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Adaptation and Application of Micro-Simulation Modeling to Recreational Use of Parks and Public Lands

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Manning, Reigner, Wimpey, Valliere, Xiao

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Prepared by:

Robert Manning
Nathan Reigner
Jeremy Wimpey
William Valliere
Xiao Xiao

Park Studies Laboratory and Vermont Tourism Data Center
Aiken Center
81 Carrigan Drive
Burlington, VT 05405

Phone: (802) 656-8873
Website: http://www.uvm.edu/parkstudieslaboratory

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1. Introduction

The goal of this project was to build foundational research expertise in integrated land use and transportation modeling for tourism travel and outdoor recreation quality and efficiency. Tourism and recreation are major and increasingly important components of the Vermont, New England, national, and international economies. Transportation is a vital element of tourism and recreation, and includes not only delivering visitors to and from their destinations but also circulation while at their destination. Moreover, in many contexts, transportation, tourism and recreation activities can be synonymous. For example, in parks and on public lands, transportation, including auto-touring and walking for pleasure, is a major form of tourism and recreation, offering visitors the opportunity to see, experience, and appreciate natural and cultural landscapes.

Transportation and recreation are complex systems. Particularly when these activities take place in parks and on public lands, visitors and tourists move across large landscapes and along distributed networks. Often the diffusion, rather than concentration, of use is a primary goal of recreation related transportation activities. Additionally, many recreationists and tourists specifically seek freedom of behavior and from intensive administration. The complexity of recreation and transportation, born of behavioral diffusion, diversity and intensity, makes monitoring and evaluating transportation and recreation in parks and on public lands difficult and expensive. Managers simply cannot observe use over the entirety of their jurisdiction, and recreation visitors and tourists are unwilling or unable to report their activities to managers. Further, actions taken to manage transportation and/or recreation systems have real consequences for resources and visitors that cannot be fully understood prior to implementation and may not be reversible should they prove to be ineffective or even detrimental. As a consequence, the difficulty of monitoring conditions and predicting management effects exacerbates the complexity of transportation and recreation systems in parks and on public lands.

Simulation models provide a tool for researchers and managers to address and overcome the complexity inherent in transportation and recreation in parks and on public lands. Simulation models replicate the arrival, distribution and behavioral patterns of transportation and recreation system users, predicting the quality of experiences given various conditions of use and management scenarios. These models combine conceptual organizations of facilities and infrastructure with representative samplings of visitor use to play out an hour, day, or season's worth of use in an electronic environment. In doing so, simulation models can serve a number of indispensable and otherwise impractical functions for researchers and managers. Consequently, simulation modeling has been the subject of a growing body of research and has been applied in both the transportation and recreation disciplines. While current modeling techniques certainly benefit managers, visitors, and transportation and recreation systems, new theories and methodologies have the potential to advance simulation modeling's application, improving it efficacy and further empowering researchers and mangers. These models can integrate land use and transportation planning and management in new and useful ways.

The University of Vermont's (UVM) Park Studies Laboratory (PSL) and Applied Trails Research (ATR) undertook a program of cooperative research with the purpose of building foundational transportation research expertise using advanced technologies for integrated transportation and land use modeling to examine the complex systems linking and supporting the sustainability of transportation, tourism travel, and recreation in parks and on public lands. The development of this expertise will allow UVM to help satisfy the large and growing needs of transportation and recreation researchers and managers for state of the art simulation modeling. Building foundational expertise in transportation and recreation simulation modeling require researchers from the PSL and ATR to work closely in all phases of the work from planning, through execution, to communication of findings and lessons learned. Simulation modeling efforts undertaken as part of this collaboration identified, tested, and optimized indicators of quality for both transportation and recreation systems and opportunities. That is, simulation models were designed and operated to examine both the functional and experiential qualities of transportation and recreation facilities and operations representative of parks and public lands.

In building foundational research expertise in simulation modeling for integrated transportation and recreation management, this research contributed both to UVM's mission and the Spires of Excellence Initiative, particularly the complex systems spire, as well as to advance the state of research and practice in the transportation and recreation fields. The development and demonstration of expertise in integrated transportation and recreation simulation modeling is a unique and desirable capability among universities. The technical capabilities built through this UTC grant enabled UVM researchers to pursue and secure externally supported research projects, facilitate outstanding student engagement and achievement, and provide service to the recreation and transportation professions.

2. Research Methodology

Conceptual Frameworks

This research was informed by conceptual frameworks. These frameworks lend structure and organization to research, defining variables of interest and arranging relationships to be characterized. Of specific utility to the project were two frameworks, one from the world of outdoor recreation and the other from transportation planning and management.

Indicators and Standards of Quality in Outdoor Recreation

Contemporary management of outdoor recreation is increasingly guided by management-by-objectives frameworks (Figure 1). The Limits of Acceptable Change framework developed by the U.S. Forest Service and Visitor Experience and Resource Protection framework, developed by the National Park Service, are prominent examples of this approach (Stankey et al. 1986, National Park Service 1997, Manning 2001, Manning 2007). This approach to outdoor recreation focuses on defining the types of outdoor recreation opportunities to be provided and maintained, and is done by formulating management objectives and associated indicators and standards of quality.

Management objectives are broad, narrative statements that define the types of outdoor recreation opportunities to be provided and maintained, including the condition of natural and cultural resources, the type of recreation experience, and the types and intensity of management actions desired for particular recreation areas or systems of public lands. In some contexts, management objectives are called “desired conditions.” Indicators of quality are more specific, measurable, manageable variables reflecting the essence or meaning of management objectives; they are quantifiable proxies or empirical measures of management objectives. Indicators of quality may include elements of the resource, social, and management environments that are important in determining the type and quality of outdoor recreation opportunities. Standards of quality define the minimum acceptable condition of indicator variables. Monitoring indicators informs managers of resource and experience conditions, which can be compared against standards or quality to judge whether or not management objectives are being achieved.

