevada, Colorado River in the Grand Canyon and the Twelve Apostles of Port Campbell National Park, Australia (Cole, 2005). Other agent-based models include iRAS (Intelligent Recreational Agent Simulator) developed by The University of Melbourne (Loiterton and Bishop, 2008) and MASOOR (Multi Agent Simulation of Outdoor Recreation) developed by Alterra Green World Research and Wageningen University of The Netherlands (Jochem et al., 2008). Table 2-1 summarizes highlighted models and their study areas.

Table 2-1: A summary of short-term visitor travel behavior models

Model/ Software	Study area	Authors	Time unit	Time interval
Travel simulation model (Extend)	John Muir Wilderness	Lawson et al., 2005	Days	92 days
	Yosemite National Park	Manning et al., 2005	Minutes	1 day
	Alcatraz Island	Valliere, Manning and Wang, 2005	Minutes	3 days
	Arches National Park	Lawson et al., 2005	Minutes	1 typical peak season day
	Isle Royale National Park	Lawson and Manning, 2003	Days	3 weeks
	Acadia National Park Carriage Road	Wang and Manning, 1999	Minutes	9AM to 5 PM
	Acadia National Park Scenic Road	Hallo, Manning and Valliere, 2005	Days	50 days
RBSim (Swarm & ArcView)	Broken Arrow Canyon	Gimblett et al., 2001	Days	A typical mid-week use day
	Bighorn Crags Portion of the Frank Church – River of No Return Wilderness	Gimblett et al., 2005	Days	89 days
	Misty Fjords National Monument in the Tongass National Forest	Gimblett et al., 2005	Days	59 days
	Port Campbell National Park, Australia	Itami, 2005	Minutes	1 day
	Prince William Sound, Alaska	Lace et al., 2008	Days	60 days (1season)
	Colorado River in Grand Canyon National Park	Gimblett, Daniel and Roberts, 2000	Minutes	7 days
MASOOR	Lobau (Danube Floodplains National Park), Vienna, Austria	Taczanowska, Arnberger and Muhar, 2008	Not explained	Not explained
	Amsterdamse Waterleidingduinen, the Netherlands	Pouwels, Jochem and Verboom, 2008	Hours	1 day
	Dwingelderveld National Park, the Netherlands	Jochem et al., 2008	Not explained	Not explained
iRAS (JACK, ESRI ArcPad)	Royal Botanic Gardens, Melbourne, Australia	Loiterton and Bishop, 2008	Hours	Not explained

Agent-based modeling (ABM) involves autonomous agents meaning that:

They act independently of any controlling intelligence; they are goal-driven and try to fulfill specific objectives; they are aware of and can respond to changes in their environment, defined as the space that supports their activities; they can also move within that environment; they are social and communicative: they interact with one another by exchanging messages using some language; they have the ability to cooperate, coordinate, and negotiate with each other, and finally, they can be designed to learn and adapt their state and behavior in response to stimuli from other agents and their environment (Marceau, 2008, p. 411 – 412).

Rules for agents are logic-oriented. Examples of rules for agents' behavior in tourism models include: finding a parking space when entering the park, leaving trails to find food and drink when tired, looking for a shortcut to reach the desired spot, leaving the park when feeling bored/satisfied/annoyed with the experience in the park, etc. ABM is stochastic and discrete-event which means it takes into account random variations of the system with probabilistic components and describes instantaneous change of the variables at non-continuous points of time (Manning, 2007). To capture the instantaneous response of agents, most agent-based models have very fine time units within a short time frame. Time units of minutes, hours or days are commonly used to run for a period of one day or several months as shown in Table 2-1.

Probabilistic simulation models have been used for various purposes in wilderness management such as describing current use patterns (Bighorn Crags, Misty Fjords, Grand Canyon and John Muir), predicting maximum sustainable use (Isle Royale, Yosemite,

Alcatraz Island and Arches), forecasting the impact of increased use levels on crowding-related variables (Acadia and Twelve Apostles), and finding ways to collect visitor data in difficult circumstances (Mt. Rainier). However, there are still challenges in applications to-date. Those models are partially validated, lacking statistical comparison of simulation results to observation data and lacking numerical confidence in predictions (Cole, 2005).

b. Long-term System Dynamics models

System Dynamics is a method of analyzing system behavior over time by dealing with feedback loops, time delays and nonlinearities influencing dynamic behavior (Ford, 2009). This methodology was first developed in the 1960s by Jay Forrester (Forrester, 1961). System Dynamics has been widely applied to many fields, predominantly in business (Sterman, 2000) and environment (Ford, 2009).

System Dynamics modeling is closely linked with Systems Thinking, a way of understanding problems by emphasizing the relationships among a system's components rather than isolating individual parts (Senge, 1990). Systems Thinking is widely used in community tourism projects where the community expresses its concerns, gets educated about the system perspective and brainstorms solutions for sustainable development. Highlighted studies involve learning laboratories for sustainable development for UNESCO biosphere reserves (Mai and Manni, 2010; Nguyen, Bosch and Manni, 2010).

Due to its usefulness in aiding mutual understanding, better decision making and collaboration among stakeholders, Systems Thinking is recommended for NPS management. The National Parks Second Century Commission suggests that Systems Thinking and multi-stakeholder dynamic models should be employed to engage the community in evaluating outcomes of land use decisions (Committee Recommendation 3). Systems Thinking should

also be used to develop collaborative and effective leadership within the NPS (Committee Recommendation 2 and 8, National Parks Second Century Commission, 2009).

There have been a wide range of System Dynamics applications in tourism and conservation. Examples include: tourism and environment in the Yucatán Peninsula (Kandelaars, 1997); resort development project management in Guilin, China (Honggang and Jigang, 2000); managing impacts of urban development, tourism, fisheries, cultivation of fish and bivalves, agriculture, salt making and sand extraction in the Ria Formosa Natural Park of Portugal (Videira et al., 2003); decision support system for tourism development (Chen, 2004); integrated modeling of environmental, social and economic systems of tourism in Dominica (Patterson et al., 2004); managing gooseneck barnacles in the marine reserve of Basque Country, Northern Spain (Bald et al., 2006); modeling conflicting interests of goat owners, cattle owners, wood gatherers and park managers involving invasive species impact on cattle, goats and tigers in Ranthambhore National Park in India (Dayal, 2007); impacts of air transportation on tourism in Jamaica (Ishutkina, 2009); sustainability of mass tourism in Southern European Island (Xing and Dangerfield, 2010); long-term development of Hakka Tung Blossom Festival in Taiwan (Li and Jian, 2011); and participatory modeling of tourism development in the Cat Ba biosphere Reserve of Vietnam (Mai, 2011). Due to the diverse applications, the research focus varies. Some modelers pay more attention to the modeling process of getting stakeholders involved (Videira et al., 2003; Mai, 2011); others pay more attention to model application. In general, some of the aforementioned tourism models share some common elements. First, attractiveness is considered as the central factor in the tourism market. While one study differs from another, each tries to measure some indices of attractiveness or tourist's utility based on a combination of the following factors: the

destination popularity, hotel/beach vacancy, tourists' daily cost, infrastructure quality and travel time (Patterson et al., 2004; Ishutkina, 2009; Xing and Dangerfield, 2010). Second, once attractiveness is determined, ways to improve it are considered. Two common policies are increasing infrastructure capacity and shortening travel time. As attractiveness is improved, most sites have problems with environmental quality which affects tourism experience and undermines attractiveness. This reflects that the development has reached its carrying capacity.

Table 2-2: A summary of long-term System Dynamics models used in conservation and tourism management

Software	Study area	Authors	Time unit	Time interval
Stella II	Yucatán Peninsula, Mexico	Kandelaars, 1997	Years	20 years
Vensim	Guilin, China	Honggang and Jigang, 2000	Years	30 years
Powersim	Ria Formosa Natural Park of Portugal	Videira et al., 2003	Years	35 years
Powersim	Hypothetical natural resource based tourism region	Chen, 2004	Years	12 years
Stella	The Common Wealth of Dominica	Patterson et al., 2004	Years	19 years
Vensim	Basque Contry, Northen Spain	Bald et al., 2006	Years	10 years
Vensim	Ranthambhore National Park, India	Dayal, 2007	Years	100 years
Vensim	Jamaica	Ishutkina, 2009	Years	70 years
Vensim	A typical island in Southern Europe	Xing and Dangerfield, 2010	Months	720 months

System Dynamics models use stocks and flows as building blocks and the supporting software could be Powersim, Stella and Vensim. Stocks are used to represent the state of the system. Flows are used to describe information or materials entering or leaving a stock over time. In addition, converters are also used to clarify flows (Ford, 2009). Unlike rules for

agents, the rules for stocks and flows are more mathematically driven. They have the form of formulae or graphs. Examples of stocks are number of vehicles in a parking lot or number of visitors on a trail. Flows could be vehicles coming into and leaving the parking lots, visitors entering and leaving the trails. Rules for vehicles and visitors could include: at what time of day do many visitors/vehicles arrive and at what rates. System Dynamics modeling (SDM) is predominantly continuous but could be discrete when needed, and can be stochastic or deterministic. SDM can also model individuals' behavior and their spatial distribution (Bendor and Metcalf, 2006). However, such application requires such intensive modeling efforts that they tend to be beyond the reach of many organizations (Ford, 2009, p.360). Instead, System Dynamics models are typically used for looking at the bigger picture. Most modelers try to combine socio-economic and resource conditions to reveal management issues. The temporal and spatial scales of system dynamics models vary widely. Time can range from minutes to hours to days to months and years. Usually, the time frame for system dynamics models is much longer than that of the agent-based models. In addition, the model scale could be local, regional, continental or global (Table 2-2).

c. Usefulness of each modeling method:

ABM is good for studying agent's behavior within a certain landscape during a short period of time. Such an application has been widely used to model campsite crowdedness and trail congestion within a typical day. ABM helps describe current use pattern, predict maximum sustainable use and forecast the impact of increased use level on crowding-related variables. Animation features of ABM give users good visualization of where visitors start their tours, where they gather and cause congestions, etc. SDM, on the other hand, is normally used to look at different aspects of a management problem over a longer time horizon. SDM is useful

when bits and pieces of each component of the system are well-known but their interactions are not well-understood. Due to this capability, interdisciplinary research is enabled. For example, increased visitation will cause trampling, wildlife disturbance and soil erosion. In certain parks, the technical department only looks at how much degradation/disturbance occurs in the resource and does the restoration planning. The tourism department takes care of visitation operation and finance. Without linking the information from these two separate departments, it is hard to strike a balance between keeping the resource unimpaired while maintaining access to the public. SDM can help by connecting the number of tourists with their impacts on resources and their spending in the park. Then, managers can decide how much visitation they want to maintain.

SDM is powerful in the sense that once the links between different sectors are established, system feedbacks and delays can be recognized. Recognizing feedback is important to managers since without knowing that, managers tend to attribute poor behavior to exogenous factors. When the system feedback takes the form of a vicious circle, this kind of management makes the problem even worse. In addition, taking delays into account can avoid bad decisions. Systems with delays often behave well in the short term but worse in the long run. For example, more infrastructure development attracts more tourists to a certain area. The fact that it takes a couple years for a project to complete encourages more new infrastructure projects (to meet the growing demand of visitors). However, by the time all the projects are completed, the area is so highly developed that it is no longer attractive to visitors. This example shows that long term projection is important to avoid mistaken decisions. SDM is also useful in the context involving different stakeholders. Often times, different stakeholders have different perspectives about the same issue driven by their

interests and positions. SDM encourages participatory modeling where each stakeholder can raise their voice so that the overall model reflects all different views. This approach helps facilitate conflict resolution once the big picture is created (Ford, 2009; Beall and Zeoli, 2008).

Another useful aspect of SDM is that it helps reveal non-linear relationships. Traditionally, managers deal with linear relationships that are quite predictable. Today, however, managers become more reactive than proactive as more non-linear relationships have been observed. In a dynamic world, that approach in management will soon become ineffective and not be able to deal with highly uncertain issues such as climate change. However, models of socio-economic and environmental systems often have to deal with “soft” sources of information such as personal intuition, stakeholder knowledge, expert judgment and case studies (Ford, 2009, p.153). As a result, SDM is useful in cases where “hard” sources of information are missing and high levels of uncertainty are involved.

This research was conducted at Washington State University where faculty and students are interested in both short-term and long-term issues of national parks. The goal here is to illustrate the System Dynamics method in a real park where managers are dealing with real challenges. In order for the illustration to be meaningful, a concrete issue is chosen: whether or not the shuttle system should be continued after the rehabilitation project of GTSR. Impacts of the shuttle as well as impacts of cars on GTSR would be best described on a typical day in the summer. As a result, the time horizon of the model was chosen for a busy day in July. Simulations of longer-term dynamics are left for future research at Washington State University.

Since the illustrative model describes activities of people getting on and off the bus and

cars entering and leaving the parking lot; the time unit is in minutes. Minute by minute dynamics are normally the domain of ABM so careful review of other modelers' accomplishments was conducted, especially their excellent work on animation to communicate the crowded conditions and the dynamic behavior of the agents. The goal of this research is to design a System Dynamics illustration that also strives for innovative display of results as they unfold during a typical July day.

In brief, the model presented here illustrates the usefulness of System Dynamics to deal with crowded conditions on the GTSR, main parking lots, the shuttle and on popular trails surrounding the Logan Pass area in GNP. This interconnected system is sometimes referred to as the GTSR Corridor. The model concludes with illustrative policy tests to learn how the corridor crowding would change with different plans for the shuttle. Ideas for future work, including simulation of longer-term dynamics, are described in the concluding chapter.

CHAPTER THREE

MODEL DESCRIPTION

3.1 Model overview

A dynamic model was constructed to describe the complex interactions between visitors driving the road, using the shuttle and hiking the trails. The model is grounded in fieldwork conducted during the summer of 2011, followed by online meetings and e-mail correspondence with park staff. The modeling also benefits from the studies by the University of Montana researchers on shuttle and trail use (Johnson et al., 2010; Dimond and Freimund, 2009 and Baker and Freimund, 2008). Stella software was used to provide a user-friendly interface and connect the three sub-models explicitly.

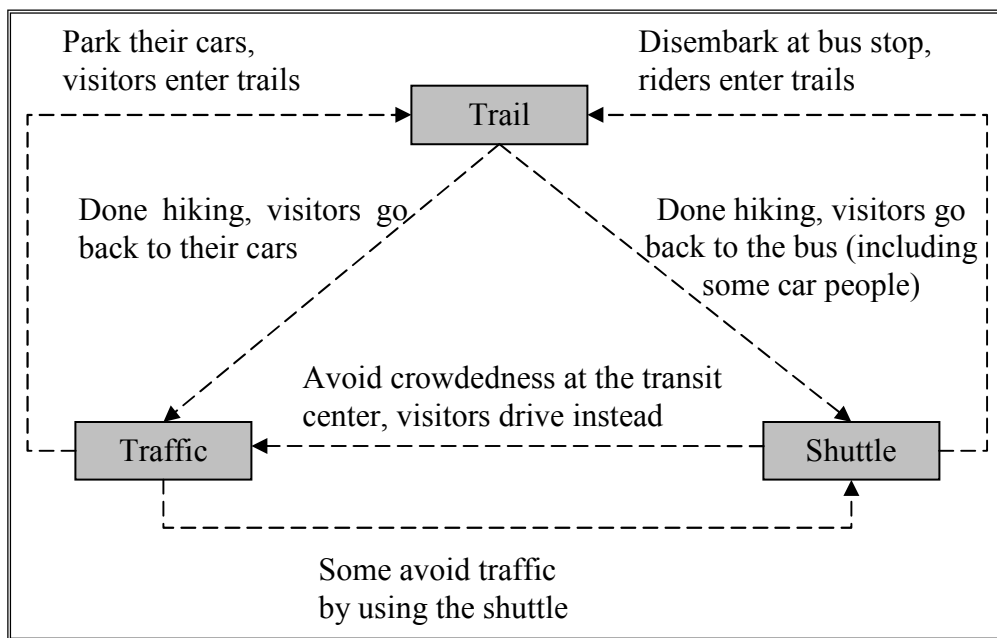


Figure 3-1: Diagram of the synthesis model describing the connections of three sub-models

Figure 3-1 shows how the three sub-models are interconnected and how each sub-model feeds input to the others. The Traffic sub-model depicts how visitors use the road and cause

parking congestion in four main parking lots: Apgar Visitor Center (AVC), Avalanche (AV), The Loop (TL) and Logan Pass (LP) (see a simple map on Fig 3-2 panel A). Once visitors park their cars, they tour the destination or hike the trails. When they finish visiting, they might go straight back to their cars or take the shuttle to get to their cars and continue on the road or go elsewhere. The Shuttle sub-model describes a small fraction of visitors (between 10 and 13%, (Johnson et al., 2010)) who choose to use the shuttle to facilitate their visit. These visitors park their cars at Apgar Transit Center (ATC) to use the shuttle. However, when there are too many people waiting at the transit center, they decide to drive their cars instead of riding the shuttle. Shuttle riders do not contribute to parking lot congestion but put more pressure on popular trails at AV, TL and LP (see simple map on Fig 3-2 panel B). The main difference between drivers and riders is that shuttle riders have to design the tour around the shuttle schedule while car users have more freedom to move between different destinations.

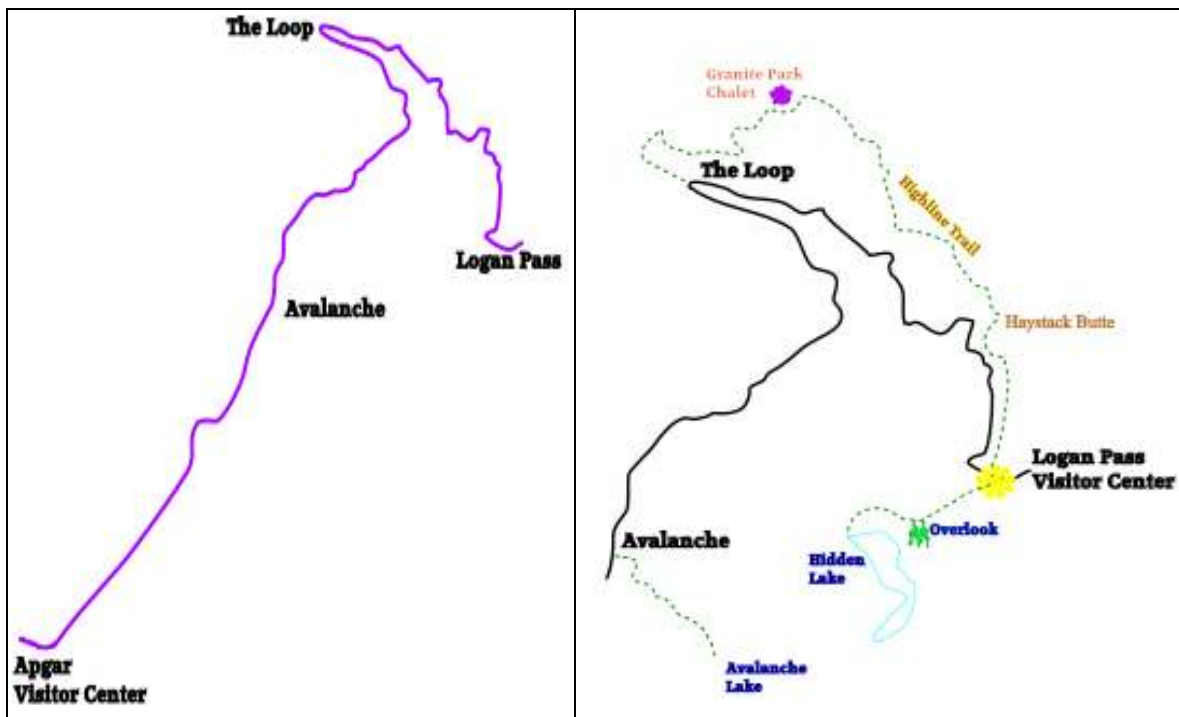


Figure 3-2: Simple maps of: A) Main destinations and parking lots, B) Main trails

The Trail sub-model describes how car users and shuttle riders visit LP Visitor Center and nearby trails such as Overlook, Highline, Hidden Lake and The Loop. The two groups of visitors may hike on the same trails and cause trail congestion. When they finish hiking, car people return to their cars and bus people return to the bus stop. The three sub-models are built initially for the west side which accounts for 60% of arrivals of annual visitation to Glacier National Park (Miller and McCool, 1994). In order to capture the full behavior of parking lot and trail congestion at Logan Pass, approximation of car users and shuttle riders of the east side is built and connected with the Trail and Traffic sub-models at LP. The following sections describe each sub-model in more detail. For a complete table of main input values, please refer to the Appendix.