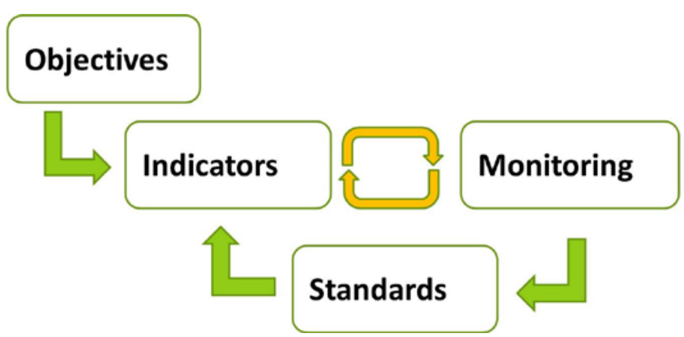


Figure 1: Management by Objectives Framework

An example may help illuminate these ideas and terms. All four of the major federal land agencies that provide outdoor recreation opportunities (National Park Service, US Forest Service, US Fish and Wildlife Service, Bureau of Land Management) manage wilderness areas designated by Congress. Review of the

Wilderness Act of 1964 suggests that areas contained in the National Wilderness Preservation System are to be managed to provide “opportunities for solitude.” Thus, providing opportunities for solitude is an appropriate management objective or desired condition for most wilderness areas. Moreover, research on wilderness use suggests that the number of other visitors encountered along trails and at campsites is important in defining solitude for wilderness visitors (Manning 2011). As such, trail and camp encounters are potentially good indicators of quality. Research also suggests that wilderness visitors may have normative standards about how many trail and camp encounters can be experienced before the quality of opportunities for solitude decline to an unacceptable degree. For example, a number of studies suggest that wilderness visitors prefer to see no more than five other groups-per-day along trails and prefer to camp out of sight and sound of other groups (Manning 2011). Thus, a maximum of five encounters along trails per day and no encounters at campsites may be good standards of quality. Management of wilderness areas adopting these types of indicators and standards of quality might include limiting use through a permit system or dispersing use to other areas in order to maintain standards of quality.

Indicators of Quality

Several studies have explored criteria that might be used to define effective indicators of quality (Schomaker 1984, Stankey et al. 1985, Merigliano 1990, Whittaker and B. Shelby 1992, National Park Service 1997, Manning 2007). These criteria can be used to further understand the role of indicators and standards of quality in outdoor recreation and to assist in evaluation and selection among potential indicator variables. Criteria for good indicators of quality include the following:

1. Specific. Indicators should define specific rather than general conditions. For example, "solitude" would not be a good indicator of quality because it is too general. "The number of other groups encountered per day along trails" would be a more specific and better indicator variable.

2. Objective. Indicators should be objective rather than subjective. That is, indicator variables should be measured in absolute, unequivocal terms. Variables that are subjective, expressed in relative terms, or subject to interpretation make poor indicators. For example, "the number of people at one time at Wild Arch" is an objective indicator because it is an absolute number that can be counted and reported. However, "the percentage of visitors who feel crowded at Wild Arch" is a subjective indicator because it is subject to interpretation by visitors – it depends on the types of visitors making the judgment, the behavior of other visitors, and other variables.

3. Reliable and repeatable. An indicator is reliable and repeatable when repeated measurement yields similar results under similar conditions. This criterion is important because monitoring of indicator variables should be conducted periodically, assessing the effects of use and management actions.

4. Related to visitor use. Indicators should be related to some aspect of visitor use: level of use, type of use, location of use, or behavior of visitors. A major role of indicators of quality is to help determine when management action is needed to control the impacts of visitor use. Thus, there should be a relationship between visitor use and indicators of quality.

5. Sensitive. Indicators should be sensitive to visitor use over a relatively short period of time. As the level or type of use changes, an indicator should respond in roughly the same proportional degree. If an

indicator changes only after impacts are substantial, it will not serve as an early warning mechanism, allowing managers to react in a timely manner.

6. Manageable. Indicators should be responsive to, and help determine the effectiveness of, management actions. That is, they must be responsive to management action. The underlying rationale of indicators is they should be maintained within prescribed standards of quality. This implies that they must be manageable.

7. Efficient and effective to measure. Indicators should be relatively easy and cost-effective to measure. Indicators of quality should be monitored on a regular basis. Therefore, the more expertise, time, equipment, and staff needed to take such measurements, the less desirable a potential indicator of quality may be.

8. Significant. Perhaps the most important characteristic of indicators is that they help define the quality of the visitor experience. This is inherent in the very term "indicator." It does little good to monitor the condition of a variable that is unimportant in defining the quality of the visitor experience.

Standards of Quality

As with indicators of quality, several studies have explored characteristics that might define good standards of quality (Schomaker 1984, Brunson et al. 1992, Whittaker and Shelby 1992, National Park Service 1997, Manning 2011). To the extent possible, good standards of quality should meet the following characteristics:

1. Quantitative. Standards should be expressed in a quantitative manner. Since indicators of quality are specific and measurable variables, standards of quality can and should be expressed in an unequivocal way. For example, if an indicator is "the number of encounters with other groups per day on the river," then the standard might be "an average of no more than three encounters with other groups per day on the river." In contrast, "low numbers of encounters with other groups per day on the river" would be a poor standard of quality because it does not specify the minimum acceptable condition in unambiguous terms.

2. Time or space-bounded. Incorporating a time- or space-bounded element into a standard of quality expresses both how much of an impact is acceptable and how often or where such impacts can occur. It is often desirable for standards to have a time period associated with them. This is especially relevant for crowding-related issues. For instance, in the above example, the standard of quality for encounters with other groups on the river was expressed in terms of "per day." Other time-bounded qualifiers might include "per night," "per trip," "per hour," or "at one time," depending upon the circumstances. Space-bounded qualifiers could be “per mile of trial,” “per campsite,” or “per square meter.”

3. Expressed as a probability. In many cases, it will be advantageous to include in the standard of quality a tolerance for some percentage of the time that a particular condition will be unavoidably unacceptable; in other words, the standard would include a probability that conditions will be at standard or better. For example, a standard might specify, "no more than three encounters with other groups per day along trails for 80% of days in the summer use season." The 80% probability of conditions being at or above standard allows for 20% of the time that random or unusual events might prevent management from attaining these conditions. This allows for the complexity and randomness inherent in visitor use patterns. In the example of encounters along a trail, several hiking parties might

depart from a trailhead at closely spaced intervals on a given day. These groups are likely to encounter each other on the trail several times during the day. On another day, the same number of groups might depart from the trailhead at widely spaced intervals and thereby rarely encounter each other. Similarly, it might be wise to incorporate a tolerance in standards for peak use days, holiday weekends, or other days of exceptionally high visitation. A standard might be set at "50 people at one time at Wild Arch for 90% of the days of the year." The amount of tolerance needed depends on the unpredictability of each individual situation and the degree to which management can consistently control conditions.

4. Impact-oriented. Standards of quality should focus directly on the impacts that affect the quality of the visitor experience, not the management action used to keep impacts from violating the standards. For example, an appropriate standard might be, "no more than ten encounters with other groups on the river per day." This could be a good standard because it focuses directly on the impact that affects the quality of the visitor experience – the number of other groups encountered. Alternatively, "a maximum of twenty groups per day floating the river" would not be as good a standard of quality because it does not focus as directly on the impact of concern – visitors experience encounters with other groups more directly than they experience total use levels. Basing standards of quality on management techniques rather than on impacts can also limit the potential range of useful management practices. For example, limiting the number of boats to twenty per day might be used to ensure ten or fewer encounters per day, but other actions, such as more tightly scheduling launch times, could also ensure an appropriate encounter rate and could be less restrictive on the level of visitation to the river.

5. Realistic. Standards should generally reflect conditions that are realistically attainable. Standards that limit impacts to extremely low levels may set up unrealistic expectations in the minds of visitors, may be politically infeasible, and may unfairly restrict visitor use to very low levels.

Levels of Service (LOS) in Transportation Management

Level of service (LOS) is a highway capacity framework that has guided transportation planning across the United States, and is reflective of the broader management objectives of the Department of Transportation: "[to] serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system" (Department of Transportation Act, 1966). It is derived from the Transportation Research Board's Highway Capacity Manual (HCM) and describes operational conditions within a traffic stream using variables such as speed, travel time, freedom to maneuver, comfort, and convenience (Transportation Research Board 2000, 2010). It defines a range of traffic conditions based upon a letter grade system (A through F) where 'A' represents the best operating conditions and 'F' the worst.

The LOS framework is formulated for numerous types of transportation facilities and multiple modes (Figure 2; Figure 3; Table 1; Transportation Research Board 2000, 2010). Some LOS conventions are intuitive like that for transit buses, which evaluates service quality by the ratio of riders to seats. Others are more abstract, like that for pedestrians on a shared use path, which is based on a rate of events between users. In some cases, difficult to comprehend numerical performance measures, like vehicles per mile per lane for cars on a freeway or ft^2 per person can be effectively visualized. By measuring and expressing factors that contribute to the quality of transportation service, performance measures serve much the same purpose of indicators of quality. The grade system has been critiqued for lacking empirical links to user perceptions (Flannery et al., 2004). While recent research has undertaken a more comprehensive view of factors important to users and has led to a number of explanatory variables that have been used to develop LOS models (Transportation Research Board 2008), it may not fully reflect experiential components of travel, especially in the context of parks and public lands.

Table 1: Levels of service for pedestrians (Transportation Research Board 2000, 2010)

Mode		**Pedestrians**	**Pedestrians**
Facility		Shared Use Path	Pedestrian Walkway
Performance Measure		events/hour	ft^2/person
Levels of Service	**A**	≤11	>60
	B	11-18	40-60
	C	18-26	24-40
	D	26-35	15-24
	E	35-45	8-15
	F	>45	≤8

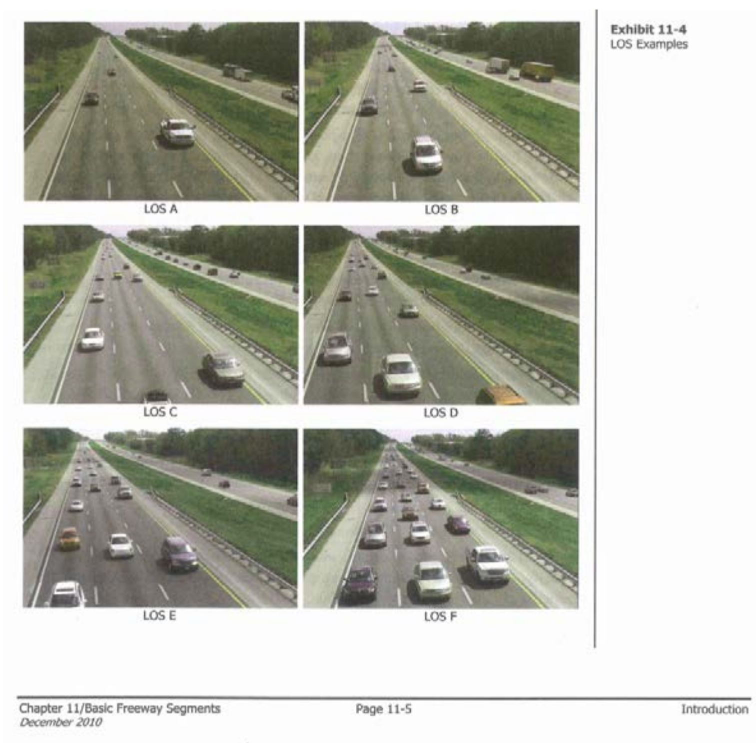


Figure 2: Vehicles per mile per lane for cars on a freeway; Highway Capacity Manual, 2010

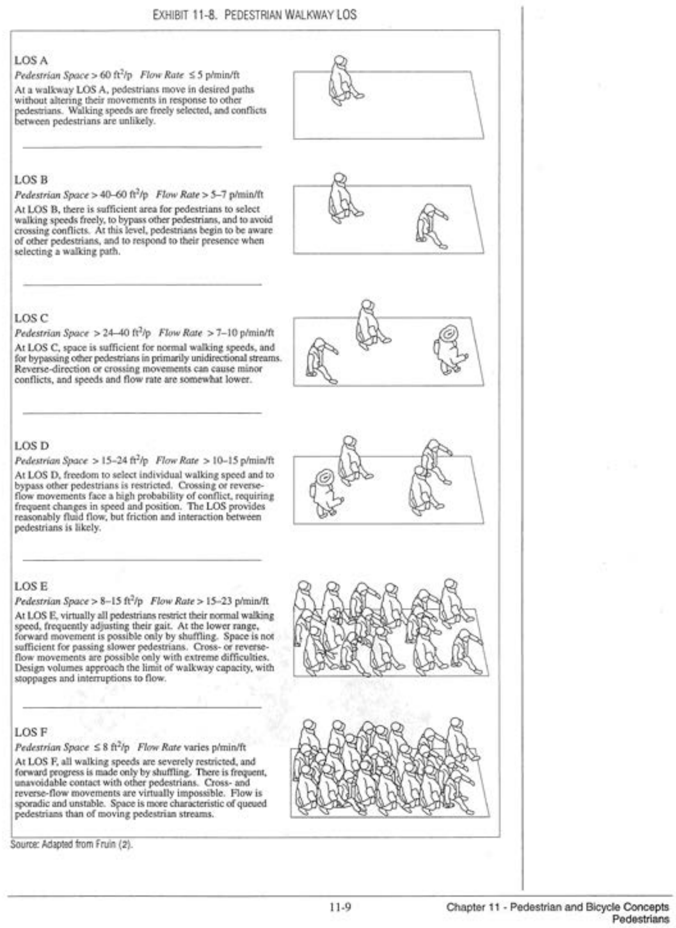


EXHIBIT 11-8. PEDESTRIAN WALKWAY LOS

LOS A
Pedestrian Space > 60 ft^2/p *Flow Rate* ≤ 5 p/min/ft
At a walkway LOS A, pedestrians move in desired paths without altering their movements in response to other pedestrians. Walking speeds are freely selected, and conflicts between pedestrians are unlikely.

LOS B
Pedestrian Space > 40–60 ft^2/p *Flow Rate* > 5–7 p/min/ft
At LOS B, there is sufficient area for pedestrians to select walking speeds freely, to bypass other pedestrians, and to avoid crossing conflicts. At this level, pedestrians begin to be aware of other pedestrians, and to respond to their presence when selecting a walking path.