3.2 Traffic sub-model

The main assumption for the Traffic sub-model is that there are six groups of visitors entering the west entrance as shown in Table 3-1. Five of the six groups stop at AVC for about 20 minutes to ask for information or have a quick look at souvenirs. The “LP only” group does not stop at the AVC because they are either returning visitors or they know the area well. If the parking lot at Apgar is full, visitors will skip this location and continue to their planned destinations. Five of the six groups are traveling GTSR. The other group (accounting for 20% of visitors) travels to a different part of GNP such as North Fork, Middle Fork, Two Medicine, etc. Since this group is not using the GTRS corridor, they are not simulated further in the model.

The first group (LP only) wants to reach LP and skip other destinations along the way. Since they want to avoid parking congestion at LP, they arrive early between 7 and 9 AM at the west entrance. This group accounts for about 5% of visitors and spends between 2 and 6 hours hiking the trails depending on which trail they take, e.g. Overlook, Hidden Lake or Highline. The

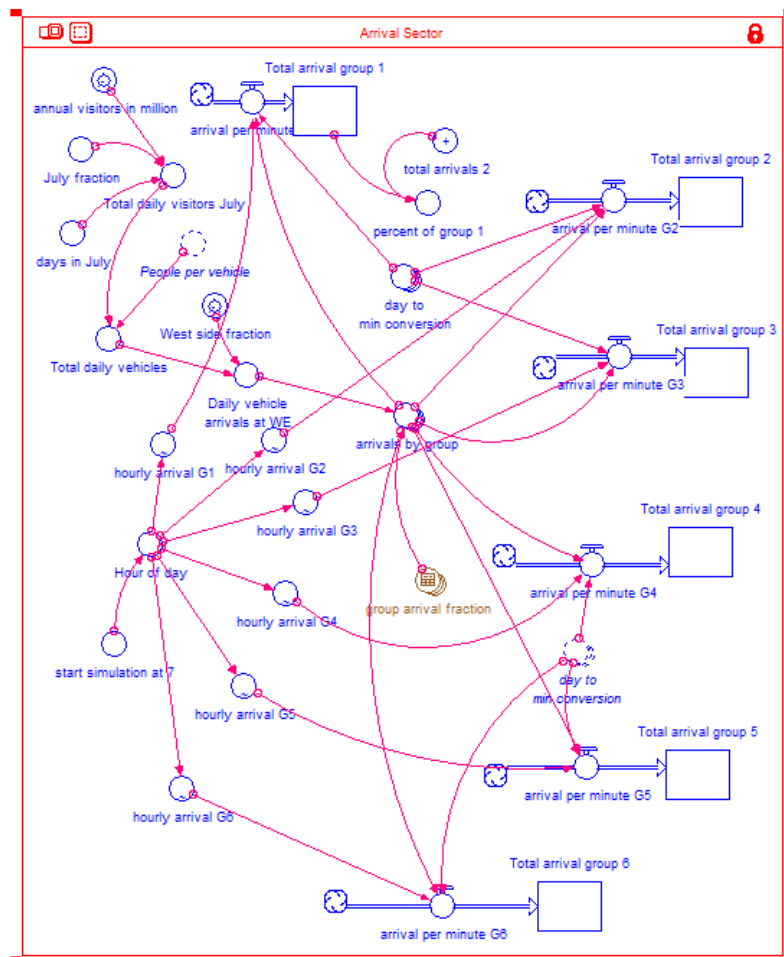
second group only stops at AV and LP and accounts for 30% of visitors. They arrive between 8AM and 2PM and stop at each location for about 2 hours.

Table 3-1: A summary of six groups of visitors in the traffic sub-model

Group	Arrival time at west entrance	Arrival fraction	Destinations	Parking durations	If failed to park at planned destination or done touring
1. LP only	7 – 9 AM	5%	Logan Pass	Between 2–6 hours depending on the trails	Go elsewhere
2. AV-LP	8AM–2PM	30%	Avalanche and Logan Pass	2 hours at AV, 2 – 2.5 hrs at LP	If failed at AV, keep going to LP, if failed at LP, go elsewhere
3. AV only	8AM–5PM	10%	Avalanche	2.5 hours at AV	Go elsewhere
4. AV-TL	8AM–2PM	10%	Avalanche and The Loop	2.5 hours at AV, 3.5 hrs at TL	If failed at AV, keep going to TL, if failed at TL, go elsewhere
5. AP only	8AM–6PM	20%	Stop at Apgar Visitor Center for information and go elsewhere but GTSR	20 minutes	Go elsewhere
6. All destination	8AM–2PM	25%	Avalanche, The Loop and Logan Pass	1 hr at AV, 1 hr at TL, 2 – 2.5 hrs at LP	Go elsewhere

The third group arrives between 8AM and 5PM and only stops at AV for 2.5 hours to take a hike to Avalanche Lake. This groups accounts for 10% of visitors. The fourth group also accounts for 10% of visitors. They only stop at AV and TL so they take a long hike at AV and a hike to the Chalet from TL. In order to do these hikes, they arrive between 8AM and 2 PM. The last group traveling GTSR accounts for 25% of visitors and also arrives between 8AM and 2PM. They stop at AV for an hour to hike Trails of the Cedar, then 1 hour at TL to view the area around the trail head to Granite Park Chalet and about 2 hours at LP hiking other short trails.

For the purpose of modeling, different groups of visitors are represented in Stella as arrays. Since this Traffic sub-model focuses on four main destinations including AVC, AV, TL and LP, there are four main sectors describing how cars attempt to park at each destination, leave the destinations when done touring or continue on the road when failing to park. Another important sector is the Arrival Sector where arrival profiles of different groups are modeled (Fig 3-3).



In the Arrival sector, total daily vehicles are calculated based on the number of annual visitors, the fraction of visitors who come in July and people per vehicle. When the west side fraction (60%) is applied to total daily vehicles, daily vehicles arriving at the west entrance are

determined. Depending on the arrival fraction of each group and arrival hours, vehicle arrivals per minute for each group is calculated. Summation of per minute arrivals of all groups yields the west entrance arrival profile to feed other sectors of this sub-model.

The general structure of main destination sectors include a *conveyor* stock of cars parking at the parking lot of interest, a *reservoir* stock of cars leaving off GTSR and a *conveyor* stock of cars enroute to the next destination on GTSR. Adding or removing the number of cars in a stock is the inflow and outflow of cars. A *conveyor* stock is used to keep track of cars at different locations when the outflow is the same as the inflow delayed by a fixed time interval. An example of a conveyor stock is cars in a parking lot at AVC, as shown in Figure 3-4. A *reservoir* stock is used to keep track of variables that accumulate during the simulation and whose outflows are not described by a fixed residence time.

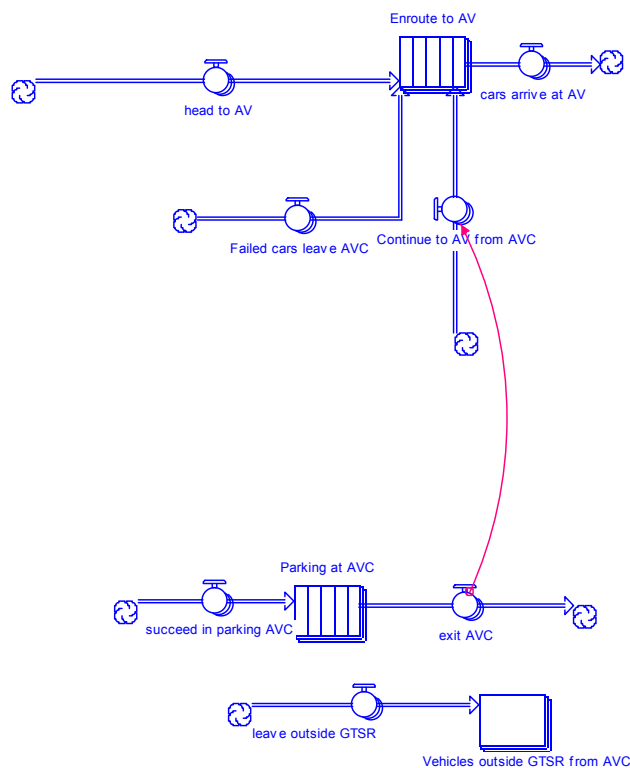


Figure 3-4: Main stocks and flows of Apgar Visitor Center sector

Figure 3-4 shows the main stocks and flows of Apgar sector. Cars succeeding in parking

Regarding detail structure, the AVC sector and the LP sector are different from the two sectors in between (AV and TL). AVC is close to ATC where car users can decide whether they want to try the shuttle or not. In addition, AVC is near the west entrance so arrival profiles of different groups from Arrival Sector are fed into this sector.

LP sector is the last sector along GTSR so the structure is much simpler. Also, LP is a place of high interest in this model where activities on different trails are described in more detail. Hence, parking duration at LP is directly connected to the trail sub-model and “Total cars parking at LP” is a reservoir instead of a conveyor stock due to variation in length of different trail hiking times. The exit flow of this stock includes two types of car users: one always uses their cars during the visit and the other uses the shuttle to facilitate a one way hike.

Figure 3-5 shows a full diagram of the AVC sector. Starting with arrivals at the west entrance, car users are divided into two categories: one wants to try the shuttle and the other only wants to drive. The “fraction wishing to use the shuttle” is controlled by the switch “Shuttle operating?”, a switch which can be turned on and off corresponding to the operational status of the shuttle. People who want to try the shuttle will drive to ATC to park their cars. However, when there are too many people waiting at the transit center, visitors start going back to their cars and driving instead. “Fraction return to the cars” is an output of the Shuttle sub-model and the information is given in the “Info?” button. This fraction shows the number of cars that return to the road. These “unserved cars” represent the overloaded status of the shuttle system. For people who only want to drive, if cars failed to park at AVC due to a full lot, they would choose either to leave GTSR or drive to AV. “Failure fraction to AV” indicates which group would continue to AV when parking fails at AVC.

The remaining sector of the traffic sub-model is shown in Fig 3-6. The main focus of this

sector is “Total cars parking at Logan Pass”. The inflow includes both cars entering from the west and east entrances. The arrival profile of cars from the east is assumed to be similar to that of the west. In order to capture the full arrival profile, west side cars are divided by the west side fraction to calculate total cars. Cars succeeding in parking at LP visit the Visitor Center and hike the trails. Unsuccessful cars will go elsewhere.

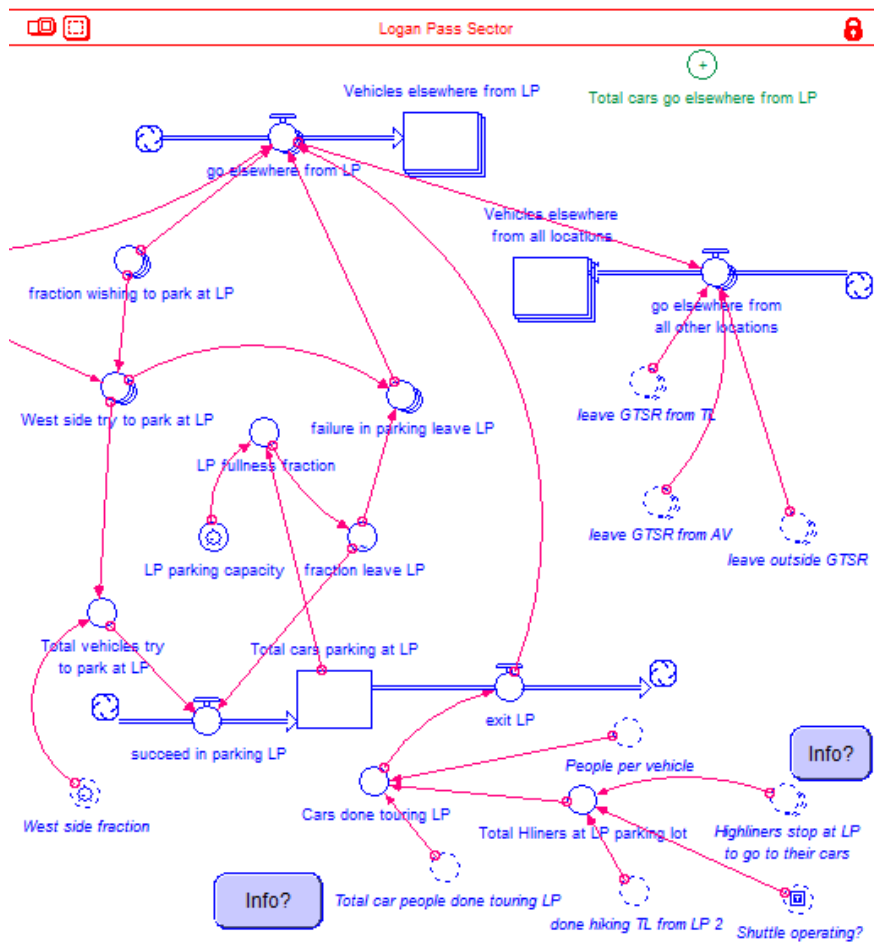


Figure 3-6: Diagram of Logan Pass traffic sector

As described earlier, cars exiting LP are driven by two types of visitors: one goes directly to their cars after touring, the other uses the shuttle to get back to their cars. The “Info?” button tells where the input comes from. “Total car people done touring LP” is calculated in the Trail sub-model and “Highliners stop at LP to go to their cars” is calculated in the Shuttle sub-model.

“Total Highliners at LP parking lot” is controlled by the switch “Shuttle Operating?” to ensure that this flow of people only occurs when the shuttle is in service. When there is no shuttle, people finished hiking from TL need to find a different way to get back to their cars or just hike to Haystack and turn around. The number of cars leaving the LP parking lot is achieved when “people per vehicle” is used to convert departing people into departing cars. One final different feature of this sector is the stock accumulating vehicles going elsewhere from all locations. This is a simple accumulation of vehicles going elsewhere from previous sectors including AVC, AV and TL.

3.3 Shuttle sub-model

The Shuttle sub-model depicts two components of a bus system: bus and people. Similar to the Traffic sub-model, the Shuttle sub-model simulates four places of interest include ATC, AV, TL and LP. There are two bus sectors modeling how buses operate at low elevation (from ATC to AV) and high elevation (from AV to LP) according to a schedule; and there are two people sectors modeling how people wait, get on and get off buses from ATC to AV and from AV to LP.

Figure 3-7 shows the main stocks and flows of two bus sectors illustrating the operation of 15 buses servicing the west side. There are four routes of buses: Express, LP morning only, ATC-AV Sprinter and ATC-AV Optima:

- The West Side Express is serviced by two 15-seat Sprinters running between the ATC and LP. These buses go straight from ATC to LP, but they stop at every bus stop on the way back to ATC. The first bus departs at 7AM. The next bus leaves 15 minutes later. These buses make three roundtrips before returning to the pool.
- The Morning Only route is serviced by four 12-seat Sprinters and two 15-seat

Sprinters running one way from ATC to LP. The first bus departs ATC at 7:20AM. The other five departures from ATC are 18 minutes apart. Once they get to AV, they serve the shorter route between AV and LP.

- The ATC-AV Sprinter route is serviced by four 15-seat Sprinters which depart empty from ATC and start service at AV. The first bus departs from ATC at 9:10AM. The other three depart about 17 minutes apart.
- The ATC-AV Optima route is serviced by three 44-seat Optimas running between ATC and AV. The first bus departs ATC at 9AM. The interval between departures is 30 minutes.

Different types of buses are modeled in Stella as arrays similar to different groups of cars in the Traffic sub-model. Conveyors are used to keep track of buses at bus stops and along the road. The only reservoir stock is the bus pool shown in Fig 3-7. The day begins with all 15 buses in the pool, and it ends with all 15 buses return to the pool after they have served their routes. Buses serving the three routes Express, LP morning only and ATC-AV Optimas leave the pool at a certain “Starting time” and start service at ATC. Sprinters serving the ATC-AV route leave the pool empty (by the flow “empty departure”) to arrive directly at AV. Express buses once loaded at ATC go straight to LP but on the way back stop at TL and AV. Each Express bus makes three roundtrips to LP. Once the “LP morning only” buses reach AV, they go up to TL and serve the small loop between LP and AV. These buses only go back to the pool at a designated time later in the day when done serving six roundtrips to LP. Both the Sprinters and Optimas serving ATC-AV route make six roundtrips daily.

The people sectors are more complicated than the bus sectors in terms of structure. There is a mix of conveyors and reservoirs where conveyors keep track of people on buses and

reservoir stocks keep track of people waiting. Adding to the complication is the different behavior of shuttle riders at different destinations and the participation of car users between TL and LP. For better explanations, a group of stocks and flows serving a certain purpose will be introduced.

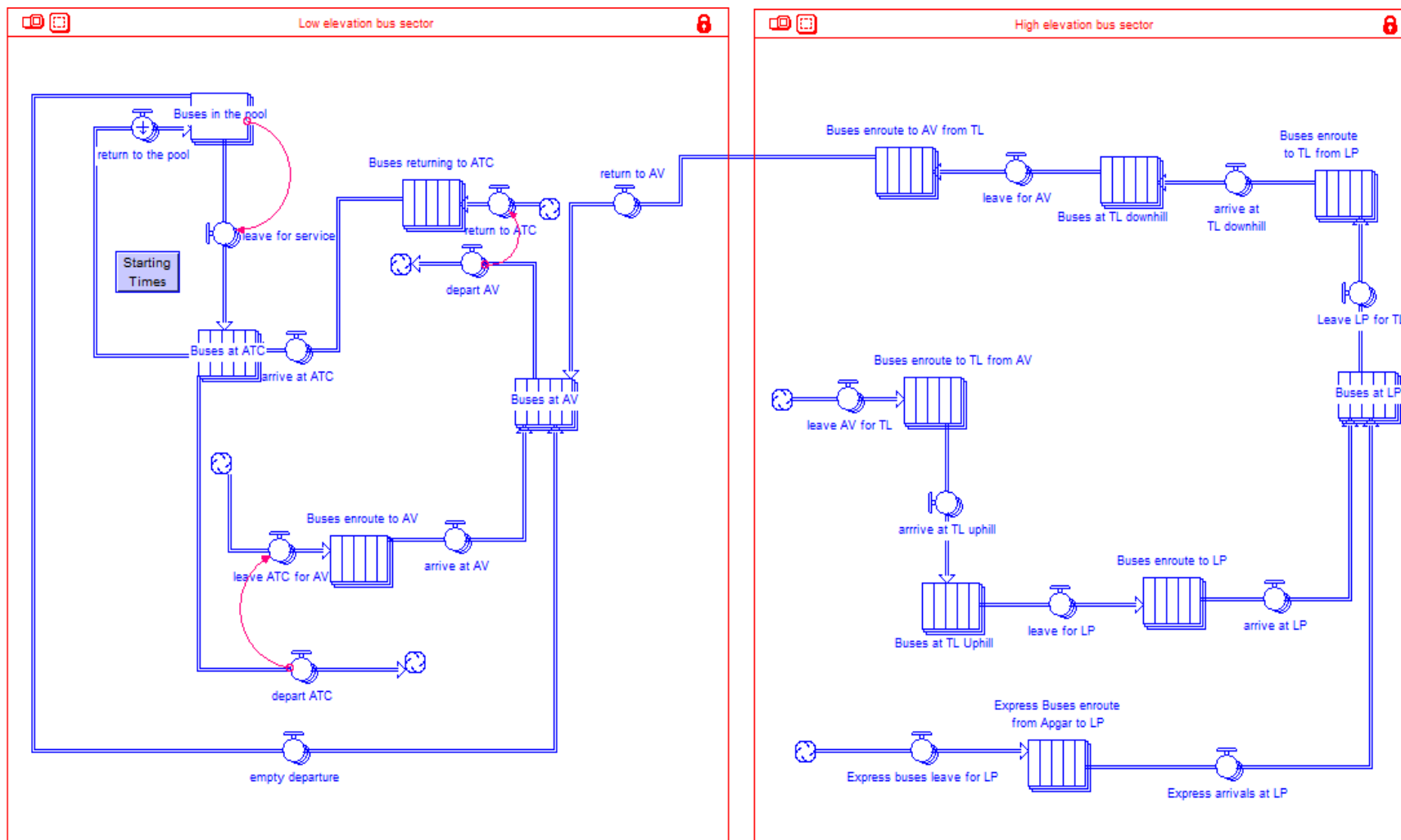


Figure 3-7: Main stock and flow diagram of two bus sectors

Figure 3-8 shows the first part of sector ATC and AV. People who want to try the shuttle arrive at ATC and spend a few minutes looking at the waiting line and consider if they still want to wait for the shuttle. If the line is too long, say 60 people, all new comers will definitely go back to their cars and drive. The flow “back to the cars” feeds back to the Traffic sub-model to include them on the road and at parking lots as shown in Fig 3-5. For those who decide to wait, they will leave the waiting room when there are buses servicing AV or LP. Another activity at ATC presented by the conveyor to the right is bringing riders back when they have completed their trip.

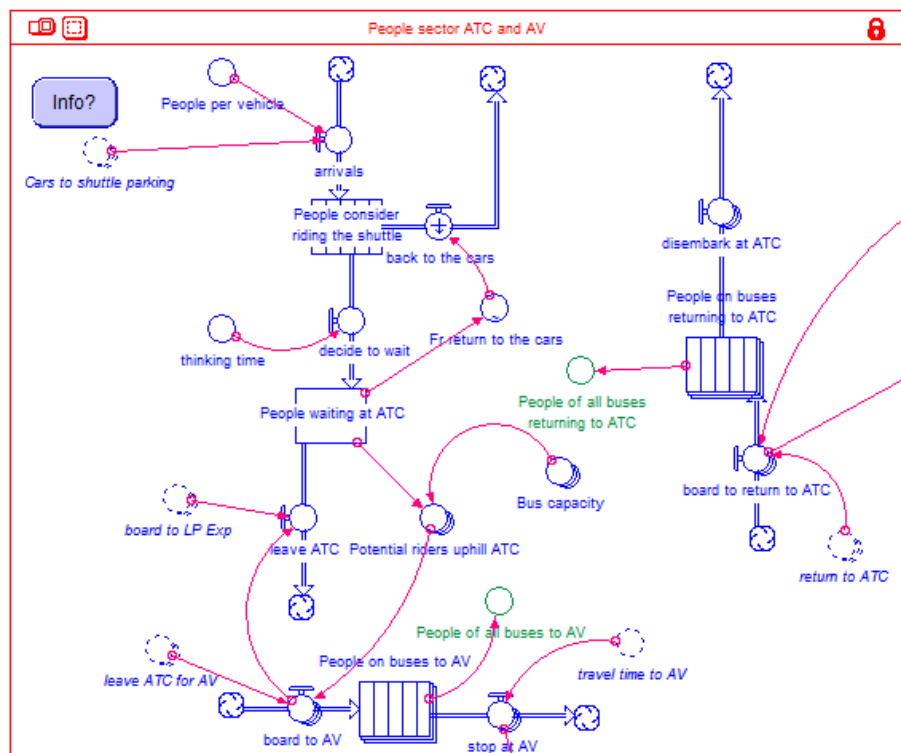


Figure 3-8: Diagram of visitors' activities at Apgar Transit Center

The next group of stocks and flows describe activities at AV (Figure 3-9). All riders disembark at AV. Some transfer to other routes to go to TL or LP. Others tour AV for about 90 minutes on average. These people are tracked by a conveyor. When visitors finish touring AV,

they might decide to return to ATC (if AV is their only destination) or keep going uphill. Either way, they have to get in line to catch the bus they need. The bottom reservoir shows the waiting line of visitors wishing to travel uphill. The other waiting line for downhill buses will be shown in TL sector (downhill segment) in Fig 3-11.

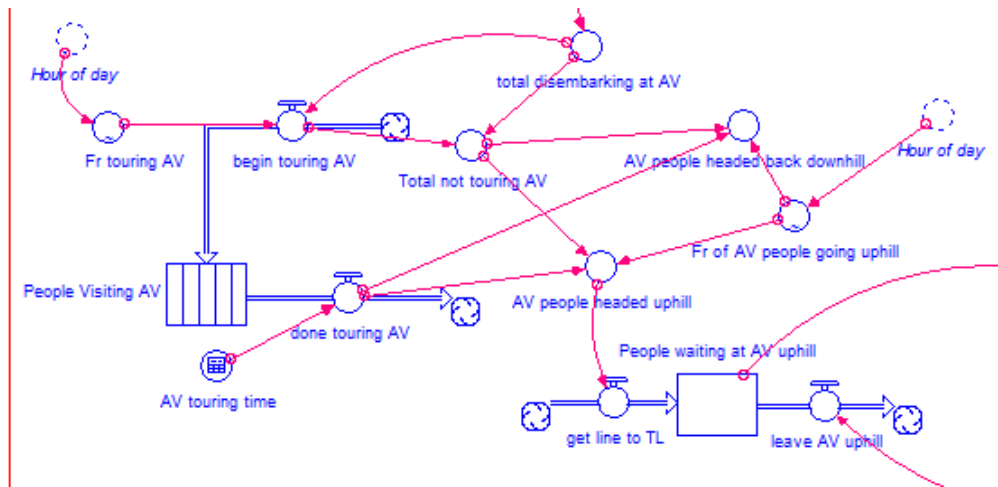


Figure 3-9: Diagram of shuttle riders' activities at Avalanche

Visitors leave AV on buses to TL (bottom left corner of Fig 3-10). Depending on the time of a day, visitors may want to visit the Chalet or go straight to LP. "Fr touring TL" divides the two groups. Another group visiting LP rides the Express buses. These riders skip AV and TL and arrive at LP quite early in the morning. Both visitors arriving at LP on express and non-express buses become input for the Trail sub-model. A special group joining riders from TL to LP is car people hiking the Highline Trail one way and catching the bus to go back to their cars. For easy recognition, these people are called Highliners. The bottom right reservoir and conveyor keep track of Highliners who join the waiting line at TL. When they get to LP, they drive their cars elsewhere. The flow "Highliners stop at LP to go to their cars" becomes one of the exit flows of cars parking at LP as aforementioned in Fig 3-6.

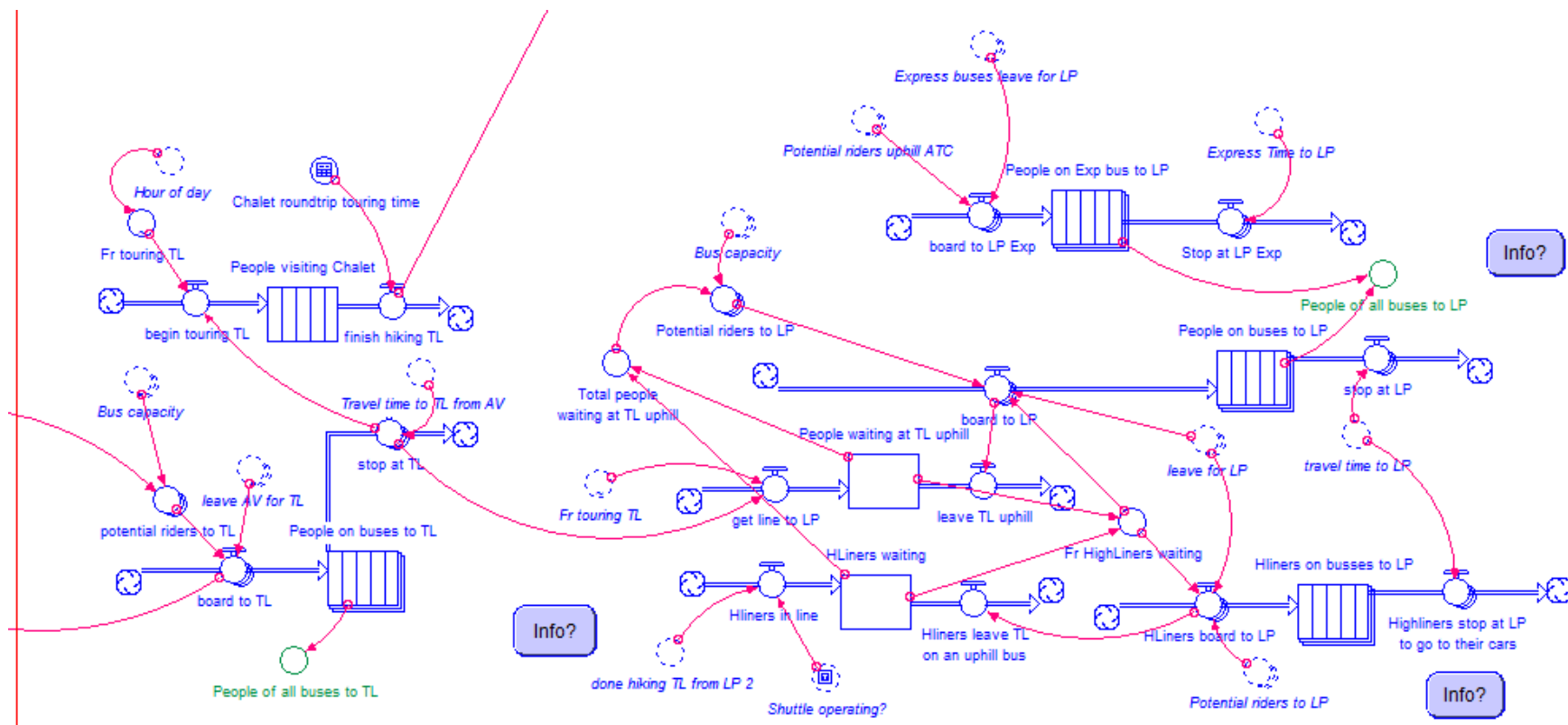


Figure 3-10: Diagram of shuttle riders' activities at The Loop and Logan Pass (uphill segment)

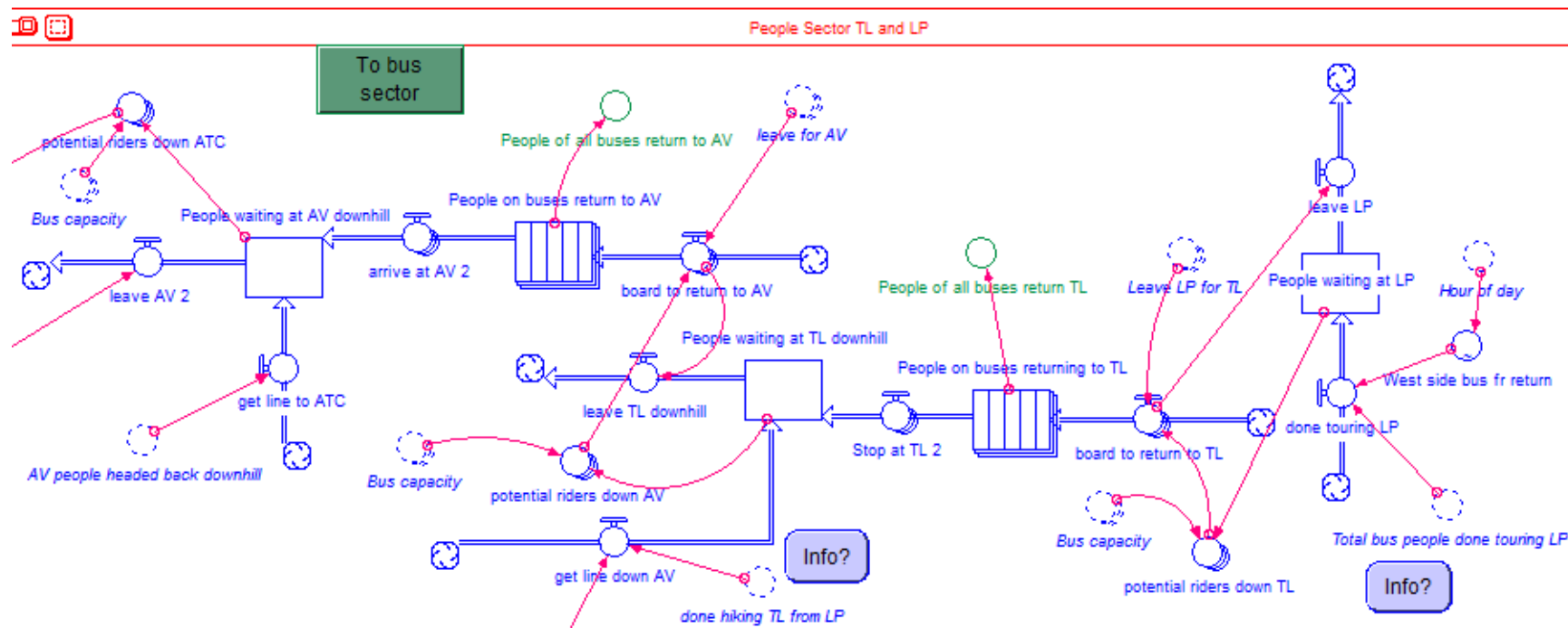


Figure 3-11: Diagram of shuttle riders' activities at The Loop and Logan Pass (downhill segment)

The downhill segment of “People sector TL and LP” starts from the right of Fig 3-11. When shuttle riders finish their visit at LP, they get in line for buses going downhill. Since bus people at LP use both east and west side shuttles, it is necessary to split this group so that only riders using the west side shuttle go back to their cars at ATC. “West side bus fr return” could depend on the time of the day when east and west side shuttles bring different numbers of people to LP. However, for simplicity, this fraction is constant in the model. Riders leave the waiting line at LP and arrive at TL. Here, a new waiting line joins them. This is a group of people taking the Highline Trail from LP all the way to TL. At the next stop of AV, there is another waiting line. This waiting line is created by people who are done touring AV and want to go back to ATC. The flow “get line to ATC” is connected with “AV people headed back downhill” shown in Fig 3-9. When the people waiting at AV manage to get on the bus, they leave AV and return to ATC. This flow of riders connects with the conveyor bringing visitors back, as shown in Fig 3-8.

3.4 Trail sub-model

The Trail sub-model is the only sub-model that does not make use of arrays. This means that each variable has only one value, whereas array variables hold separate values for each element in the array. The previous sectors make extensive use of arrays, as indicated by the three dimensional icons (i.e. “People on buses return to AV” in Figure 3-11). Arrays are not used in Trail sub-model since visitors are no longer associated with a particular group of arrivals or a specific bus that brought them to LP.

The Trail sub-model uses conveyors to keep track of visitors or hikers during their visit. This sub-model describe five main tours that visitors may take when they get to LP: (1) a combination of the Visitor Center and the boardwalk for a total duration of 2 hours, (2) a roundtrip hike to Overlook of Hidden Lake for 2.5 hours, (3) a longer roundtrip hike to Hidden

Lake for 4 hours, (4) a roundtrip hike to Haystack Butte on the Highline Trail for 2 hours 15 minutes and (5) a strenuous hike on the Highline Trail to Granite Park Chalet and all the way to The Loop for 6 hours. Since both car people and bus people can take any of the tours, two sectors with similar structure are used to keep track of the two categories separately (Fig 3-12 and 3-13). Subscript 2 is used for car people to distinguish them from bus people touring the same place.

Bus people arriving at LP include visitors both from the west side and the east side. The input from west side bus riders are described earlier and shown in Fig 3-10. However, since the east side shuttle is not fully described, a simplified delivery is used so that the effect of the shuttle system on LP area can be evaluated. Between 8AM and 5PM, 12 riders arrive at LP every 30 minutes from the east side. “Actual bus people arrivals per minute” is connected with “Shuttle operating?” to make sure the input is synchronized with shuttle operational status. Over the course of the day, about 50% of visitors at LP stay around the Visitor Center (VC) and 50% hike the trails (Johnson, personal communication, 2011). Toward the end of the day, more people stay around the Visitor Center to catch the bus easily. Of all hikers, 15% hike the Highline Trail to The Loop and that fraction fades around 2PM. For hikers who turn around at Haystack Butte, 5% take the hike in the morning. The fraction increases up to 35% around 3PM and declines toward the end of the day (see Table A-3 of the appendix for more detail). About 7% of the remainder hike Hidden Lake Trail and the rest hike Overlook Trail. To test the effect of the shuttle system on trails, a variable named “Logan Pass Shuttle Testing Factor” is applied to “Actual bus people arrivals per minute” (Fig 3-12).