LOS C
Pedestrian Space > 24–40 ft^2/p *Flow Rate* > 7–10 p/min/ft
At LOS C, space is sufficient for normal walking speeds, and for bypassing other pedestrians in primarily unidirectional streams. Reverse-direction or crossing movements can cause minor conflicts, and speeds and flow rate are somewhat lower.

LOS D
Pedestrian Space > 15–24 ft^2/p *Flow Rate* > 10–15 p/min/ft
At LOS D, freedom to select individual walking speed and to bypass other pedestrians is restricted. Crossing or reverse-flow movements face a high probability of conflict, requiring frequent changes in speed and position. The LOS provides reasonably fluid flow, but friction and interaction between pedestrians is likely.

LOS E
Pedestrian Space > 8–15 ft^2/p *Flow Rate* > 15–23 p/min/ft
At LOS E, virtually all pedestrians restrict their normal walking speed, frequently adjusting their gait. At the lower range, forward movement is possible only by shuffling. Space is not sufficient for passing slower pedestrians. Cross- or reverse-flow movements are possible only with extreme difficulties. Design volumes approach the limit of walkway capacity, with stoppages and interruptions to flow.

LOS F
Pedestrian Space ≤ 8 ft^2/p *Flow Rate* varies p/min/ft
At LOS F, all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent, unavoidable contact with other pedestrians. Cross- and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving pedestrian streams.

Source: Adapted from Fruin (2).

11-9 Chapter 11 - Pedestrian and Bicycle Concepts Pedestrians

Figure 3: Pedestrian walkway levels of service; Highway Capacity Manual, 2000

For instance, attempts to describe the quality of bicycle and pedestrian travel have focused primarily on user interactions rather than a more holistic set of experiential factors. The HCM defines LOS for shared-use paths based upon “hindrance,” or the number of events (the passing of two users classified as meetings or overtakings) a pedestrian or cyclist experiences while traveling on a greenway (Transportation Research Board 2000). Models employing this concept have been developed to incorporate hikers, bikers, and joggers but remain reliant primarily upon the number of overtakings between users (Virkler 1998). And, while some studies have begun to incorporate real-time human perceptions into a bicycle level of service (Landis 2003), they too have focused primarily upon impacts from other road users upon cyclists rather than environmental elements such as the level of corridor or facility development. Furthermore, it has been suggested that some modes of transportation, such as pedestrian activity include a ‘breadth of experience’ (Demerath 2003) that has not yet been included in LOS measures.

Integrating Indicators and Standards of Quality and LOS

The relationship between indicators and standards of quality and LOS is expressed by the HCM’s interpretation of *quality of service*. As defined by the 2010 HCM, quality of service “describes how well a transportation facility or service operates from the traveler's perspective" (Transportation Research Board 2010). While the quality of service concept was included in an earlier edition of the HCM, its definition focused primarily on "quantitative measures to characterize operational conditions" (Transportation Research Board 2000) rather than the traveler's perceptions of those conditions. The LOS concept has always been represented in the HCM as the A to F stratification of quality of service, but only in its most recent edition is the emphasis upon including user perceptions for defining LOS made clear. The introduction of numerous traveler perception-based models for describing LOS in the 2010 manual further highlights the importance of this evolution of the LOS concept.

Similar to the indicators and standards of quality based approach, these traveler perception-based models set thresholds derived from user perceptions of quality. Furthermore, both present a continuum of conditions that represent a range of service quality. Standards of quality define a minimum acceptable condition, and transportation "planning efforts typically use…LOS C or D, to ensure an acceptable" operating service (Transportation Research Board 2000). Therefore, it follows that the integration of these frameworks be anchored around a minimum acceptable condition of quality equivalent to LOS E. That is to say, any of the conditions deemed *acceptable* by travelers would represent LOS A-D, while any of the conditions rated as *unacceptable* by travelers would be representative of LOS F. LOS E indicates both a minimum level of acceptability from a traveler's perspective, and a level of service that transportation planners aim to exceed. This rational nexus between indicators and standards of quality and quality of service therefore provides another means of incorporating user perceptions into LOS.

Bechtel Summit Reserve Case Study Scenario

The Summit Bechtel Family National Scout Reserve (Summit) is an 11,000 acre Boy Scout camp in Mount Hope, West Virginia. It is adjacent to the New River Gorge National Recreation Area. The Summit has extensive and diverse recreational opportunities, including swimming, boating, shooting, mountain biking, rock climbing, hiking, camping, and canopy tours. In addition to recreational facilities, the Summit has domestic and administrative facilities to support a maximum occupancy of 40,000 campers per night.

A primary purpose of the Summit is to host the National Jamboree and similar mass events. These events, attended by a maximum of 60,000 visitors, often include programmed activities throughout the day and assemblies, like speeches and concerts, in the evening. Walking is the primary mode of transportation for visitors to the Summit. It is facilitated by a trail network of approximately 35 miles in extent. The cost of design and layout for this trail network supplied matching funds for this modeling project.

The trail network and activity programming combine to establish the case study scenario used to develop the modeling research methodology. This scenario is the analytical period. In essence, it is the morning commute of scouts and leaders from their overnight camps to their activity centers at 9:00 am. The modeling of scenarios can be expressed as a series of research questions:

- At what time do scouts need to leave their camps to arrive at their activity centers by 9:00 in the morning?

- Can the trail network as designed accommodate the demands of this morning commute?
- Which locations within the trail are experience the most capacity related challenges when accommodating this demand?
- How do capacity related challenges affect the pedestrian experience of trail segments?

Answering these research questions requires modeling at multiple scales. One of these scales is the “macro” scale. The macro-scale encompasses the entirety of the trail network. This trail network leads pedestrians from their overnight camp origins to their activity centers. Modeling at the macro-scale focuses on transportation system function. Indicators of quality for macro-scale models including variables like flow rate (persons/duration of time/width of path), density (persons/square unit of path area), space (square unit of path area/person), and delay (difference between desired travel speed and maximum realized travel speed). Standards of quality for these variables can be drawn from Levels of Service. Macro-scale models suggest locations within the trail network that have capacity related challenges under the modeled scenario.

The other scale of modeling is the “micro” scale. The micro-scale encompasses specific segments of the trail network that are of specific interest. This interest can stem from trails experiential or functional significance, or a capacity challenge revealed from the macro-scale models. Intersections, bridges, and experientially exceptional trail segments are examples of the locations typically modeled at the micro-scale. Modeling at the micro-scale focuses on the experience of individuals using the trail network. Indicators of quality for micro-scale models include density (persons/square unit of path area), space (square unit of path area/person), delay (difference between desired travel speed and maximum realized travel speed), encounters (the rate at which a referent pedestrian passes or is passed by other pedestrians, and PPV (the number of people per view from the vantage of a referent hiker). Standards of quality for these variables can be drawn from Levels of Service, visitor survey responses, or deviations from free-flow times. Micro-scale models suggest use levels at which specific trail segments or areas have their capacity exceeded. Micro-scale models are agent-based microsimulation models that stochastically simulate the behavior and experiences of individual pedestrians using the trail networks.