Figure 3-12: Diagram of Bus People Sector visiting the Visitor Center and other trails at Logan Pass

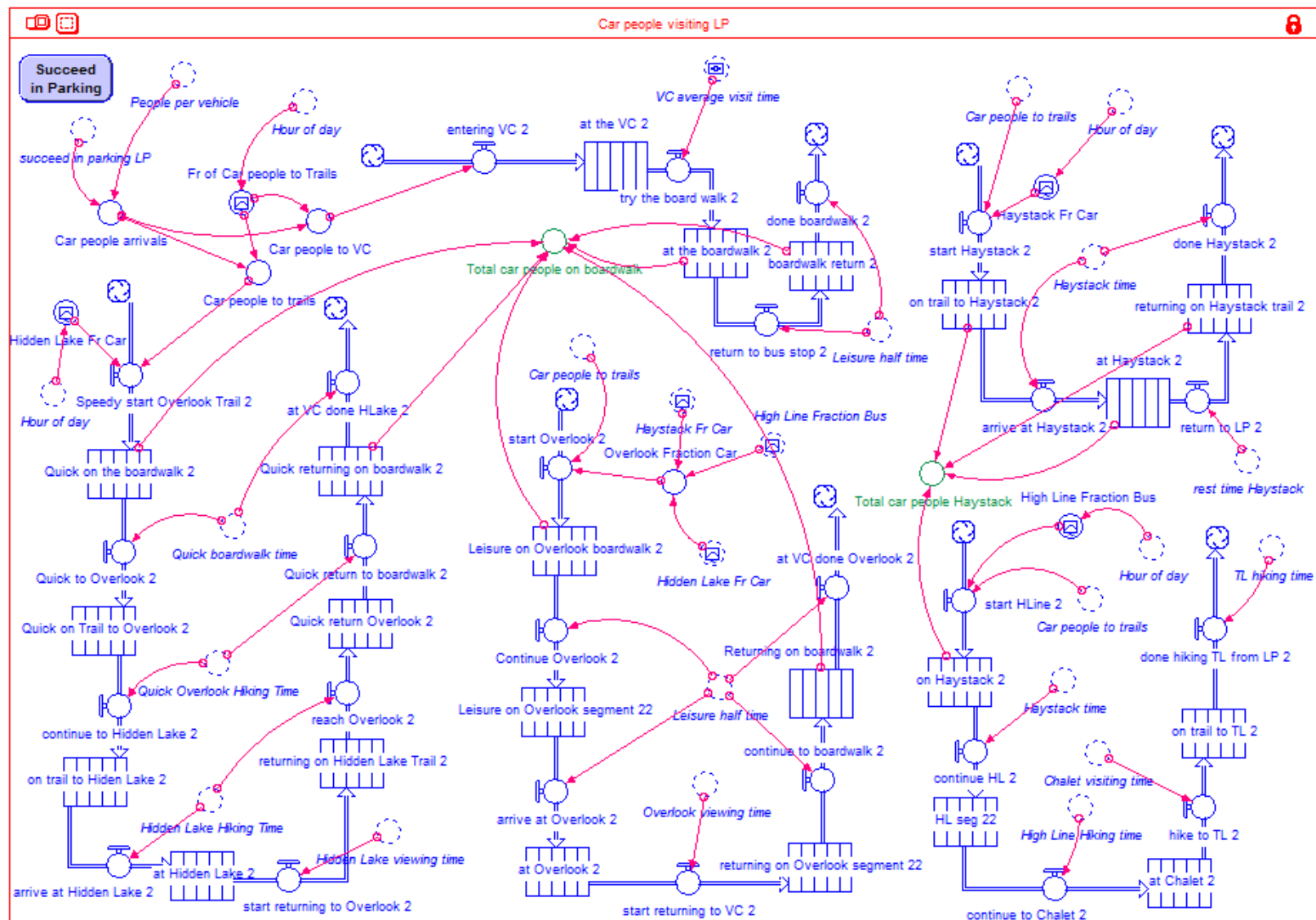


Figure 3-13: Diagram of Car People Sector visiting the Visitor Center and other trails at Logan Pass

LP visitors are assumed to visit the VC for one hour, then spend 30 minutes on the boardwalk and 30 minutes returning. For visitors hiking the Overlook, they walk leisurely on the boardwalk for 30 minutes, continue the second segment to Overlook for 30 minutes, spend another 30 minutes viewing the Overlook and return to the VC in 60 minutes. For those who aim to hike all the way to Hidden Lake, they speed up in the Overlook Trail segment so it only takes them 45 minutes (20 minutes on the boardwalk and 25 minutes on the second segment). They continue to Hidden Lake and arrive at the lake in one hour. They also spend 30 minutes viewing the lake and taking pictures, then return to Overlook in 60 minutes and take another 45 minutes to reach VC. The boardwalk has been considered a very crowded place at LP. To calculate total people on the boardwalk, both visitors staying around the VC, hikers to Overlook and Hidden Lake are counted in both directions. For hikers trying the first part of the Highline, it will take 60 minutes to get to Haystack Butte, 15 minutes to rest there and 60 minutes to go back. For those who want to hike the Highline Trail to The Loop, it will take about 4 hours to hike to the Chalet, 30 minutes to visit the Chalet and 1.5 hours to hike to The Loop. When all visitors finish their hike or visit in LP area, they catch the bus at the VC or at TL. As a result, these people feed into the Shuttle sub-model as shown in Fig 3-11.

The input for “Car People Visiting LP” is simpler and slightly different from the “Bus People Visiting LP” (Fig 3-13). Only cars able to park at LP from the Traffic sub-model are linked with this sector. To calculate the actual number of people from cars, “people per vehicle” is used. Similar to the previous sector, it is assumed that 50% of visitors hike the trails. In more detail, 15% hike the Highline, 5 – 35% hike to Haystack, 7% of the remainder hike Hidden Lake and the rest hike Overlook. The same hiking and visiting time, and the same approach is used to calculate people on the boardwalk. When all visitors finish their tour at LP, they go back to their

cars and leave LP parking lot. This is where the Trail sub-model and Traffic sub-model are connected once more as shown in Fig 3-6. For those who hike to TL (also called Highliners), they want to take the shuttle back to LP to get to their cars. Hence, the flow of car people done hiking at TL is linked with the Shuttle sub-model between TL and LP as shown in Fig 3-10, and later the exit flow of Highliners is linked back to the Traffic sub-model in Fig 3-6.

3.5 Feedback loops

There are two main feedback loops in this model: one in the Traffic sub-model and the other in the ATC sector of the Shuttle sub-model. Although the two feedback loops seem different, they are both called negative (or balancing) feedback. Figure 3-14 is a hybrid diagram which shows a simplified stock and flow diagram of the model with the two feedback loops. The negative feedback at major parking lots involves parking lot congestion. When more cars want to drive GTSR, there are more cars attempting to park at main attractions and they will cause the parking lot to fill quickly. As the parking lot gets full, more cars leave due to failure in parking. This feedback keeps the number of cars at a parking lot staying within the capacity.

The negative feedback at ATC involves crowdedness which indicates how well the shuttle serves the potential demand. The crowdedness loop starts with cars driving to ATC to park. When there are more cars coming, there are more people waiting. When the waiting line gets too long, visitors become impatient and consider leaving ATC to drive instead. As more cars leave ATC, fewer cars want to park there to try the shuttle. This feedback loop makes the waiting line stay at a manageable length.

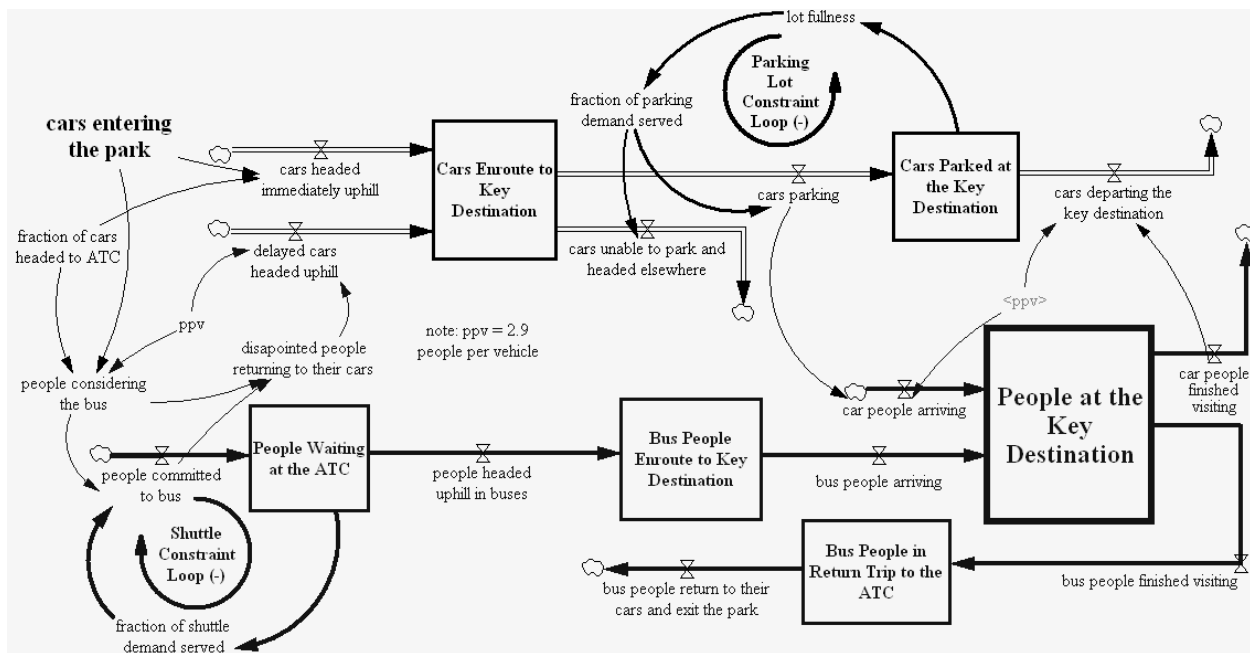


Figure 3-14: Causal loop diagram of Parking lot congestion and Transit center crowdedness

The interesting thing here is the interaction between the negative feedback loop of the road and feedback of the shuttle. Parking lot congestion causes more people to withdraw from driving the road and switch to the shuttle. However, when these people have to deal with the crowded transit center, they choose to drive instead and accept the fact that they may not be able to park at their planned destination. Regarding visitor experience, encountering congestion reduces the quality of the visit tremendously. This might lead to displacement as mentioned in Manning's book and generally reduces the annual visitation at the park. This dynamic of a bigger picture is not modeled in this study but will be of interest in future studies.

CHAPTER FOUR

BASE CASE SIMULATIONS

This chapter presents the base case simulation results which allow the comparison between “No shuttle” and “Current shuttle” scenarios to evaluate the effect of the shuttle system on parking lot congestion, road congestion, and trail use. The time horizon of the model is 12 hours from 7AM to 7PM. Annual visitors are 2 millions and only same day visitors are taken into account. Time is measured in minutes, and a single simulation runs for 720 minutes. The simulations use the Euler method of numerical integration with a time step (DT) of 0.25 minutes. This short value is required to accurately simulate the fast-acting dynamics (especially when cars encounter full parking lots that they cannot find a place to park). With a DT of 0.25, the model recalculates all variables 4 times per minute. The entire 720 minute simulation requires 2,880 calculations, an unusually large number of calculations for a system dynamics model (Ford 2009, p.44). An entire simulation requires around 30 seconds on a laptop computer. This short simulation time is important as it promotes interactive experimentation with the model.

4.1 Parking lot congestion

The status of the four parking lots of interest, including Apgar Visitor Center (AVC), Avalanche (AV), The Loop (TL) and Logan Pass (LP), stays almost the same before and after the shuttle introduction (Fig 4-1). The parking lot at AVC is full between 7:30 AM and 5PM. Avalanche parking lot is full between 8:45AM and 3PM. The Loop parking lot fills up quickly at 9AM until 3:30PM. Logan Pass parking lot is packed from 9:40AM until 3:30PM.

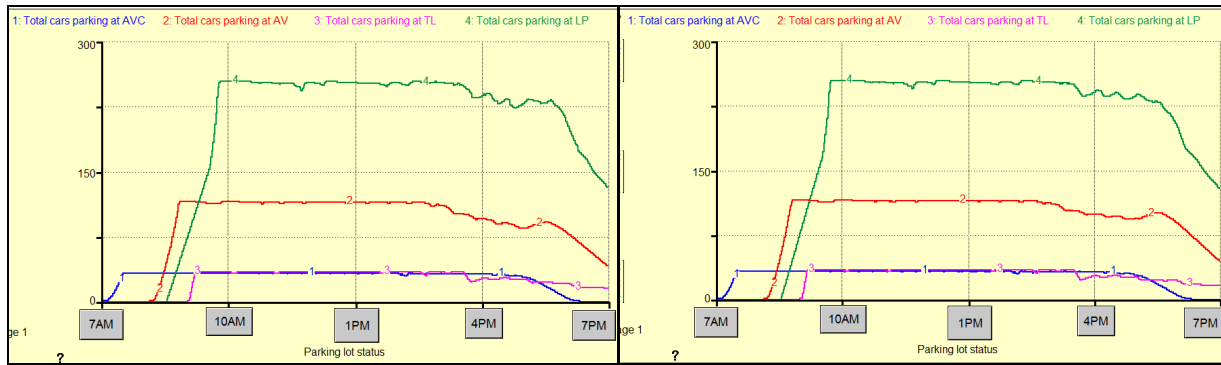


Figure 4-1: Parking lot status, Left: Current shuttle, Right: No shuttle

A closer look at LP parking lot before and after the shuttle introduction reveals that without the shuttle system there is a slightly faster fill up rate before 10AM and a higher number of cars in the parking lot after 4PM (Fig 4-2). Overall, the shuttle has little to no effect on reducing parking congestion at major parking lots. This result agrees with the observation reported by Johnson et al. (2010).

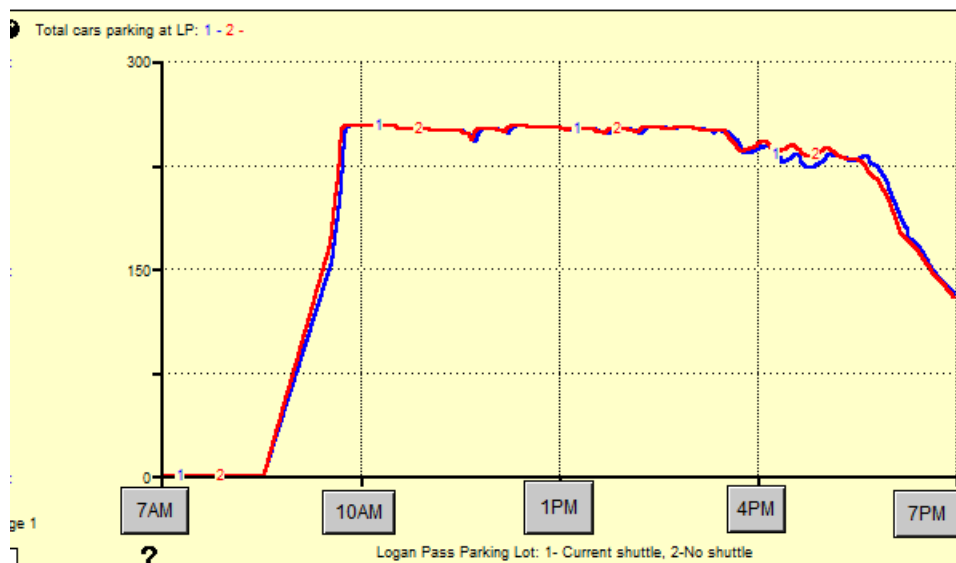


Figure 4-2: Comparison of Logan Pass parking lot before and after the shuttle

One explanation for little difference in the status of the parking lots is the number of cars which failed to park at a planned destination. Figure 4-3 shows a side by side comparison of “No shuttle” and “Current shuttle” scenarios. When the shuttle is operating, the number of cars fail to

park at AVC, AV, TL and LP are 2515, 2185, 1131 and 1727 respectively. These numbers translate into 79% of cars fail to park at AV, 87% at TL and 78% at LP. When there is no shuttle, number of cars failing to park are even higher: 2813 at AVC, 2405 at AV, 1237 at TL and 1898 at LP. The percent of cars failing to park are 80%, 88% and 79% at AV, TL and LP respectively. It is also noted that the capacity of the parking lot at AVC, AV, TL and LP is 33, 115, 34 and 254 respectively. Comparing the failed cars and the maximum capacity, it is obvious that the parking demand is so high that the current parking lots fail to serve. If the shuttle system is designed to serve 10% of total visitors then it will provide only a slight reduction in the number of cars that fail to park at their target destinations.

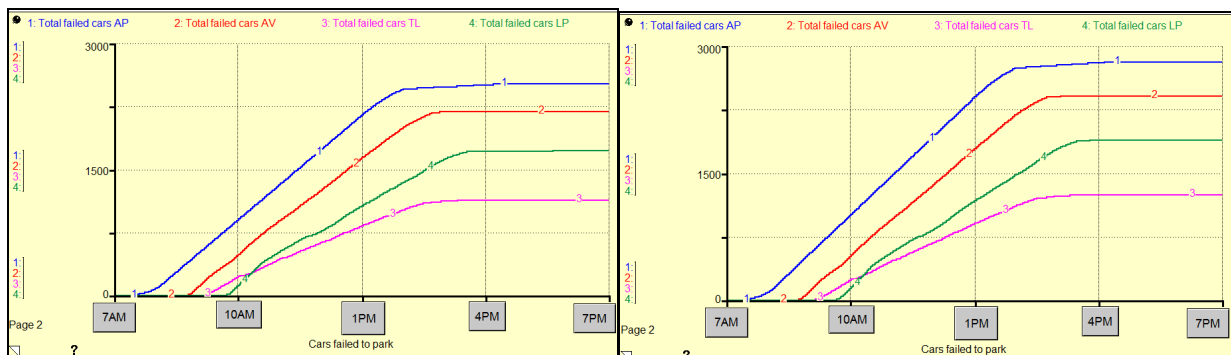


Figure 4-3: Total cars fail to park, Left: Current shuttle, Right: No shuttle

4.2 Road congestion

Road congestion has also been a big concern, especially during road rehabilitation. Figure 4-4 shows a screen capture of the road map at 10AM when all the parking lots are full (warning lamp in red) and the shuttle is operating. At this time of the day, there are 338 cars going to AV, 98 cars to TL and 240 cars to LP. This image also helps visualize how cars are likely to fail to park at these parking lots. Take the example of LP, when there are already 254 cars in the lot: the 240 cars on the way to LP will not be able to park there.

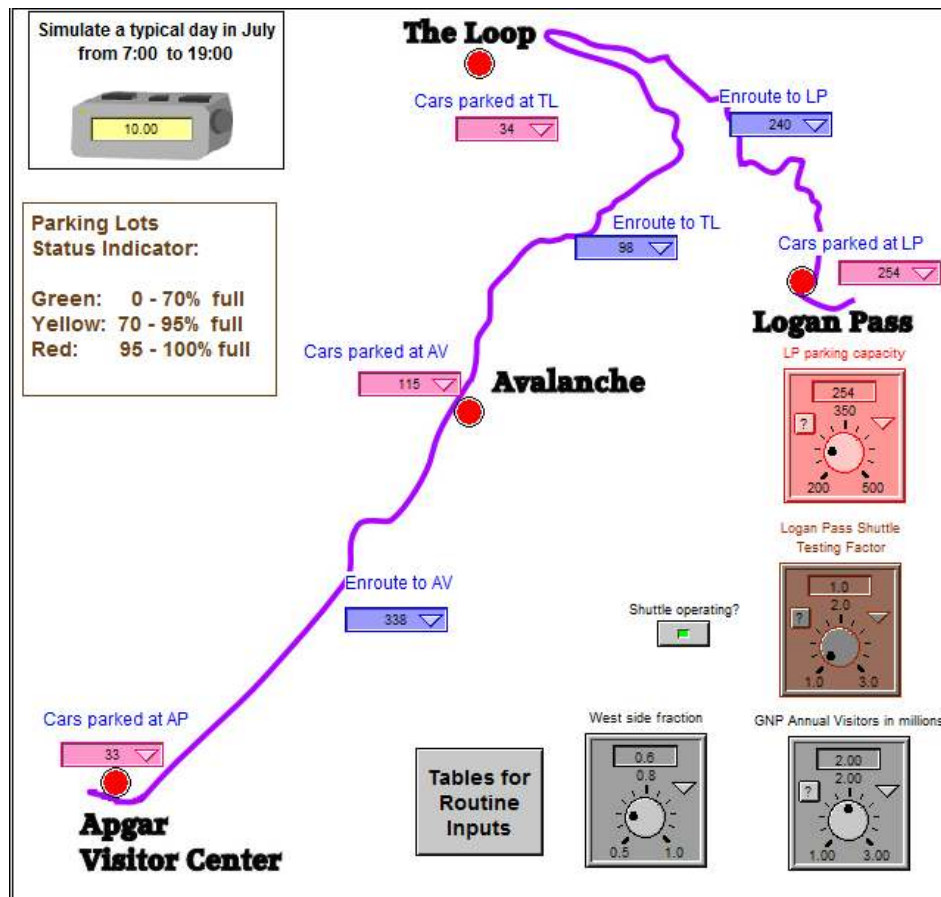


Fig 4-4: A simple map of GTSR displaying number of cars parking in each lot and traveling on the road

Graphs of cars traveling the road throughout the course of the day are shown in Figure 4-5. For both “No shuttle” and “Current shuttle” scenarios, the same pattern occurs. There is a high influx of cars going to AV around 9AM, to TL between 9 and 10AM and to LP around 10AM. There is a slight difference in the peak value between “No shuttle” and “Current shuttle”: 433 vs. 419 for AV, 137 vs. 133 for TL and 249 vs. 240 for LP. However, there is a noticeable change in the average value of the day: 360 vs. 330 for AV, 190 vs. 100 for TL and 175 vs. 160 for LP. These numbers suggest that the shuttle does help alleviate the amount of cars traveling the road during the day. However, during busy hours from 9 – 10AM, the effect is minimal.