Model Elements

Four primary model elements are used to construct and integrate the macro-scale and micro-scale models described above. These elements include spatial data for the trail network, the macro-scale network model, a computational model that integrates the macro-scale network model with micro-scale simulation models, and micro-scale agent-based microsimulation models.

Spatial Data

Spatial data for the trail network supplies a foundation for all other elements in our modeling approach and in the operation of the models. The spatial data have three primary elements: origins, destinations, and trail links. Each of these elements is codified with vector data. Origins and destinations are points. Trail links are lines. Figure 4 illustrates the spatial data upon which the modeling effort is based. In this depiction, trails are illustrated with white lines, origins are illustrated with blue tent symbols, and destinations are illustrated with pink activity icons.

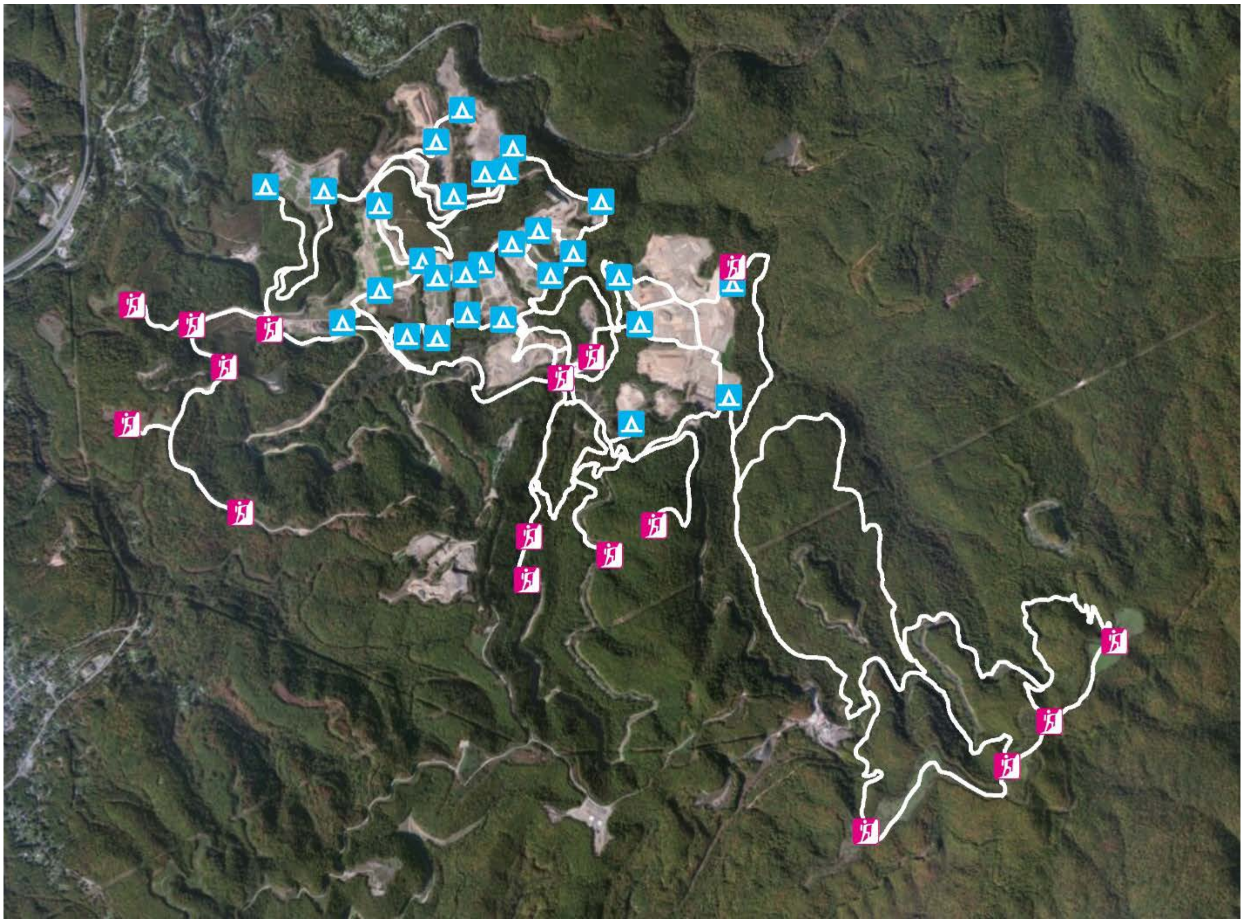


Figure 4: Bechtel Summit Reserve Spatial Data

The set of spatial data are used to generate the inputs needed for macro-scale network models as well as the spatial frameworks of micro-scale models.

Macro-scale Model

The macro-scale model is a network model operated with ArcGIS Network Analyst. The network model calculates information about routes or trips. Each route departs from an origin and arrives at a destination. At the Summit, origins are campsites and destinations are activity sites. The routes is the path each pedestrian will take from their origin to their destination, from their camp to their activity site. This path traverses trail segments. The sequence of trail segments from camp to activity site is a route. Often, many potential routes are possible between any origin and destination pair. The specific route, and subsequent sequence of trail segments, selected for each origin-destination pair is chosen to minimize travel cost. Travel cost is the amount of time, energy, or expenditure required to traverse a trail segment. As a trail becomes steeper, more rugged, and/or more crowded, its travel cost may increase. Increase travel cost may be expressed in reduced travel speeds, increased delay, and/or reduction in experiential quality. The network model calculates routes between 29 origins and 19 destinations. Table 2 and 3 list the origins and destinations. Figure 5, Figure 6, and Figure 7 and depict the location of origins, destinations, and trail segments respectively.

Table 2: Network Model Origins

Number	Origin Name
1	A1
2	A2
3	A3
4	B1
5	B2
6	C1
7	C10
8	C11
9	C2
10	C3
11	C4
12	C5
13	C6
14	C7
15	C8
16	C9
17	D1
18	D2
19	D3
20	D4
21	D5
22	E1
23	E2
24	E3
25	E4
26	E5
27	E6
28	F1
29	F2