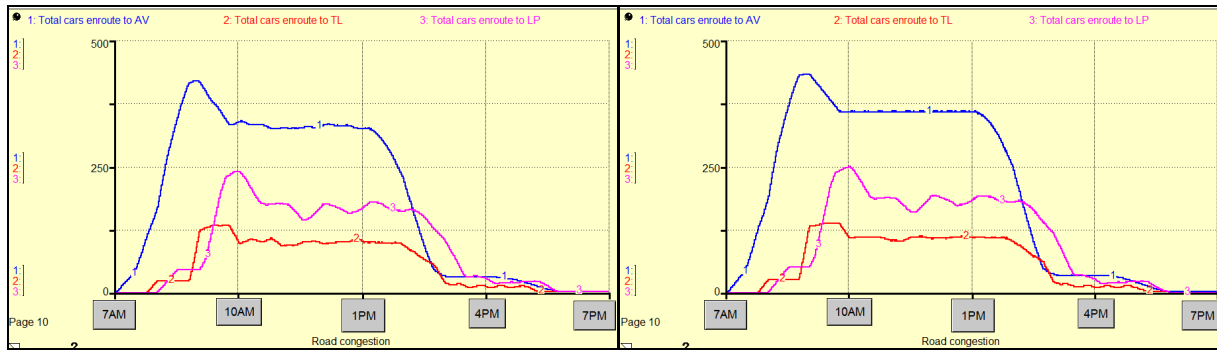


Fig 4-5: Total cars going to Avalanche, The Loop and Logan Pass, Left: Current shuttle, Right: No shuttle

4.3 Trail use

The shuttle brings visitors to the trails at AV, TL and LP. Since the main focus of this model is the LP area connecting with TL, impact of the shuttle system is mainly evaluated for LP and TL trails. Figure 4-6 shows the number of total visitors and the peak number of visitors at a certain time of the day at the Visitor Center and five other trails. The simulation results show that when the shuttle is in operation there is a 22% increase in the total visitation at the VC, 20% increase on the boardwalk, 18% increase on Overlook and Hidden Lake, 19% increase on TL, and 20% increase on Highline Trail. Comparing the peak number of visitors, TL has the highest increase of 60 visitors, Overlook, the boardwalk and Highline have an increase of 30, 28 and 23 visitors respectively. Other locations have a slight increase.

When comparing number of car visitors in the Logan Pass area before and after the shuttle, results show that there is a slight decrease after the shuttle (2383 vs. 2440). The difference in number of people translates into about 20 cars less in the LP parking lot. Although Figure 4-2 shows that the parking lot congestion looks similar before and after the shuttle, a close look reveals that the lot is full 4 minutes later in the “Current shuttle” scenario compared to “No shuttle”. During that time, the arrival rate at the West entrance is 9 cars per minute.

Knowing that 80% of cars entering the west drive the corridor, the potential number of car along GTSR is 29 ($4 \times 9 \times 0.8$). It is possible that 20 out of 29 cars drive to LP. Although the shuttle does not reduce a lot of car people at LP, this is still an interesting insight from the model.

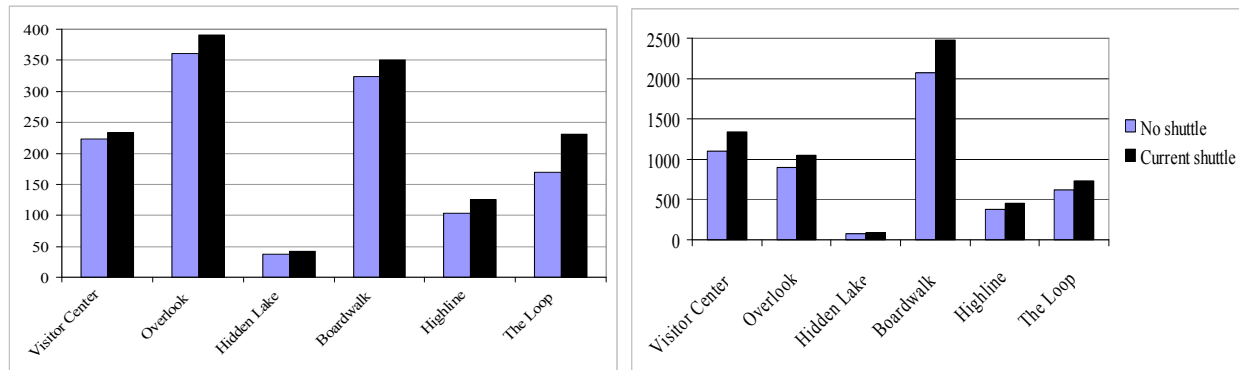


Figure 4-6: Comparison of No shuttle and Current shuttle scenarios, Left: Peak visitor, Right: Total visitor

4.4 Visitor distribution on Logan Pass trails

Detailed comparative graphs of visitors on each trail are shown in Fig 4-7. These graphs reveal the general pattern that the increase in the number of hikers occurs mostly between 10AM and 4PM. The effect might occur somewhat sooner or later than 10AM depending on the distance between these trails and the VC. From the result of parking lot congestion, because the TL and LP parking lots are full between 9AM/9:40AM and 3:30PM, this is the best time interval for the shuttle to deliver more people to trails.

On the boardwalk, the shuttle starts bringing a small group of people between 8AM and 8:30AM. Between 8:30 and 9:40 AM, more and more car people are coming so the effect of the shuttle is minimal. After 9:40 AM when the LP parking lot is packed, the shuttle shows more impacts on the boardwalk until the end of the day.

On the Overlook trail, the first few bus people show up starting from 8:30 AM. Between

9AM and 10:10AM, there is no difference in the number of people on this trail between “No shuttle” and “Current shuttle” scenarios. After 10:10 AM, the shuttle brings 18% more visitors to this trail. The Hidden Lake trail is farther than the Overlook trail so the first group of bus people does not show up until 8:45AM. The shuttle shows more impact on this trail between 10:30AM and 5:30 PM.

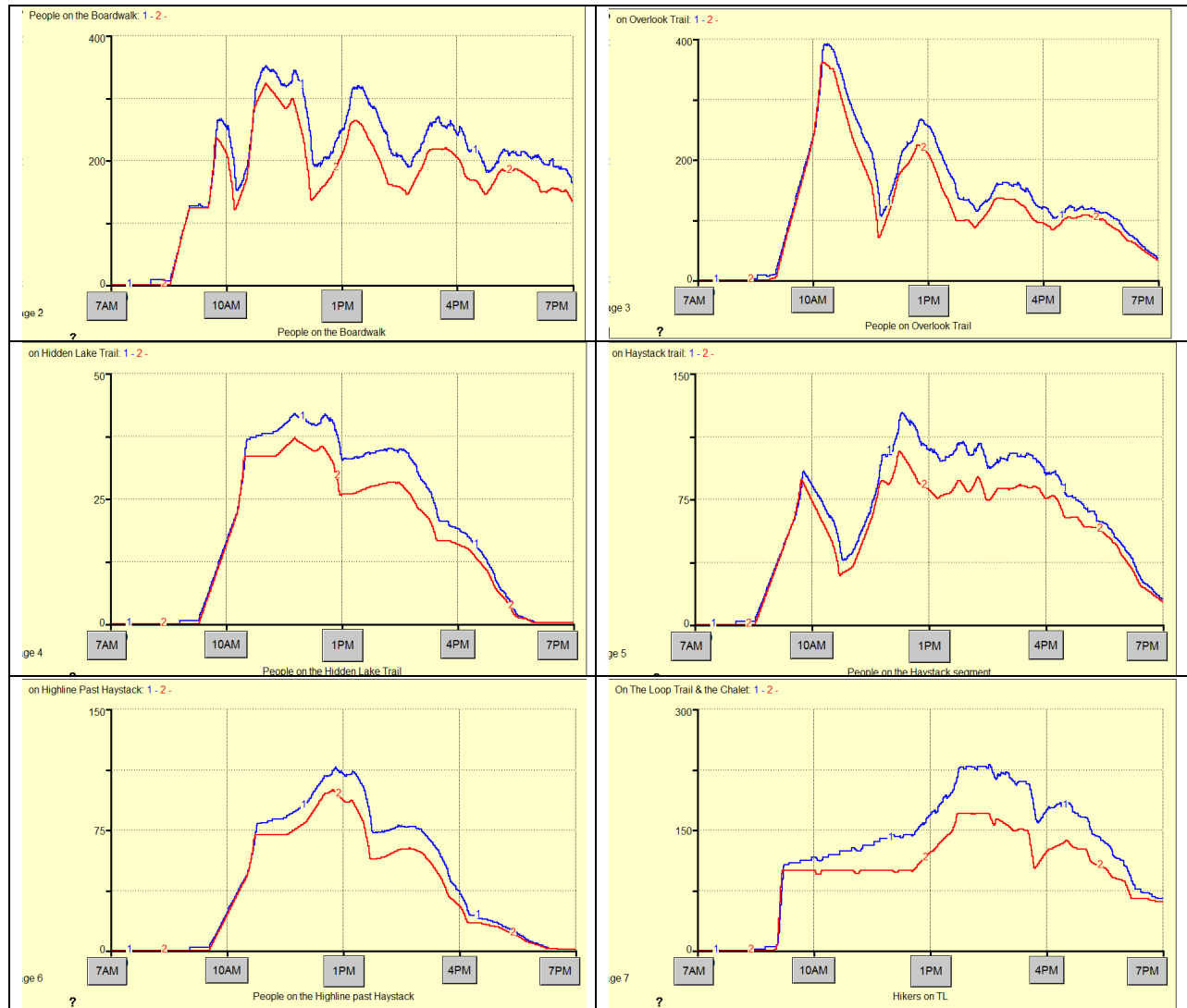


Figure 4-7: Comparative graphs of people on trails, Blue- Current shuttle, Red- No shuttle

On the Highline trail, especially the first segment to Haystack, some early bus people arrive between 8AM and 8:30AM. Between 8:30AM and 9:45AM, car people dominate the trail.

More bus people come after 9:45AM until the end of the day. For the segment of Highline past Haystack, the first bus people group does not show up until 9AM. Car people arrive at this segment between 9:30AM and 10:45AM. The shuttle keeps bringing more hikers to this segment from 10:45AM to 5:30PM.

Of all the trails, TL experiences the most instant increase from the shuttle. This is because not only visitors can get off the bus at TL to take a short hike but also car people make use of the shuttle to fulfill their one way hike. The first group of bus people arrives at TL at 8:30AM and more bus people are coming after 9:10AM till the end of the day.

Figure 4-7 also reveals that the visitor numbers on trails have two different patterns. The first pattern is similar to bell-shaped which is observed on remote trails such as Hidden Lake, TL and Highline segment past Haystack. Hikers of peak hour arrivals accumulate on these trails due to long hiking time and when they leave, new arrivals do not create a similar peak. The second pattern shows more arrival and departure surges on trails closer to the VC such as the boardwalk, Overlook and Haystack segment of Highline. These trails serve as the transition zone to the remote trails so when hikers move to more remote trails or return to the VC, the number on trails drops significantly. In addition, since hiking time to these trails is short, the peaks can be formed quickly.

4.5 West side shuttle ridership

Decreased road congestion and increased trail use correlate with the capacity of the shuttle to deliver visitors to their planned destinations. With an annual visitation of 2 millions and 30% of them visiting the park in July, the daily visitors in July are about 19,355. Since 60% of visitors enter the park using the West entrance, and about 80% travel GTSR, total visitors traveling the road daily are 9,290. The shuttle was planned to serve 10% of visitors so the total

potential riders are 929. Figure 4-8 shows the potential demand, served and unserved demand. There are 715 visitors able to use the shuttle to facilitate their visits which accounts for 77% of total demand. These visitors might have multiple destinations in a day so they might get on and get off the shuttle several times. Detailed results at each location show that at the end of the day there are 366 visits to AV, 93 visits to TL and 316 visits to LP. Knowing that 301 visitors only visit AV, 414 remaining visitors might visit TL only, LP only, AV and TL or AV and LP. In order for a visitor to make a round trip to AV, he/she has to catch the shuttle from ATC to AV and another shuttle to get back to ATC. To make a round trip to TL/LP, he/she has to catch a shuttle from ATC to AV then transfer to a smaller shuttle from AV to TL/LP meaning that he/she has to get on the shuttle 4 times for a round trip. Assuming that 414 riders only visit TL or LP, the total daily ridership is roughly 2,258.



Figure 4-8: Potential riders, served and unserved demand of the shuttle system

CHAPTER FIVE

SENSITIVITY ANALYSIS AND POLICY TESTING

Many assumptions have been used during the construction of the model. In order to test the robustness of the model and reveal useful insights for policy making, this chapter is dedicated to sensitivity analysis. Tests will be conducted for annual visitation, visiting time at the Visitor Center, LP parking capacity and attractiveness of Highline Trail after the shuttle introduction. The main policy to be tested is whether or not the shuttle should be continued. This will be done by simulating the increase in trail use due to the shuttle. Scenarios of doubling or tripling the number of people delivered to LP by the shuttle are also simulated to compare with the base case.

5.1 Annual visitation

The number of visitors has a great impact on parking lot congestion and road use. These impacts translate into other effects such as trail congestion, trail widening, vegetation trampling and wildlife disturbance. Statistics shows that since 1969 annual visitation has exceeded 1 million and there were nine years when the number exceeded 2 million (NPS stats, 2011). In this test, annual visitation varies from 1.5 million to 3 million and there is no shuttle. Changes are observed at AV parking lot, LP parking lot, Overlook Trail, Highline Trail and the Visitor Center.

Avalanche parking lot becomes full faster as visitations rise. When the visitation increases from 1.5 million to 3 million, congestion time shifts from 9AM to 17 minutes earlier. The parking lot stays full longer as there are more visitors. When there are 1.5 million people, AV parking lot is no longer full after 2:30PM (blue curve in Fig 5-1), but it is still full until

5:20PM when the visitors are doubled (green curve in Figure 5-1).

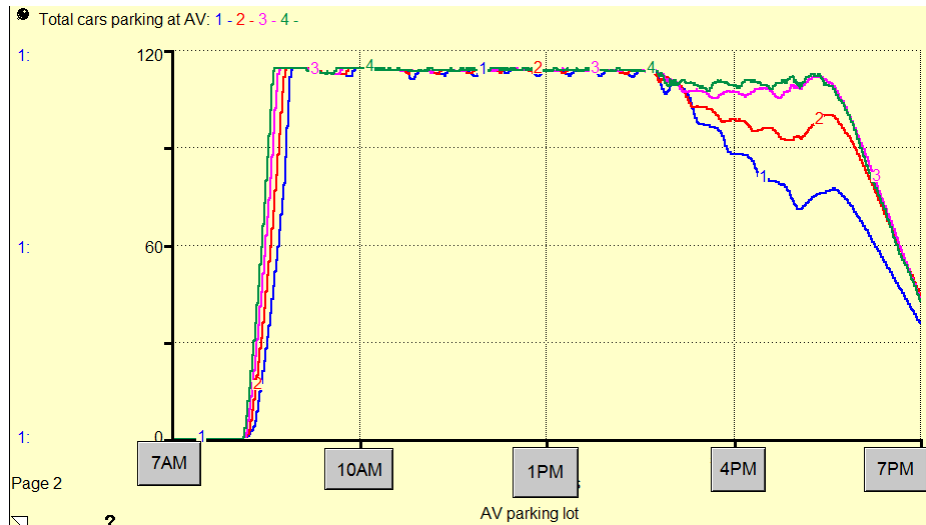


Figure 5-1: Cars parking at Avalanche corresponding to 1.5, 2, 2.5 and 3 million visitors

Blue: 1.5 million, Red: 2 million, Magenta: 2.5 million, Green: 3 million

Figure 5-2 is a comparative graph of total cars parking at LP. When there are 1.5 million visitors, the parking lot is full at 10AM but when there are twice as many visitors, the parking lot is full 30 minutes earlier. Between 4PM and 5 PM, number of cars in the case of higher visitation stays higher. However, between 5PM and 6:30PM, there's a faster drop for the case of higher visitation. From 6:30 to 7PM, there's not much difference between different scenarios.

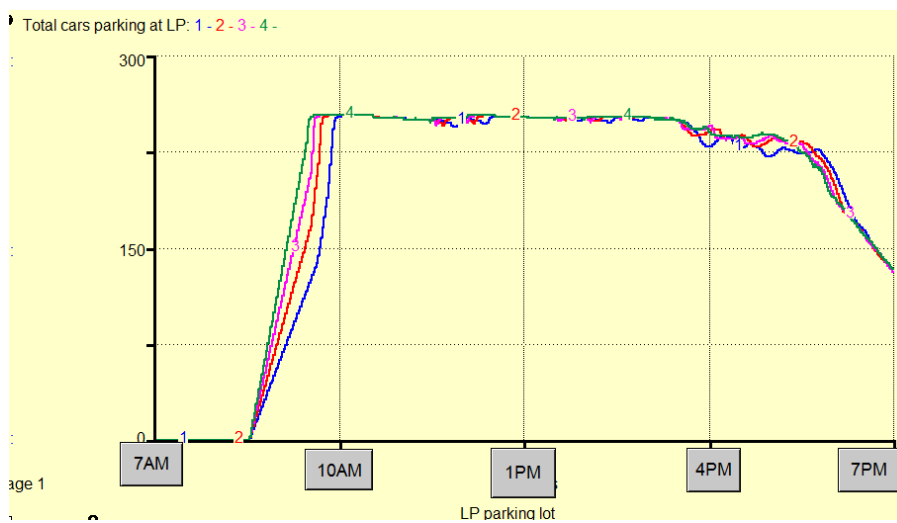


Figure 5-2: Cars parking at Logan Pass corresponding to 1.5, 2, 2.5 and 3 million visitors

Blue: 1.5 million, Red: 2 million, Magenta: 2.5 million, Green: 3 million

From the status of AV and LP parking lots, it can be inferred that multiple destination visitors will not be able to fulfill their wish when there are “too many” visitors. If they can park at lower elevation lots, when they finish touring the place, they will not be able to park at higher elevation lots. In contrast, if they can’t park at lower elevation lots, they will be able to park at higher elevation lots earlier and finish their trips early. This is why a faster drop in number of cars is observed at LP between 5PM and 6:30PM. In both situations, they have to make their trips short. Since the parking lot fills up quickly when there is higher visitation, visitors will tend to arrive even earlier in the day to avoid congestion.