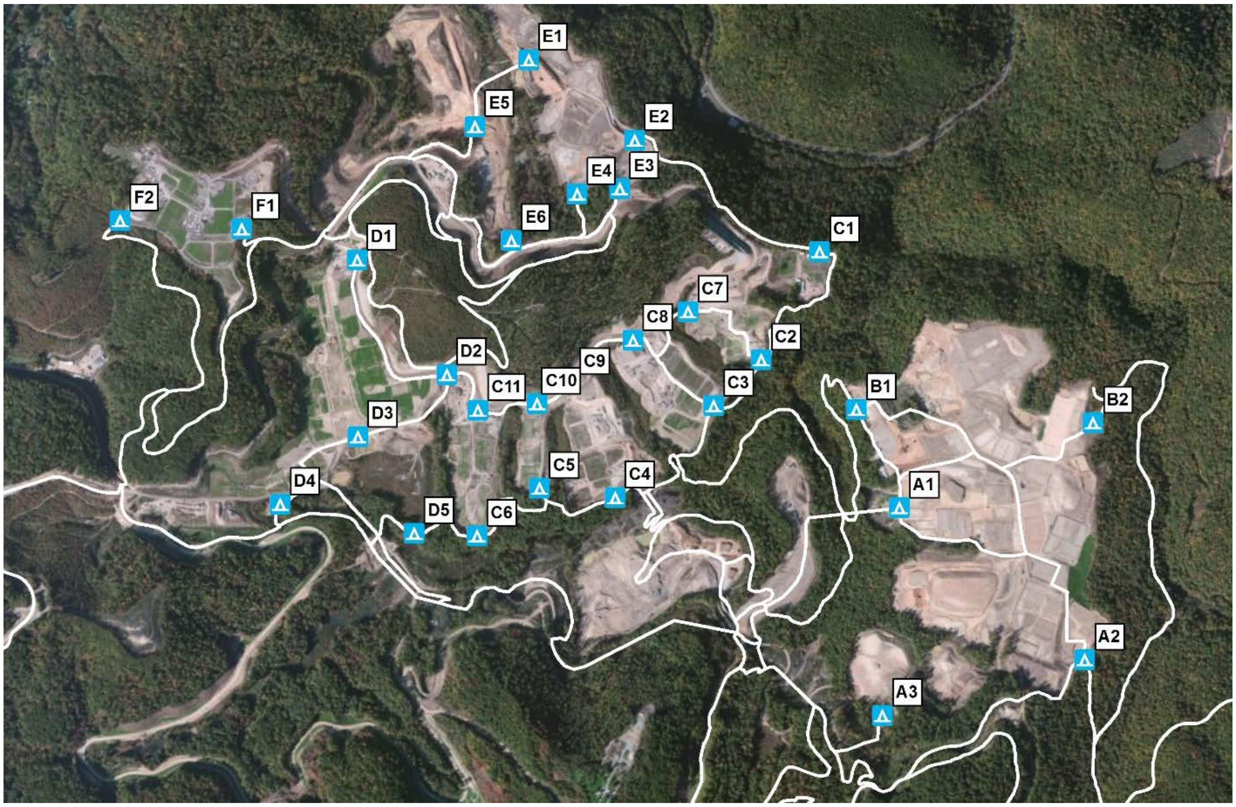


Figure 5: Network Model Origins

Table 3: Network Model Destinations

Number	Code	Name	Activity
1	AP	Action Point	Orientation
2	AV1	The Ropes	Rappelling
3	AV2	Low Gear	Mountain Biking
4	AV3	The Rocks	Rock Climbing
5	AV4	High Gear	Mountain Biking
6	BS	Bus Stop	Rafting
7	GG1	Garden Grounds	Hiking
8	GG2	Garden Grounds	Hiking
9	GG3	Garden Grounds	Hiking
10	GG4	Garden Grounds	Hiking
11	MM1	The Park	Skateboarding
12	MM2	The Trax	BMX Biking
13	MM3	The Pools	Swimming
14	MM4	The Cloud	Technology
15	MM5	The Bows	Archery
16	MM6	The Barrels	Riflery
17	TC1	The Canopy	Canopy Tour