Figure 5-3 shows the total daily visitors on Overlook Trail, Highline Trail and at the Visitor Center when the visitation changes from 1.5 million to 3 million. There is no major difference among different scenarios. Since there is no shuttle in these scenarios, the ability to park determines whether these visitors can do their planned activities or not. From the analysis of LP parking lot, people tend to arrive earlier and leave sooner as the visitation increases. As a result, the increase in trail use is extremely small.

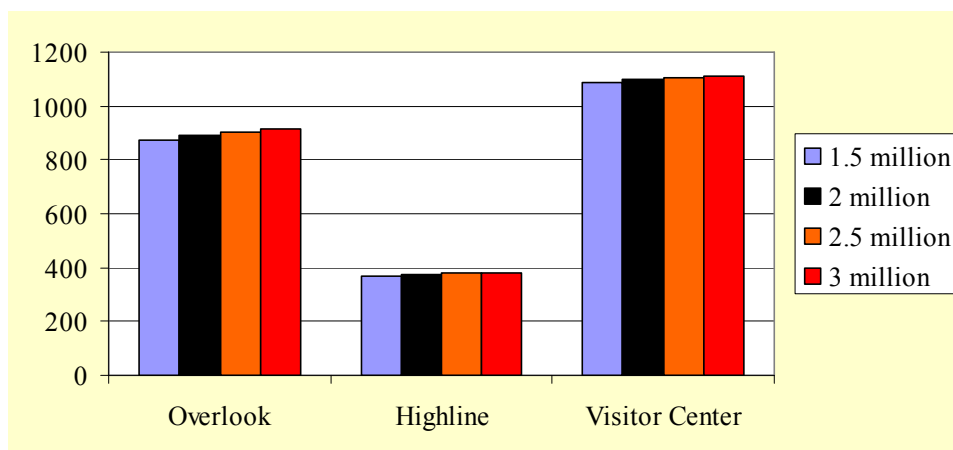


Figure 5-3: Total daily visitor on trails and at the Visitor Center in four annual visitation scenarios

In this test, total visitors on Overlook, Highline or at the Visitor Center behave similarly when the annual visitation fluctuates. To avoid repetition, only a comparative graph of Overlook Trail is shown in Fig 5-4. Overlook hikers of the “3 million scenario” arrive at the trail 25 minutes earlier and leave the trail 20 minutes sooner than hikers of “1.5 million scenario”. At the end of the simulation, the “3 million scenario” only brings 40 more hikers to Overlook Trail compared to the “1.5 million scenario”.

Figure 5-4: Total hikers on Overlook Trail corresponding to 1.5, 2, 2.5 and 3 million visitors

5.2 Visiting time at the Visitor Center

Comparative graphs are created for three scenarios in which VC visiting times change from 30 minutes to 60 minutes and 90 minutes. When the visiting time is shorter, there will be more cars entering and leaving LP parking lot. Between 10AM and 4PM, this effect is hard to see due to the existing fullness of the lot. Generally after 4PM, there are more cars in the parking lot when the visiting time is longer. There is a noticeable dip after 5PM in Fig 5-5 when the visiting time is 90 minutes but in the scenario of 60 minutes, no similar dip is observed. This is because longer visiting times mean viewer people return to their cars during the day and there are fewer vacancies to allow newly arriving cars to park at Logan Pass.

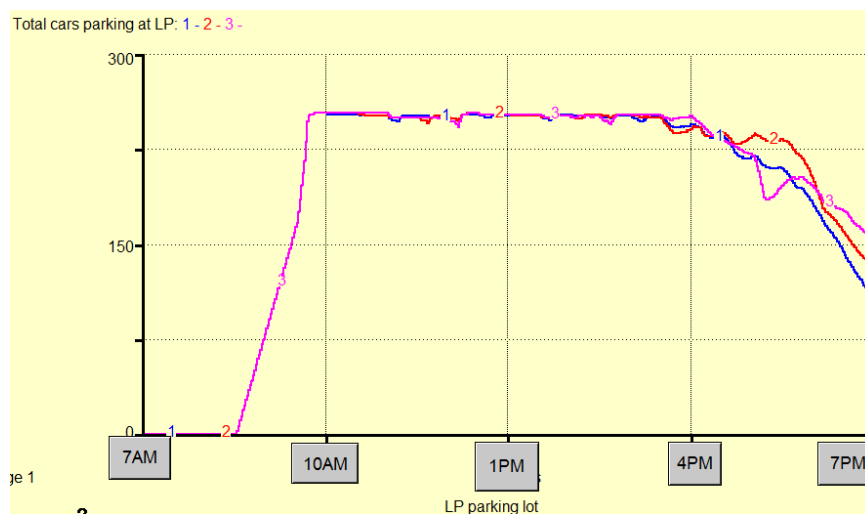


Figure 5-5: Total cars parking at Logan Pass corresponding to 30 minute, 60 minute and 90 minute visiting time at the Visitor Center. Blue: 30 minutes, Red: 60 minutes, Magenta: 90 minutes

There is an obvious increase in the total number of visitors at the Visitor Center when the visiting time is shortened. Without running the model, one would guess that cutting the visiting time by half would double the number of visitors. However, Figure 5-6 shows a smaller increase. There are 1,168 visitors, 1,097 visitors and 1,011 visitors corresponding to 30 minute, 60 minute and 90 minute visiting times. There are certain times in a day when the total visitors of the three

scenarios look the same: by 10AM, noon and 3PM (Fig 5-6). The reason is because with a short visiting time, there's a constant flow of people entering and leaving the VC and for a longer visiting time, people entering and leaving might be in a pulse pattern. The pulse pattern has a higher peak compared to a constant flow which translates to a larger number of available parking spaces at one time and these spaces can quickly be filled early in the day. Toward the end of the day, there are fewer people coming so a longer visiting time means fewer people to visit the site. The formulation of different groups in the Traffic sub-model affects the arrival pattern and the dynamic at the VC. However, the main limiting factor here is not the space within the VC but the LP parking lot. LP parking lot is already full so reducing the time does not make a big difference. If the limiting factor is the space inside the VC then reducing the visiting time in half would double the amount of people there.

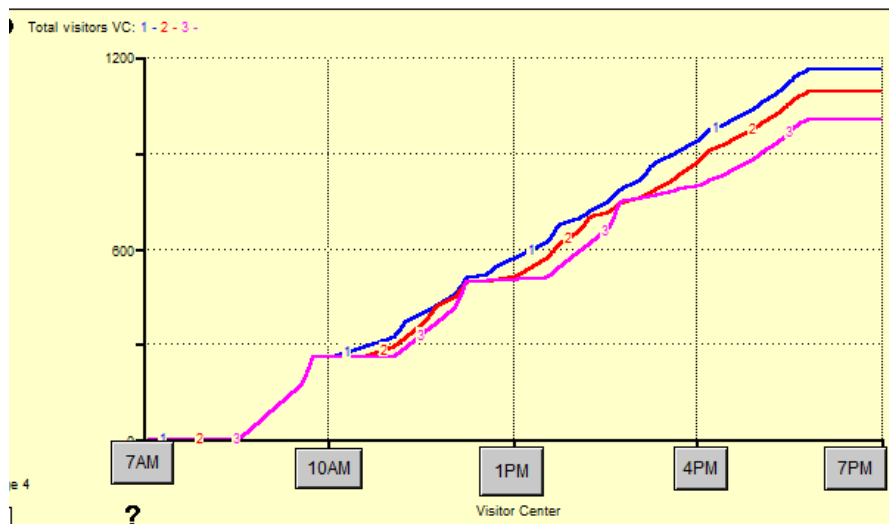


Figure 5-6: Total daily visitors at the Visitor Center corresponding to 30 minute, 60 minute and 90 minute visiting time. Blue: 30 minutes, Red: 60 minutes, Magenta: 90 minutes

A shorter visiting time at VC accumulates not only more people at the VC but also more people on nearby trails. Figure 5-7 summarizes the main results at Overlook and Highline Trails for three scenarios. The Overlook Trail has a higher increase rate than Highline Trail. This is

because average hiking time on Overlook is shorter than that of the Highline, visitors can arrive and leave the parking lot easier. Overall, the results of Figure 5-7 imply that when the visiting/hiking time of any location/trail surrounding LP is shorter, there will be more visitors to all locations/trails. One explanation for this is because these visitors share the same parking lot. When one group can leave earlier, other groups can fill the empty spots in the parking lot and start their tours.

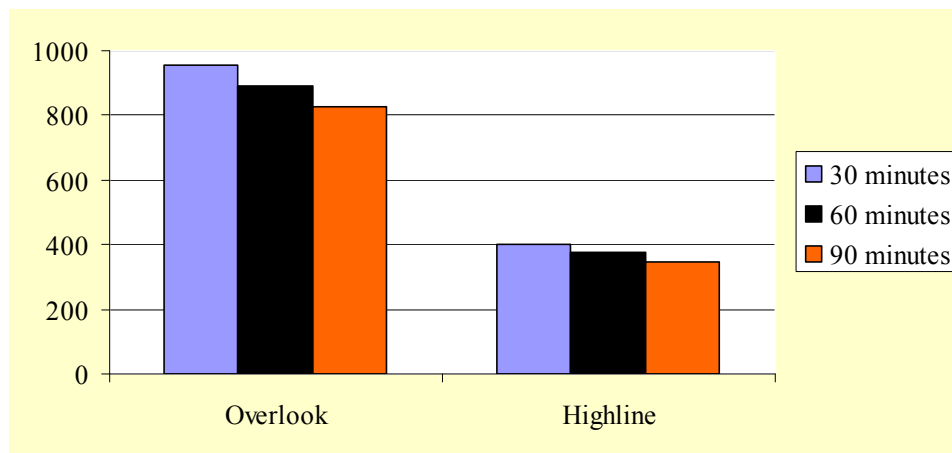


Figure 5-7: Total daily visitor on Overlook Trail and Highline Trail in three visiting time scenarios

Although the visiting time is mainly decided by visitors, management activities can also affect visitors' decisions. Enlarging the VC, adding more interpretive signs, adding more guided tours, more viewing space and more rest area/chairs will make the VC more attractive and make visitors stay longer. Since the parking space is limited, longer visitors' stay at the VC would limit the parking space for hikers to other trails. Overall, the number of car hikers will be reduced. A similar implication might also apply for AVC. It is assumed that most visitors stop at AVC for about 20 minutes to ask for information or buy souvenirs. If AVC is larger and has more activities to attract visitors, they will stay longer and reach the LP area later in the day.

5.3 Logan Pass parking capacity

This test simulates a hypothetical scenario to see how the model reacts. The goal is to increase understanding, not a test of actual policy proposal. It is well known that changing the parking lot in reality is not feasible due to limited capital, difficult topography and the effort to protect natural resources. In this test, there are 2 million visitors, 60% entering from the West side, visiting time at the VC is 60 minutes and there is no shuttle. Three scenarios are simulated: keeping the current capacity, reducing the current capacity in half or doubling the current capacity.

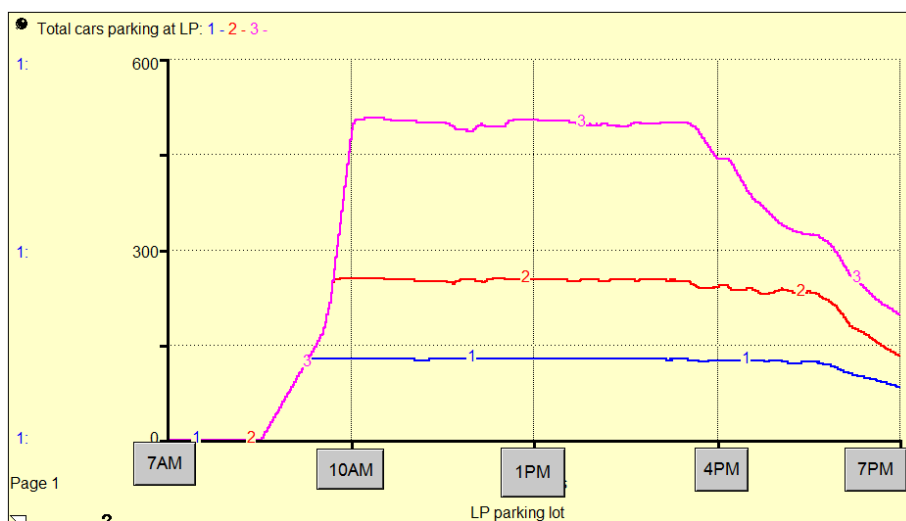


Figure 5-8: Total cars parking at Logan Pass parking lot corresponding to 127, 254 and 508 parking spots. Blue: 127, Red: 254, Magenta: 508

Figure 5-8 shows LP parking lot status under these three scenarios. Generally, when the parking lot is smaller, it becomes full faster and stays full longer. The parking lot is full for almost 8.5 hours when the capacity is 127. This busy time reduces to approximate 6 hours with the current capacity and to 5.5 hours with the doubled capacity. In addition, there is less oscillation in the number of cars when the capacity is smaller. The reason is that when the parking lot is smaller, there are fewer available spaces which will then be filled quickly. For the

case of a larger parking lot, the empty space created by a departing car is not immediately filled by an arriving car so the oscillation is more discernable.

It is easily inferred that the more capacity the parking lot, the more visitors on trails and at the VC. However, the increase in the number of hikers or visitors is not directly proportional to the increase in parking lot capacity. Figure 5-9 indicates that Highline has the highest increase of the three locations. Hikers on Highline increase 90% when the parking space doubles from 127 to 254. When the parking space changes from 254 to 508, the increase is 81%. Overlook number of visitors increase 89% and 79% when the parking capacity increases from 127 to 254 and 254 to 508 respectively. However, at the VC, the increase is 85% and 70% respectively. It is noted that in the scenario of high parking capacity, most people are done visiting before 4PM. Around 4PM, visitors tend to stay around the VC than to try the trails. The fast drop in number of visitors affects the number of visitation in the VC more significantly than on trails.

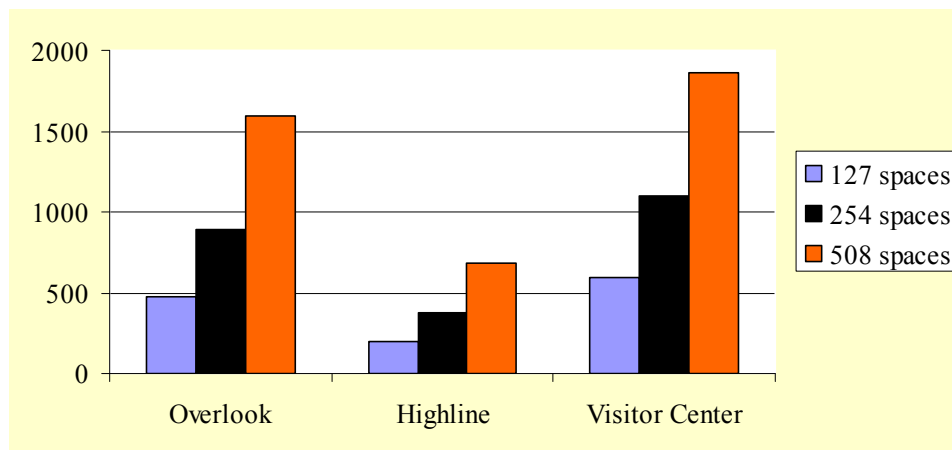


Figure 5-9: Total daily visitor at the Visitor Center and on trails in three parking capacity scenarios

5.4 Attractiveness of Highline Trail

Chapter four presents the results of hikers on trails before and after shuttle introduction. Johnson et al. (2010) discussed that the shuttle system makes the Highline Trail more attractive

because most hikers can do a one way hike by driving to one of the trailheads and using the shuttle to go back to their cars. In this model, the Highline fraction includes the Haystack fraction and Highline fraction to TL. For the base case, this total fraction is set at 20% until 10AM and is fluctuated between 35% and 20% toward the end of the day. To take the observation of Johnson et al. into consideration, three scenarios are simulated in which:

- The total fraction of car people to Highline before the shuttle reduces 10% compared to after the shuttle
- The Haystack fraction is the same but the fraction to TL after the shuttle for both car and bus people reduces to 10% and 5%

Given that the shuttle brings more hikers to Highline Trail, the number of hikers only increases dramatically when the overall attractiveness of the Highline increases. Figure 5-10 shows that changing the HL fraction to TL alone does not account for major increase on HL trail.

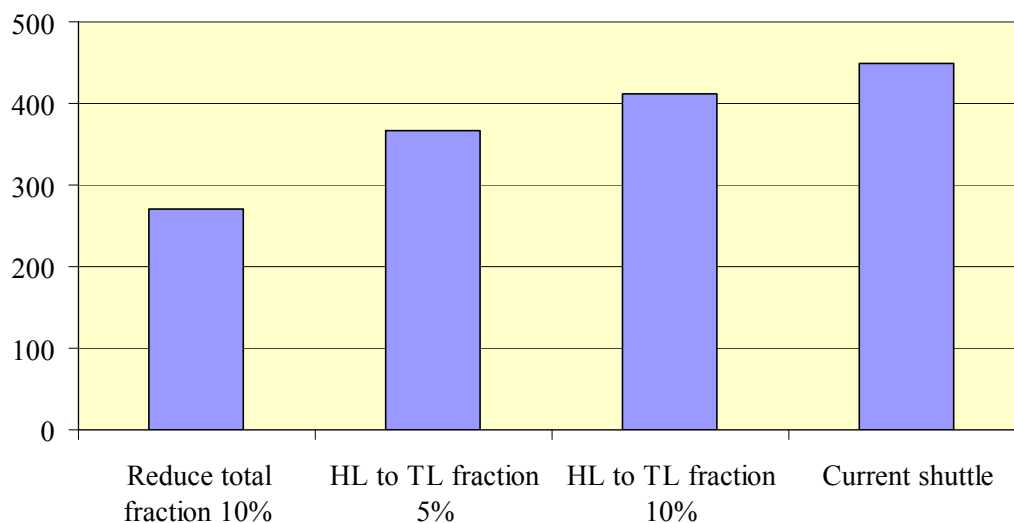


Figure 5-10: Hikers to Highline Trail in three scenarios compared with “Current shuttle” scenario

5.5 Effect of the shuttle on Logan Pass trails

The initial idea of having the shuttle is to reduce traffic congestion during road habilitation. The shuttle system has been shown to reduce road congestion and it puts more people on trails. Whether the shuttle should be continued or expanded after the rehabilitation project is one of the main concerns. In this test, a multiplier is applied to the total number of riders delivered at LP. Two scenarios of doubling and tripling the shuttle system are compared with the “Current shuttle” and “No shuttle” scenarios.

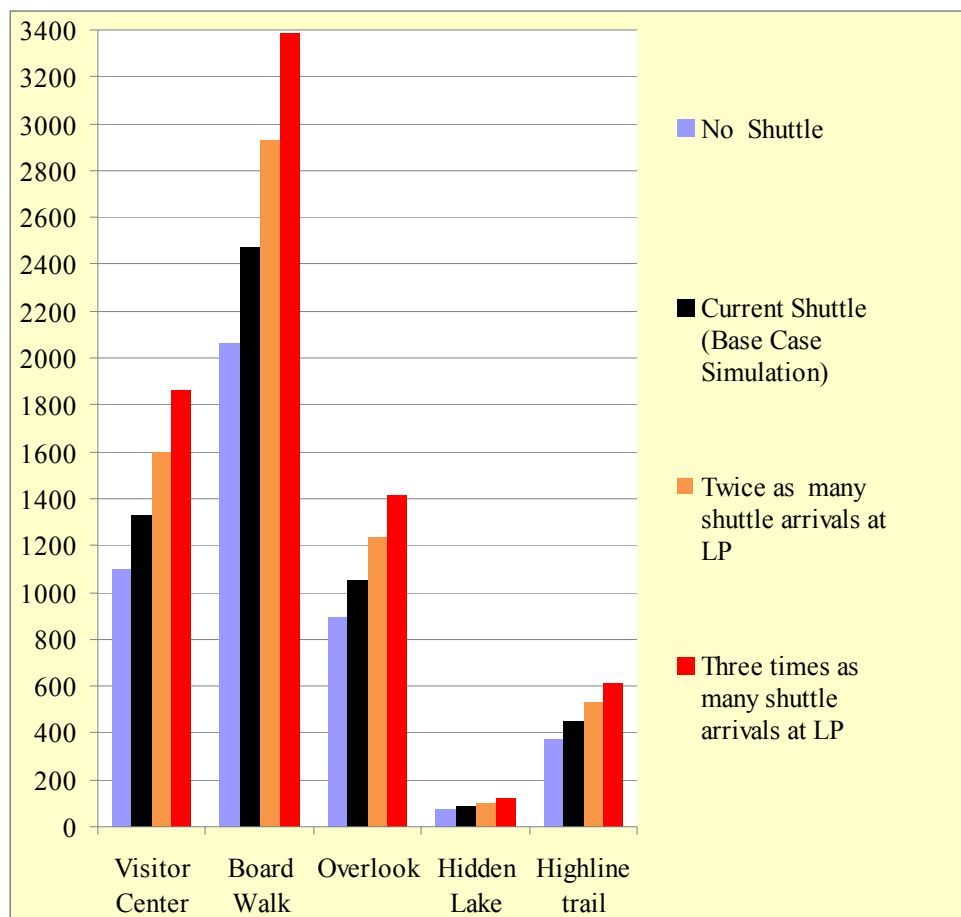


Figure 5-11: Total daily visitors at the Visitor Center and on trails in different shuttle scenarios

Figure 5-11 shows the total daily visitors at each location and Table 5-1 gives the percent increase compared with “No shuttle” scenario. From this test, it seems that the effect of the

shuttle on trails is not as dramatic as the effect of expanding the parking lot. However, whether the shuttle should be continued or expanded depends on levels of acceptable change defined by the park. The behavior of visitors on trails may be more of a concern than the sheer number of total visitors or peak number of visitors at one time. Given that, results on peak number of visitors at each location are also shown here for comparison (Figure 5-12).

Table 5-1: Percent increase in total daily visitors of three shuttle scenarios compared with “No shuttle”

	Current shuttle	Doubled shuttle	Tripled shuttle
Visitor Center	22%	46%	70%
Boardwalk	20%	42%	64%
Overlook	18%	38%	59%
Hidden Lake	18%	38%	59%
Highline	20%	42%	65%

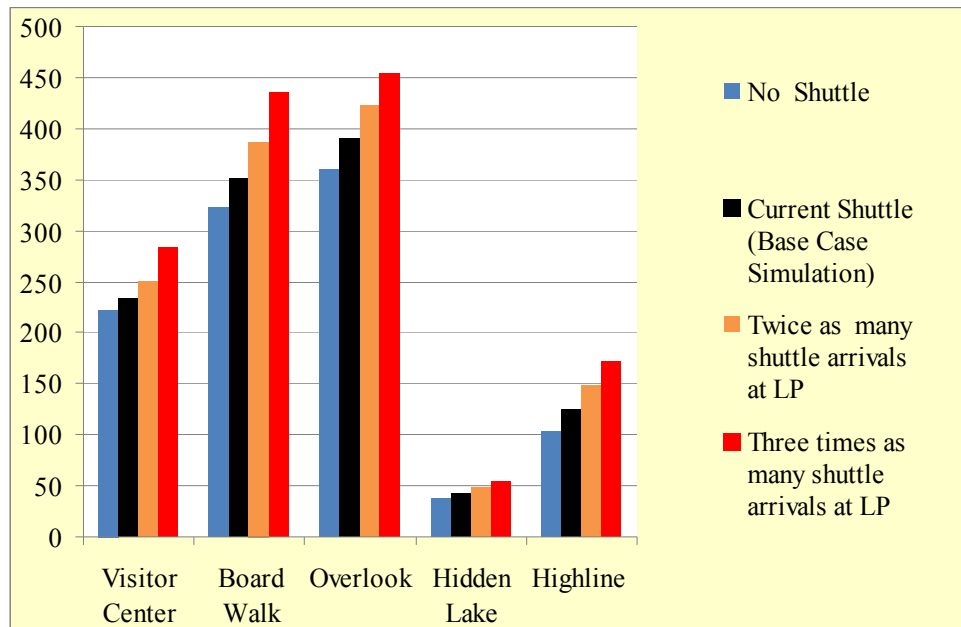


Figure 5-12: Peak number of visitors at one time at each location of three shuttle scenarios.

CHAPTER SIX

FURTHER WORK, DISCUSSION AND CONCLUSION

6.1 Further work

This model was developed in an iterative process of model formulation, testing, feedback from GNP staff, new formulations, new tests, and more feedback from staff. The model is sufficiently developed and tested to illustrate the usefulness of the system dynamics method in a national park. As with all good models, there is room for improvement, especially if the model is to be used for policy testing. For example, further work could include the east side traffic, east side shuttle, and a reservation system.

The model in this dissertation was built initially for the west side traffic so the east side traffic was assumed to have the same pattern at LP. This simple assumption might ignore important dynamics on the east side. To improve the usefulness of the model, a detailed description of the traffic from the east side including several major parking lots would help understand how both east and west side traffic contributes to parking lot congestion and trail use around the LP area. In addition, adding the east side traffic will describe where visitors (currently denoted “elsewhere”) go when they cannot visit their first or second choice destinations. The east side shuttle in this model is a simple delivery of people at LP after a certain interval. The effect of the shuttle would be fully evaluated if more buses were added to follow a schedule and activities of shuttle riders at major bus stops were characterized.

Another addition to the shuttle system is the reservation system. During the first meeting with the park staff, the reservation system was mentioned as one way to reduce the unserved demand. Taking the reservation system into account would help better assess the role of the

shuttle.

As stated earlier in chapter two and three, the longer-term dynamic of the park system are of interest to Washington State University researchers. This model could be designed to fit within a larger system of models to represent the displacement effect of visitors over a longer time interval. As for now, the model uses the exogenous variable of annual visitors. Including longer-term effects can make this variable endogenous. A larger model system could reveal what kind of management policy can accommodate or restrict more people to the site. The idea is to emphasize that carrying capacity is related to visitor experience and management actions as discussed by Manning (2007).

6.2 Discussion

Another avenue for future research is to compare the simulation findings with the behavior of visitors to GNP described in reports by the University of Montana. It is important to distinguish the difference in methodology used to recognize the contribution of each research. The research by the University of Montana was done by surveying shuttle riders, non-shuttle riders and hikers. Most of these hikers (85%) use the Highline Trail, some of them use Hidden Lake (3%) and the remaining use trails to the east side of LP. Of the 415 hikers they surveyed, 60% were at TL, 25% at the Chalet and 10% at LP. Their conclusion was that 83% of hikers use the shuttle (Johnson et al., 2010). In this model, in addition to Highline, TL and Hidden Lake, Overlook Trail and the Visitor Center, where most visitors go to, are also described. Another major difference is that the survey data is subject to fluctuation in annual visitation. The model in this research is more of a hypothetical model where users can input their data or compare shuttle and non-shuttle scenarios with the same annual visitation. The model should be treated as a tool to explore the connections of different aspects and test users' intuition or policies.

From the sensitivity tests of chapter five, it can be concluded that car people have more impacts than shuttle people. It appears that making a good management policy comes down to the core question of whether the park wants to serve more visitors or to allow current limitations (i.e. parking) to control the use of certain trails. Although the main intention of this research is to help better manage the park, the model does not aim to give a concrete answer for such value-laden questions. Instead, the modeling analysis provides information on the nature of the tradeoffs. This is a common practice with System Dynamics modeling. Although it is possible to combine System Dynamics with value oriented evaluations, this is seldom done and is not done here. However, formal methods to deal with ethical questions can be combined with system dynamics model, as was demonstrated in a simulation/evaluation of socioeconomic impacts in energy boom towns in the west (Gardiner and Ford, 1980).

Other insights from the sensitivity tests include the effect of the shuttle on road congestion and the effect of long visiting times on the total number of visitors. One effect of the shuttle is to reduce numbers of cars driving the road. So if road repair or maintenance is difficult especially in high elevations, then maintaining the shuttle is necessary. The test of visiting time suggests that increasing visiting time, for example at the VC, by enlarging the facility, adding more viewing decks, more interpretive signs and guided tours is an indirect way to limit hikers on the trails. Since the number of parking spaces at LP is constant, increasing attractiveness at one destination would change the fraction of visitors to other destinations.

6.3 Conclusion

The model built for the case of Glacier National Park in Montana has shed light on parking lot use, trail use and the role of the shuttle system. Parking lot congestion suggests that the number of cars unable to park highly exceeds the current capacity of the simulated parking lots.

As the shuttle is planned to remove 10% of visitors from the road, the simulation suggests that 8 out of 10 potential users are served. Road congestion has improved after the shuttle introduction, but parking lot congestion is not changed. The focus of the study is trail impacts at Logan Pass. The study shows that the current shuttle would increase hikers by 18 to 22%. These are the main conclusions from the illustrative model. More importantly, the case study has demonstrated the usefulness of System Dynamics to aid in visitor management at a national park. Future plans at GNP call for additional modeling to support the development of the General Management Plan.

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APPENDIX

MODELING PROCESS AND COMPLEXITY

The model in this research, although is built strictly for illustrative purposes, has a high level of complexity both in the modeling process and modeling techniques. Previous chapters have described model parameters and how the model is structured for a general audience. This section gives more technical information for modelers. This appendix includes two main parts. The first part will discuss the modeling process and techniques. The second part will list key inputs with their values for Traffic, Shuttle and Trail sub-models.

The modeling approach using in this dissertation is interactive and iterative. In the first online meeting, modelers introduced the SDM method and a hypothetical bus model to the park staff. The hypothetical model included a system of 8 buses operating between the entrance and the mountain top. The buses left the entrance center every 15 minutes and their capacity was 30 seats each. The hypothetical model also illustrated unserved demand by showing how people arriving at the transit center decided to wait for buses or drive their cars. Performance curve of the shuttle system was also introduced and compared with a 12 bus system. Examples of policy test involved changing the bus capacity to increase served demand. After the first meeting, the park staff arranged several meetings at the park so that modelers could explain the purpose of this research and acquire more information from the transit team, interpretive and volunteer manager, revenue and finance managers and wilderness specialists.

Back from the visit, a new complex model was built for the specific case of the park. The synthesis model at that time had a traffic map in the interface with the main focus on the trails around the LP using exported inputs from the Traffic and Shuttle sub-models. The Traffic sub-model was structured with 5 groups, the Shuttle sub-model had 10 buses: 2 Express, 4 Morning only and 4 Optima. Visitors at LP were designed to make one of the 3 trips: the VC, a hike to the

Overlook and then to Hidden Lake, and a hike to the Highline. Feedbacks from the park staff suggested that there should be one more group in the Traffic sub-model who stops at every parking lot in the model. The Shuttle sub-model should have 15 buses instead of 10 with the inclusion of buses departing empty from the ATC and start servicing at AV. Tours at the LP areas should be more descriptive. The changes include: adding the boardwalk to the VC tour, separating the Overlook hikers from Hidden Lake hikers and including the Chalet to the Highline hike.

The second improvement of the model integrated all the suggestions, added a trail map to show number of visitors at each location and mechanically connect the three sub-models together. The park staff reacted that the increase in Highline trail seemed much less significant than a typical day in July. They suggested adding the Haystack segment to the Highline and changing the Highline fraction throughout the day as they still saw visitors watching sunset in the Haystack segment. As a result, the last improvement of the model was for the Trail sub-model and trail fractions.

Regarding model structure, the complexity comes from many factors. The first one is connecting the three sub-models. These are separate models which can run on their own. So when they are connected together, careful check of how each sub-model feeds input to the other was very time-consuming. For example, how car people decide to ride the shuttle then leave the transit due to crowding and join the road; how car people arrive at LP, take the tours and go back to their cars; how bus people arrive at LP, take the tour and catch the bus back down; and how some car people hike to TL then take the bus to return to their cars. The most difficult part is to split car people catching the bus from TL to LP from other bus riders to make sure they return to their cars accurately.

The second complexity involves the use of arrays. In the Traffic sub-model, arrays are used to keep track of visitor groups. In the Shuttle sub-model, arrays are used to keep track of buses. When connecting these two sub-models, it is very hard to keep track of both types of arrays when visitors are using the bus. This means that when visitors get line and catch the bus, all groups mingle together (they lose their groups) but when the bus reaches a stop, people know where to get off (they are still in their groups). To simplify the problem, it is assumed that bus people lose their groups and they decide where to get off depending on time of a day. For examples, when it is early, more people want to visit LP and TL but when it gets late more people stay around AV.

The third complexity comes from the Shuttle sub-model where bus sectors and people sectors are connected. The bus sectors keep track of buses to make sure they follow their routes and schedules. The people sectors describe how people get line, get on, get off a bus and when they finish their tours, they know how to connect to the returning buses. As riders depend on bus schedules, co-flows are used to synchronize the two types of sectors.

The fourth complexity involves checking the total. For example, when the shuttle delivers X number of visitors, the increase in visitors on all trails and the VC should also be X. Another important check is how shuttle riders dispersing all over the corridor either manage to catch the bus back or stay to the proximity trails/VC of the bus stop at the end of the simulation time. This accounting task requires a lot of graphs to compare and in some sub-models the accounting sectors occupy half of the sub-model. As the model gets more complicated with more variables, more checking is necessary to make sure the model is accurate which requires more investment of time.

The fifth complexity concerns of the ambitious visual display in the interface. Two

simple maps of the GTSR and LP trails are included to help visualize the road status, parking lot status and visitor distribution. This effort tries to mimic the animated features of ABM counterparts. Although the levels of detail are not as high as ABM, the visual display gives an interactive feeling for model users and helps them visualize the big picture better.

TABLE A-1: MAIN PARAMETERS OF THE TRAFFIC SUB-MODEL

Variable	Value	Note
<i>Converters</i>		
Fr wishing to use the shuttle	0.1 for LP only, AV-LP, AV-TL, AV only and all destination group. 0 for AP only group	
Shuttle operating?	0 or 1	0: no shuttle, 1: shuttle
Fr wishing to park at AP	0 for LP only, 1 for other groups	
Failure fraction to AV	0 for AP only, 1 for other groups	
Fr go to AV	0 for AP only, 1 for other groups	
AVC parking time	20	
Travel time to AV by car	45	
Fr wishing to park at AV	0 for LP only and AP only, 1 for others	
Failure fraction to TL	0 for AP only and AV only, 1 for others	
Fr go to TL	0 for AP only and AV only, 1 for others	
AV parking time	0 for LP only and AP only, 120 for AV-LP, 150 for AV only and AV-TL, 60 for all destinations	
Travel time to TL	15	
Fr wishing to park at TL	1 for AV-TL and all destination groups, 0 for others	
Failure fraction to LP	1 for LP only, AV-LP and all destinations groups, 0 for others	
Fr go to LP	1 for LP only, AV-LP and all destinations groups, 0 for others	
TL parking time	210 for AV-TL, 60 for all destinations, 0 for others	
Travel time to LP by car	30	
Fr wishing to park at	1 for LP only, AV-LP and all destinations, 0 for others	
West side fraction	0.6	
People per vehicle	2.9	NPS stats, 2011
GNP annual visitors in million	2	
July fraction	0.3	NPS and FHA, 2003
Days in July	31	
Group arrival fraction	5% LP only, 30% AV-LP, 10% AV only, 10% AV-TL, 20% AP only and 25% all destinations	
Hourly arrival G1	7 – 9AM	LP only
Hourly arrival G2	8AM – 2PM	AV-LP

Variable	Value	Note
Hourly arrival G3	8AM – 5PM	AV only
Hourly arrival G4	8AM – 2PM	AV-TL
Hourly arrival G5	8AM – 6PM	AP only
Hourly arrival G6	8AM – 2PM	All destinations
AP parking capacity	33	App C, GTSR Transportation & Visitor Use Study, WIS, 2001.
AV parking capacity	115	
TL parking capacity	34	
LP parking capacity	254	

Other key parameters include failure fraction leave AVC, AV, TL and LP. These fractions depend on the fullness fraction of each parking lot and are described by a non-linear relationship. For simplicity, these fractions are assumed to describe the same behavior so only one figure is shown. When a parking lot is 90% full, 5% of cars leave that parking lot. 10% leave the parking lot when it is 95% full and all cars leave the parking lot when it is completely full.