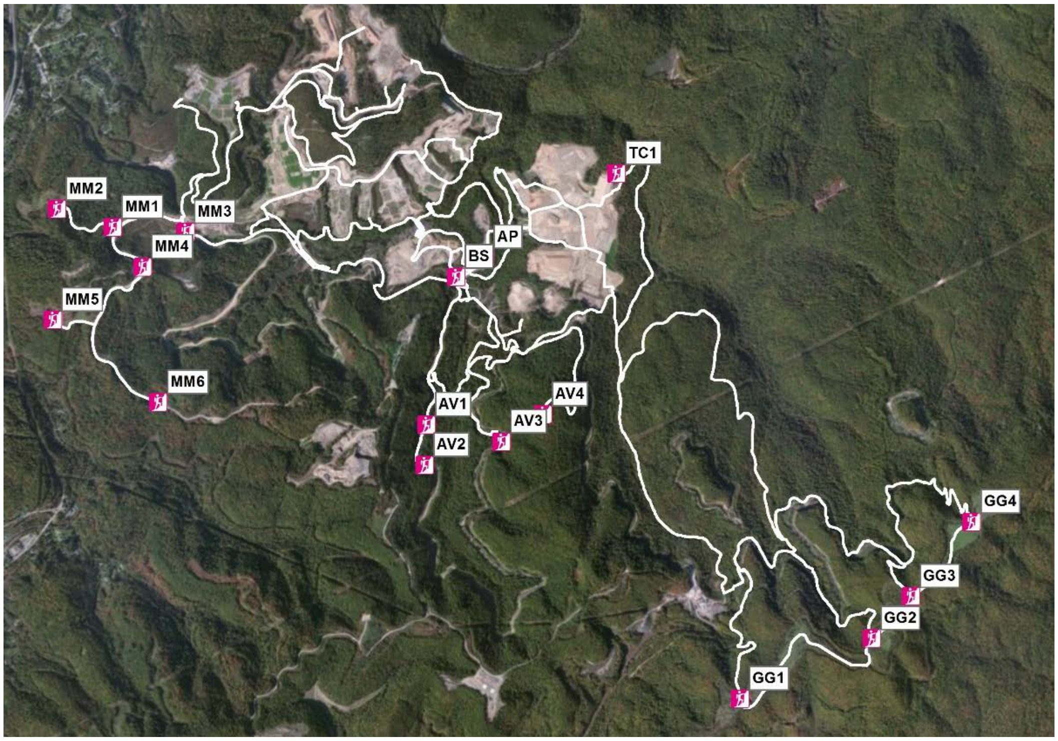


Figure 6: Network Model Destinations

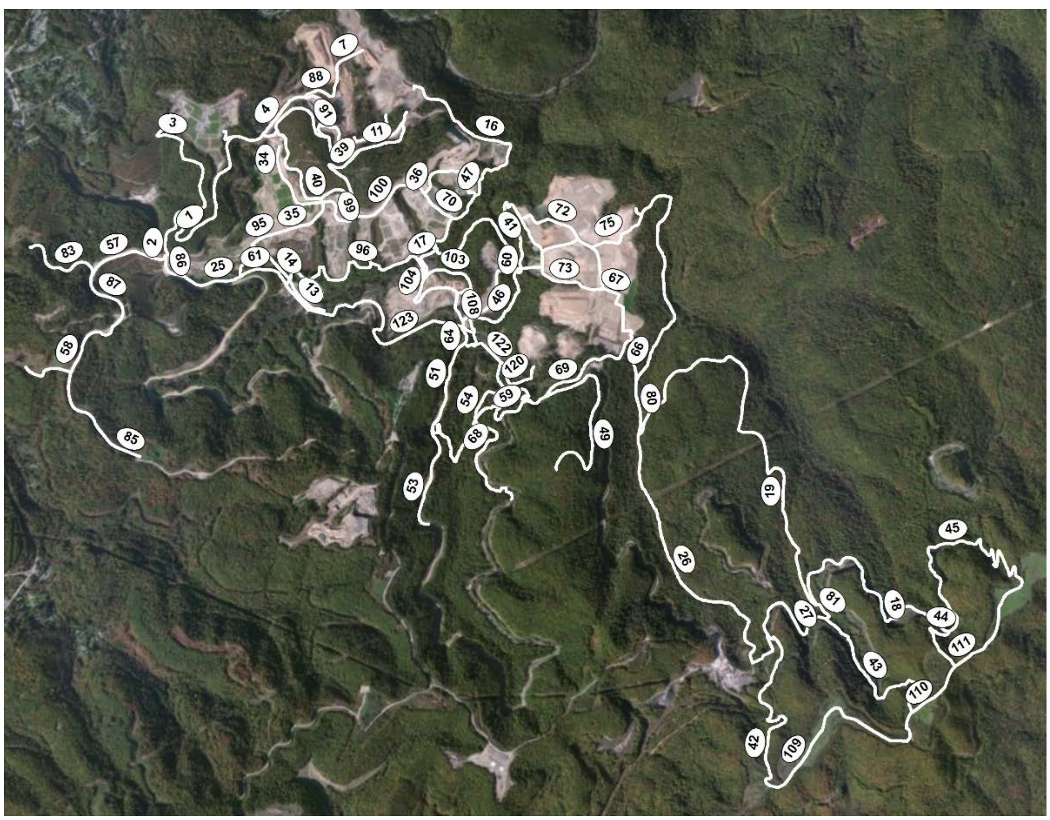


Figure 7: Network Model Trail Segments

The macro-scale network model uses origin-destination pairs and the trail network at its inputs for identifying and computing statistics for least-cost paths. Output from the network model was generated for each of the 493 least-cost routes from each origin to each destination (29 origins x 17 destinations = 493 routes). The output is expressed as a string of trail segments for each origin-destination pair. Figure 8 depicts network model output. The first line provides an example. The origin of the route is camp A1 and the destination is Adventure Point (AP). The least-cost, or shortest, route from A1 to AP is by leaving A1 on trail segment 119, then progressing on segments 116 and 71, until arriving at AP. The longest routes, in terms of number of trail segments, run across 32 trail segments from the E camps to Garden Grounds #4 (GG4).

Origin	Destination	Route ID	Link1	Link2	Link3	Link4	Link5	Link6	Link7	Link8
A1	AP	A1-AP	119	116	71					
A2	AP	A2-AP	67	73	119	116	71			
A3	AP	A3-AP	120	121	122	52	56	125	71	
B1	AP	B1-AP	79	126	119	116	71			
B2	AP	B2-AP	75	77	74	126	119	116	71	
C10	AP	C10-AP	101	100	112	70	97	17	63	102
C11	AP	C11-AP	33	101	100	112	70	97	17	63
C1	AP	C1-AP	47	15	97	17	63	102	103	106
C2	AP	C2-AP	15	97	17	63	102	103	106	124
C3	AP	C3-AP	97	17	63	102	103	106	124	127
C4	AP	C4-AP	98	62	63	102	103	106	124	127
C5	AP	C5-AP	30	29	98	62	63	102	103	106
C6	AP	C6-AP	96	29	98	62	63	102	103	106
C7	AP	C7-AP	36	70	97	63	102	103	106	124
C8	AP	C8-AP	112	70	97	63	102	103	106	124
C9	AP	C9-AP	100	112	70	97	63	102	103	106
D1	AP	D1-AP	34	99	33	101	100	112	70	97
D2	AP	D2-AP	99	33	101	100	112	70	97	63
D3	AP	D3-AP	95	14	32	12	123	24	107	124
D4	AP	D4-AP	114	61	12	123	24	107	124	127
D5	AP	D5-AP	28	96	29	98	62	63	102	103
E1	AP	E1-AP	7	88	4	9	40	94	99	33
E2	AP	E2-AP	16	47	15	97	17	63	102	103
E3	AP	E3-AP	6	11	39	94	99	33	101	100
E4	AP	E4-AP	23	89	11	39	94	99	33	101
E5	AP	E5-AP	88	4	9	40	94	99	33	101
E6	AP	E6-AP	22	90	89	11	39	94	99	33

Figure 8: Example Network Model Output

Computational Model

Macro- and micro-scale models are linked by a computational model that transforms macro-model outputs into micro-model inputs. The computation model is a coordinated series of database queries, calculations, and database updates. Initial versions of the computational model were constructed in Excel spreadsheets. Later iterations used the R programming language for database functions and computations.

The computational model uses attributes from the spatial data set and outputs from the macro-scale network models as input data. Figure 9 illustrates the elements of the computational models and their flow from input data, through intermediate computational steps, to the final output data products. The output data products serve as the input data for micro-scale microsimulation models of pedestrian experiences. Each element of the computational model diagramed in Figure 9 is labeled with number and title. The following section describes each of these elements and provides examples of key Excel formulas in italics where appropriate.

0_NetworkInputs codifies the routes and numbers of pedestrians modeled for the Summit scenario. This includes lists of each origin, destination, and origin-destination pair. Each origin-destination pair represents a pedestrian route. The number of pedestrians departing from each origin is determined by the camps' capacities. For this modeling scenario, it is assumed that pedestrians will equally distribute themselves among the destinations with the exception of on specific destination volumes for special activities like off-site community services. These destination distributions result in a list of pedestrians per route. These data are the inputs for the macro-scale network model and are user defined.

1_RouteLinks is the primary output from the macro-scale network model. This table of data has one record for each origin-destination pair. Each origin-destination pair represents a route. The 1_RouteLinks table codifies the series of trail segments that constitute the least-cost path between origin and destination for each route. Individual trail segments are generically called links. A series of links build to construct a route.

1.1_RoutePeds is a companion table to 1_RouteLinks. It combines the number of pedestrians per route calculated in 0_NetworkInputs with the table structure of 1_RouteLinks. In doing so, it has a record for each route and a string of pedestrian volumes for each link of each route.

2_SegmentLengthandCost lists the length and travel cost for each trail segment. In our modeled scenario, travel cost is expressed as a travel time based on the length of the trail multiplied by a travel speed (1.8 miles per hour). The travel speed and desired arrival time (9:00 am) are codified as user-defined parameters in this table.