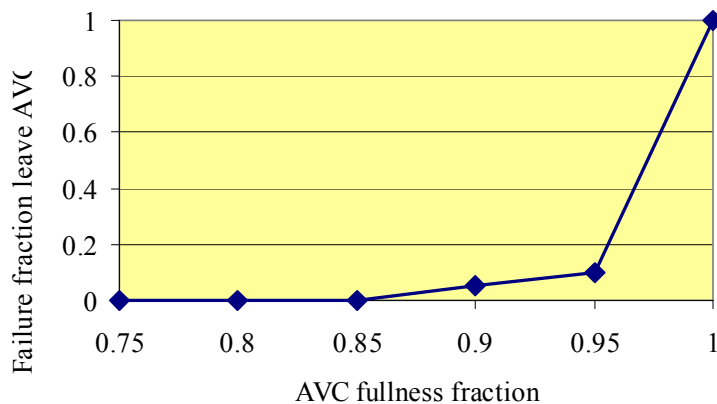


Figure A-1: Failure fraction leave Apgar Visitor Center correlates with Avalanche parking lot fullness

TABLE A-2: MAIN PARAMETERS OF THE SHUTTLE SUB-MODEL

Variable	(Initial) Value	Note
<i>Stocks</i>		
Buses in the pool	1 for each array	All 15 buses are in the pool at the beginning of the simulation
<i>Converters</i>		
Start time [WS Express 1]	1	
Start time [WS Express 2]	15	
Start time [LP morning only 1]	20	
Start time [LP morning only 2]	38	
Start time [LP morning only 3]	56	
Start time [LP morning only 4]	74	
Start time [LP morning only 5]	92	
Start time [LP morning only 6]	110	
Start time [Optima 1]	120	
Start time [Optima 2]	150	
Start time [Optima 3]	180	
Start time [ATC-AV1,2,3,4]	1000	These buses don't start service at ATC, start time is set longer than 720 minutes
Empty start time [WS Express 1, 2]; [LP morning only 1,2,3,4,5,6]; [Optima 1,2,3]	1000	Set high values so these buses do not start service empty at ATC
Empty start time [ATC-AV1]	130	
Empty start time [ATC-AV2]	147	
Empty start time [ATC-AV3]	164	
Empty start time [ATC-AV4]	181	
Return time [WS Express 1]	560	
Return time [WS Express 2]	574	
Return time [LP morning only 1]	658	
Return time [LP morning only 2]	676	
Return time [LP morning only 3]	694	
Return time [LP morning only 4]	712	
Return time [LP morning only 5]	730	Set higher than the time frame so the last bus can still service
Return time [LP morning only 6]	748	
Return time [ATC-AV1]	675	
Return time [ATC-AV2]	692	
Return time [ATC-AV3]	709	
Return time [ATC-AV4]	726	
Return time [Optima 1]	680	
Return time [Optima 2]	710	
Return time [Optima 3]	740	Set higher than the time frame so the last bus can still service

Variable	(Initial) Value	Note
Layover time at ATC	2 minutes	
Fr Express	1 for WS Express 1 and 2, 0 for other buses	
Express time to AV	30 minutes	Empty bus travel fast from ATC to AV
Travel time to AV	45 minutes	Regular travel time between ATC and AV
Layover time at TL uphill	2 minutes	
Layover time at TL downhill	2 minutes	
Fraction return to ATC night	1	For all buses
Travel time to TL from AV	15 minutes	
Fraction return to ATC day	0 for LP morning only and 1 for others	
Express time to LP	90 minutes	From ATC
Travel time to LP	30 minutes	
Layover time at LP	2 minutes	
Thinking time	5 minutes	For visitors at ATC to consider if they want to wait for the bus or drive their cars instead
Bus capacity [WS Express 1]	15 seats	
Bus capacity [WS Express 2]	15 seats	
Bus capacity [LP morning only 1]	12 seats	
Bus capacity [LP morning only 2]	12 seats	
Bus capacity [LP morning only 3]	12 seats	
Bus capacity [LP morning only 4]	12 seats	
Bus capacity [LP morning only 5]	15 seats	
Bus capacity [LP morning only 6]	15 seats	
Bus capacity [ATC-AV1]	15 seats	
Bus capacity [ATC-AV2]	15 seats	
Bus capacity [ATC-AV3]	15 seats	
Bus capacity [ATC-AV4]	15 seats	
Bus capacity [Optima 1]	44 seats	
Bus capacity [Optima 2]	44 seats	
Bus capacity [Optima 3]	44 seats	
AV touring time	90 minutes	
Chalet roundtrip touring time	210 minutes	
West side bus fraction return	0.58	

Fraction return to the cars at ATC depends on number of people waiting at ATC. When there are 30 people waiting, 10% of new comers return to their cars. All people return to their car if the waiting line has 60 people (Figure A-2)

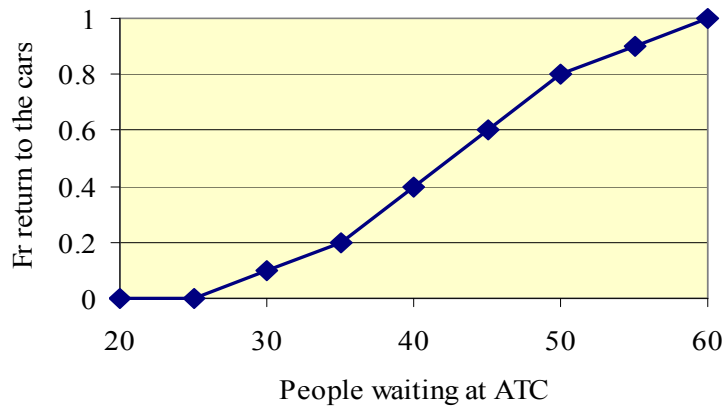


Figure A-2: Fraction return to the cars as a function of People waiting at Apgar Transit Center

Fraction touring AV depends on hour of a day. From 8AM to 12PM, about 20% of shuttle riders tour AV. This fraction increases quickly between noon and 1PM. Between 1PM and 6PM, all shuttle riders visit AV (Figure A-3)

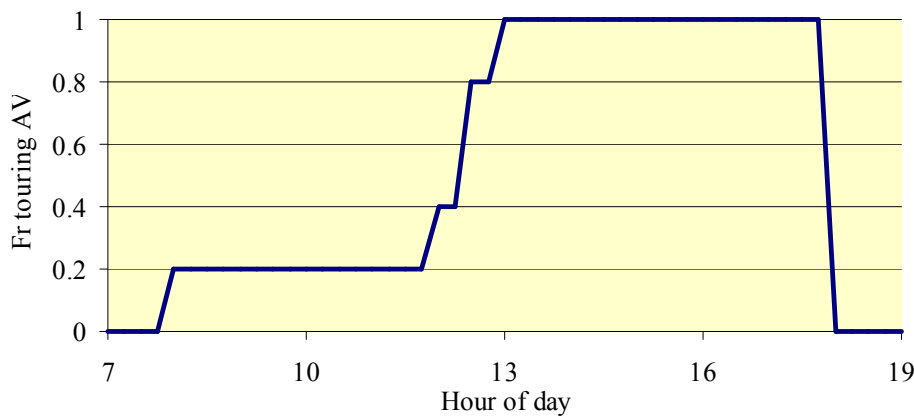


Figure A-3: Fraction touring Avalanche as a function of Hour of day

Fraction of AV people going uphill depicts fraction of shuttle riders who want to catch a bus to go to TL or LP after touring AV. This fraction also depends on hour of a day. All riders go

uphill in the morning until noon. This fraction decreases sharply from noon to 1 PM. Between 2:30PM and 4PM, only 10% go uphill and no one goes uphill after 4PM.

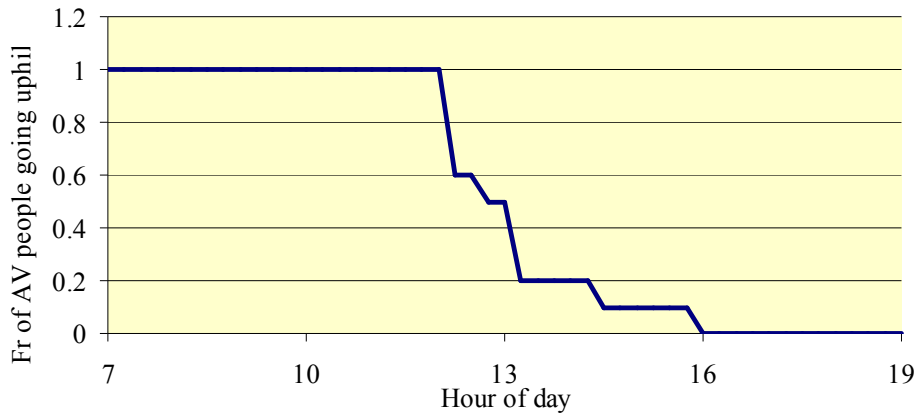


Figure A-4: Fraction of Avalanche people going uphill as a function of Hour of day

Fraction touring TL describes the fraction of uphill people from AV who want to visit TL. This fraction is set at 30% from the morning to 4PM. After 4PM, this fraction falls to zero.

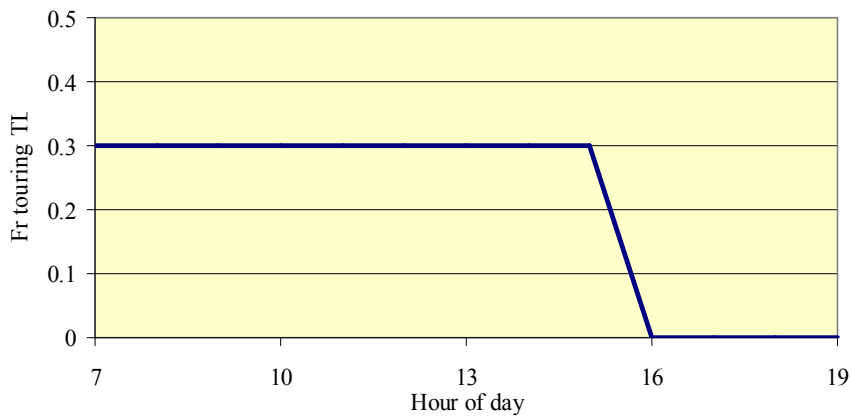


Figure A-5: Fraction touring The Loop as a function of Hour of day

TABLE A-3: MAIN PARAMETERS OF THE TRAIL SUB-MODEL

Variable	Value	Note
<i>Converters</i>		
Quick boardwalk time	20 minutes	Applies for Hidden Lake hikers
Quick Overlook hiking time	25 minutes	Applies for Hidden Lake hikers
Hidden Lake hiking time	60 minutes	
Hidden Lake viewing time	30 minutes	
Leisure half time	30 minutes	Applies for hikers on the boardwalk and the segment to the Overlook
Overlook viewing time	30 minutes	
VC average visit time	60 minutes	
Haystack time	60 minutes	Hiking time from LP to Haystack
Rest time Haystack	15 minutes	
Highline hiking time	180 minutes	
Chalet visiting time	30 minutes	
TL hiking time	90 minutes	

Fraction of bus people to trail depends on hour of a day. About 65% of bus people visit the trails from early morning until 10AM. This fraction drops gradually over the course of the day. Starting from 6PM bus people do not hike any trails because they have to stay close to the bus stops to catch the last bus.

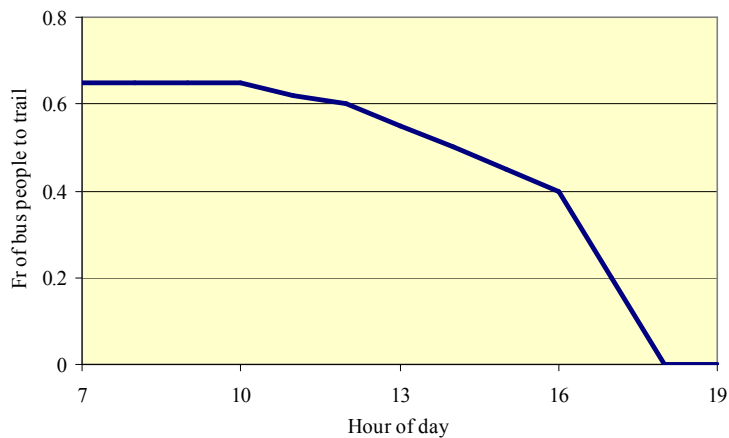


Figure A-6: Fraction of bus people to trail as a function of Hour of day

Hidden Lake fraction bus is the fraction of bus people hiking Hidden Lake. This fraction stays constant at 7% from the morning until 2PM. After 2PM, no bus people want to try this trail because of long hiking time.

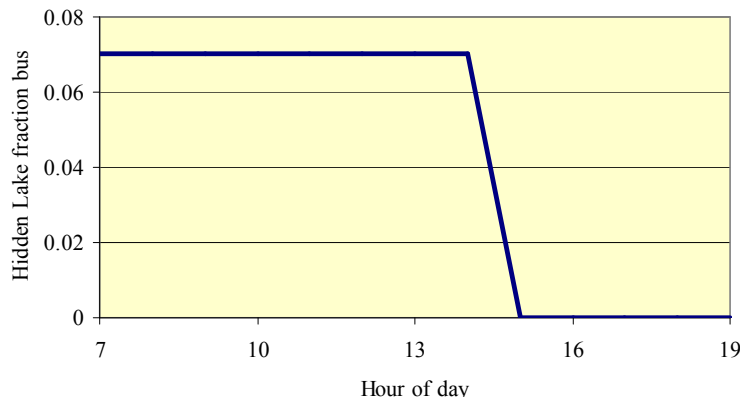


Figure A-7: Hidden Lake fraction bus dependent on time of the day

Haystack fraction bus is the fraction of bus people hiking the Highline Trail and turn around at Haystack Butte. This fraction stays at 5% in the morning until 10AM. The fraction increases starting from 11AM and reaches a peak of 35% at 3PM. Toward the end of the day, this fraction drops and no bus people visit this trail segment after 6PM.

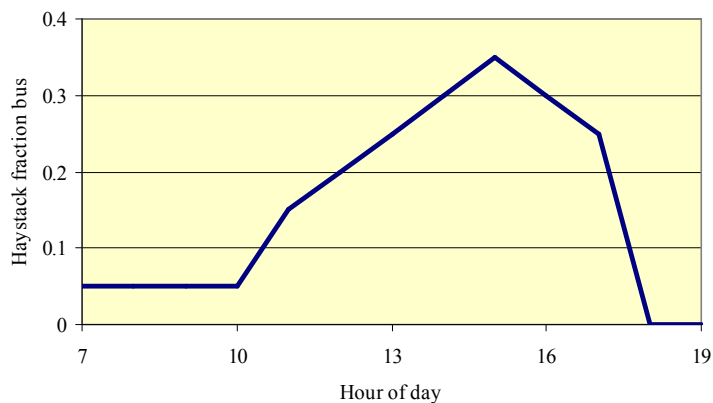


Figure A-8: Haystack fraction bus dependent on time of the day

Highline fraction bus is the fraction of bus people hiking the Highline Trail all the way to TL. This fraction stays constant at 15% until noon and drops to 5% at 2PM. After 3PM, bus people do not want to try this strenuous trail.

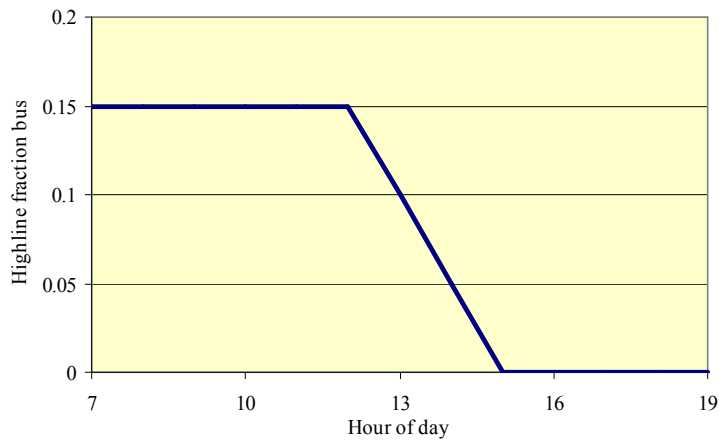


Figure A-9: Highline fraction bus dependent on time of the day

Fraction of car people to trail is time dependent and similar to the fraction of bus people to trail. About 65% of car people visit the trails from early morning until 10AM. This fraction drops gradually over the course of the day and all car people finish hiking at 7PM.

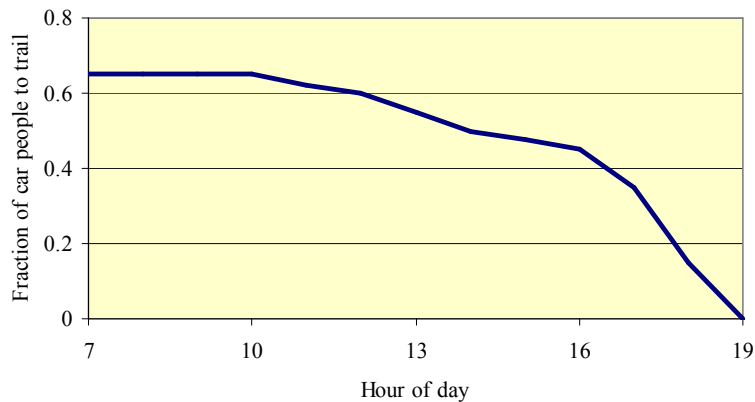


Figure A-10: Fraction of car people to trail dependent on time of the day

Hidden Lake fraction car is the fraction of car people hiking Hidden Lake. This fraction stays constant at 7% from the morning until 2PM. After 2PM, no car people want to try this trail because of long hiking time.

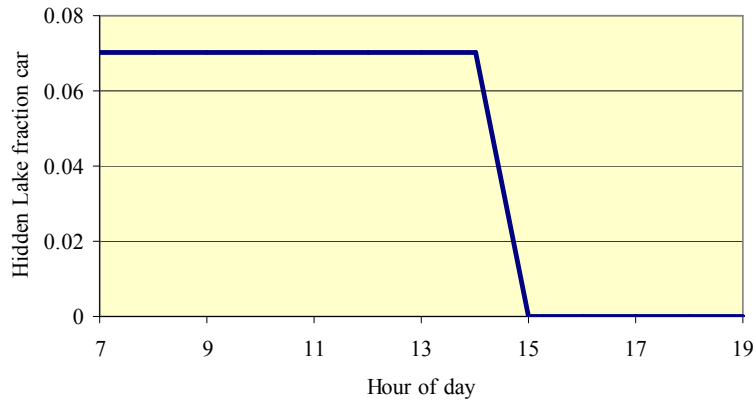


Figure A-11: Hidden Lake fraction car dependent on time of the day

Haystack fraction car is the fraction of car people hiking the Highline Trail and turn around at Haystack Butte. This fraction stays at 5% in the morning until 10AM. The fraction increases starting from 11AM and reaches a peak of 35% at 3PM. Toward the end of the day, this fraction drops and car people finish visiting this trail segment at 7PM.

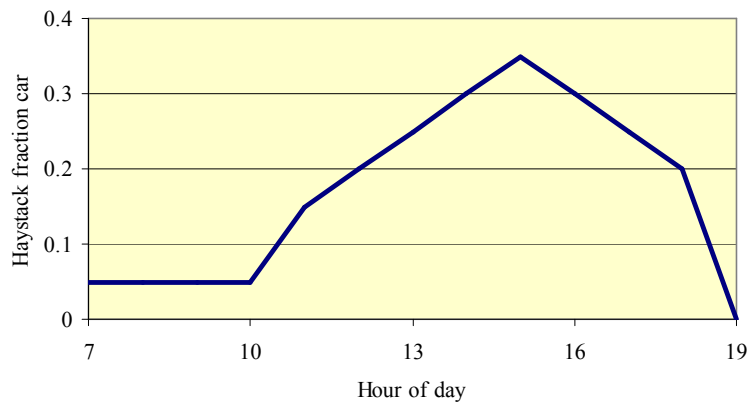


Figure A-12: Haystack fraction car dependent on time of the day

Highline fraction car is the fraction of car people hiking the Highline Trail all the way to TL. This fraction stays constant at 15% until noon and drops to 5% at 2PM. After 3PM, car people do not want to try this strenuous trail.

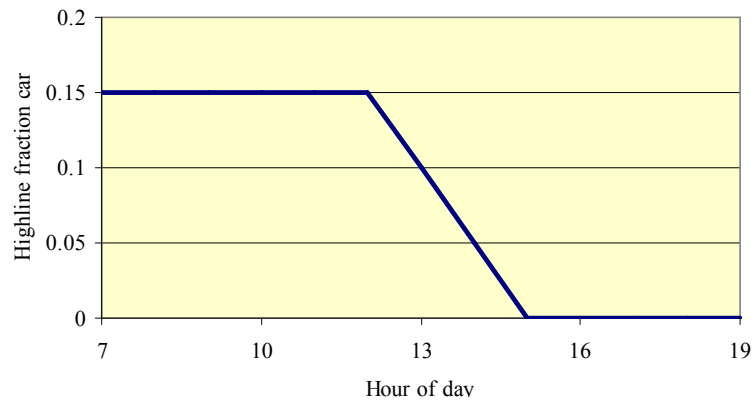


Figure A-13: Highline fraction car dependent on time of the day