3_RouteTImeCost combines information from 1_RouteLinks and 2_SegmentLengthandCost to generate time costs for each link in a route. This table is constructed using the same format at 1_RouteLinks. In 1_RouteLinks, each record is a series of trail segments. In 3_RouteTimeCosts trail segment numbers are replaced with the travel cost in time (hours, minutes, and seconds) for each segment. These series of travel times per link are summarized for each record to calculate the total time required to travel a route. This time, subtracted from the 9:00 am to identify the time pedestrians must depart their camp origins to arrive at their activity site destinations by the required time. This calculation serves as a baseline, assuming no effects from pedestrian interactions that might slow travel times. These effects are modeled later in the process by micro-scale microsimulation models.
=IF(ISNA(LOOKUP('1_RouteLinks'!G2,'2_SegmentLengthandCost'!$B$2:$B$128,'2_SegmentLengthandCost'!$F$2:$F$128)),0,(LOOKUP('1_RouteLinks'!G2,'2_SegmentLengthandCost'!$B$2:$B$128,'2_SegmentLengthandCost'!$F$2:$F$128)))/1440

4_TImeOnLink accumulates the travel times from 3_RouteTimeCost and subtracts them from the 9:00 am desired arrival time to identify what time pedestrians traveling each route will enter each segment of each route. Like 3_RouteTimeCost, this table has the same structure as 1_RouteLinks. It is based primarily on the data from 3_RouteTimeCost, using the desired destination arrival time from 2_SegmentLengthandCost.

5_TimeSegmentLoading is a matrix with trail segments arrayed along the y-axis and times arrayed along the x-axis. The modeling scenario developed for the Summit uses five minute time-steps for the computational model. The table calculates the number of routes using each trail segment at each five minute time –step.
=COUNTIFS('1_RouteLinks'!$G$2:$AK$494,'5_TimeSegementLoading'!C$2,'4_TimeOnLink'!$H$2:$AL$494,">="&'5_TimeSegementLoading'!$B5)-COUNTIFS('1_RouteLinks'!$G$2:$AK$494,'5_TimeSegementLoading'!C$2,'4_TimeOnLink'!$H$2:$AL$494,">="&'5_TimeSegementLoading'!$B4)

5.1_Ped_TimeSegLoad attributes 5_TimeSegmentLoading with the number of pedestrians for each route. This attribution is applied by combining the number of pedestrians per route from 1.1_RoutePeds with route timings for trail segment use from 4_TimeOnLink with the time-base route summaries from 5_TimeSegmentLoading. The result is a matrix similar to that in 5_TimeSegmentLoading but with number of pedestrians per trail segment per time step rather than the number of routes using each trail segment at each time step.
=SUMIFS('1.1_RoutePeds'!$G$2:$AO$494,'1_RouteLinks'!$G$2:$AO$494,'5.1_PedCount_TimeSegLoad'!C$2,'4_TimeOnLink'!$H$2:$AP$494,">="&'5.1_PedCount_TimeSegLoad'!$B5)-SUMIFS('1.1_RoutePeds'!$G$2:$AO$494,'1_RouteLinks'!$G$2:$AO$494,'5.1_PedCount_TimeSegLoad'!C$2,'4_TimeOnLink'!$H$2:$AP$494,">="&'5.1_PedCount_TimeSegLoad'!$B4)

6_TimeLoadingColumn is the output of the computational model. The computations of this table summarize the pedestrian loads, and length weighted pedestrian loads, for each trail segment and each time-step. It presents data similar to 5.1_Ped_TimeSegLoad in columnar, rather than matrix, form. Columnar format is more directly transferable as input data for GIS visualization and micro-scale simulation models.
=VLOOKUP('6_TimeLoadingColumn'!$A2,'5_TimeSegementLoading'!$B$4:$DY$50,'6_TimeLoadingColumn'!$F2,FALSE)

The output of the computational model transforms the results from the macro-scale network model into the inputs necessary for the micro-scale microsimulation models. This is done by attributing each trails segment at each time step with the expected pedestrian load.

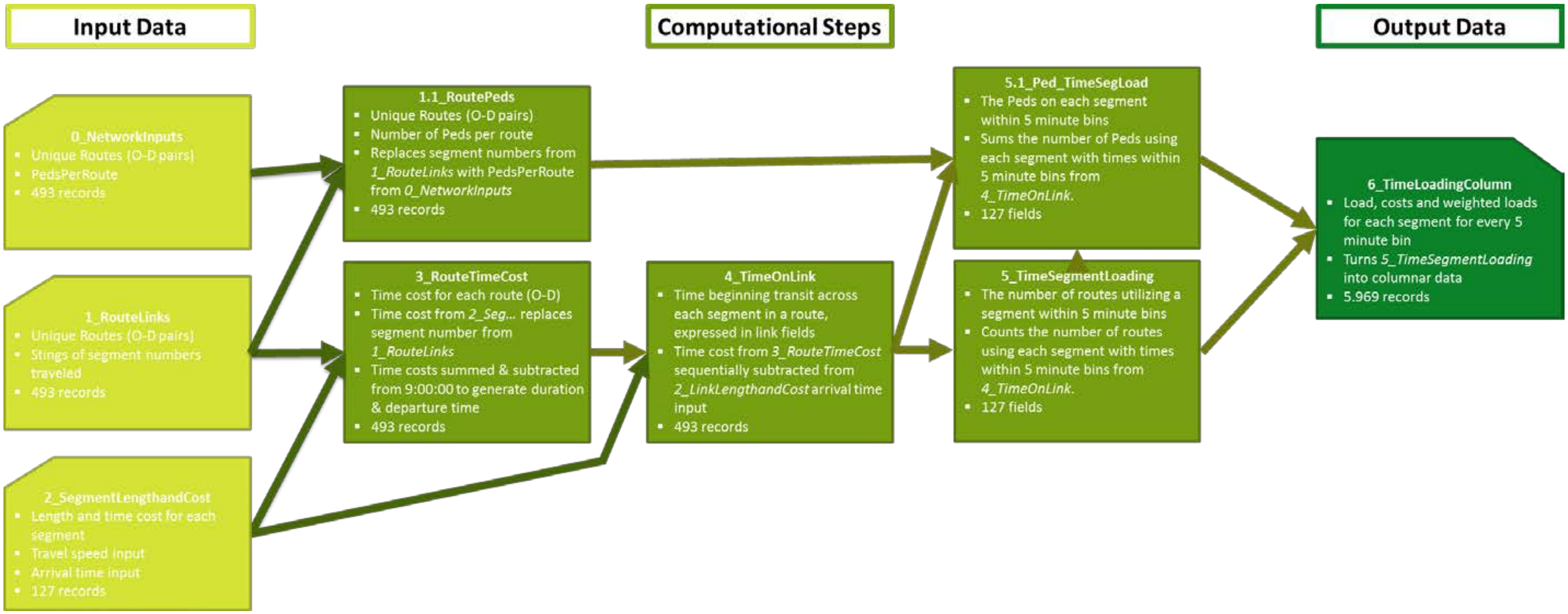


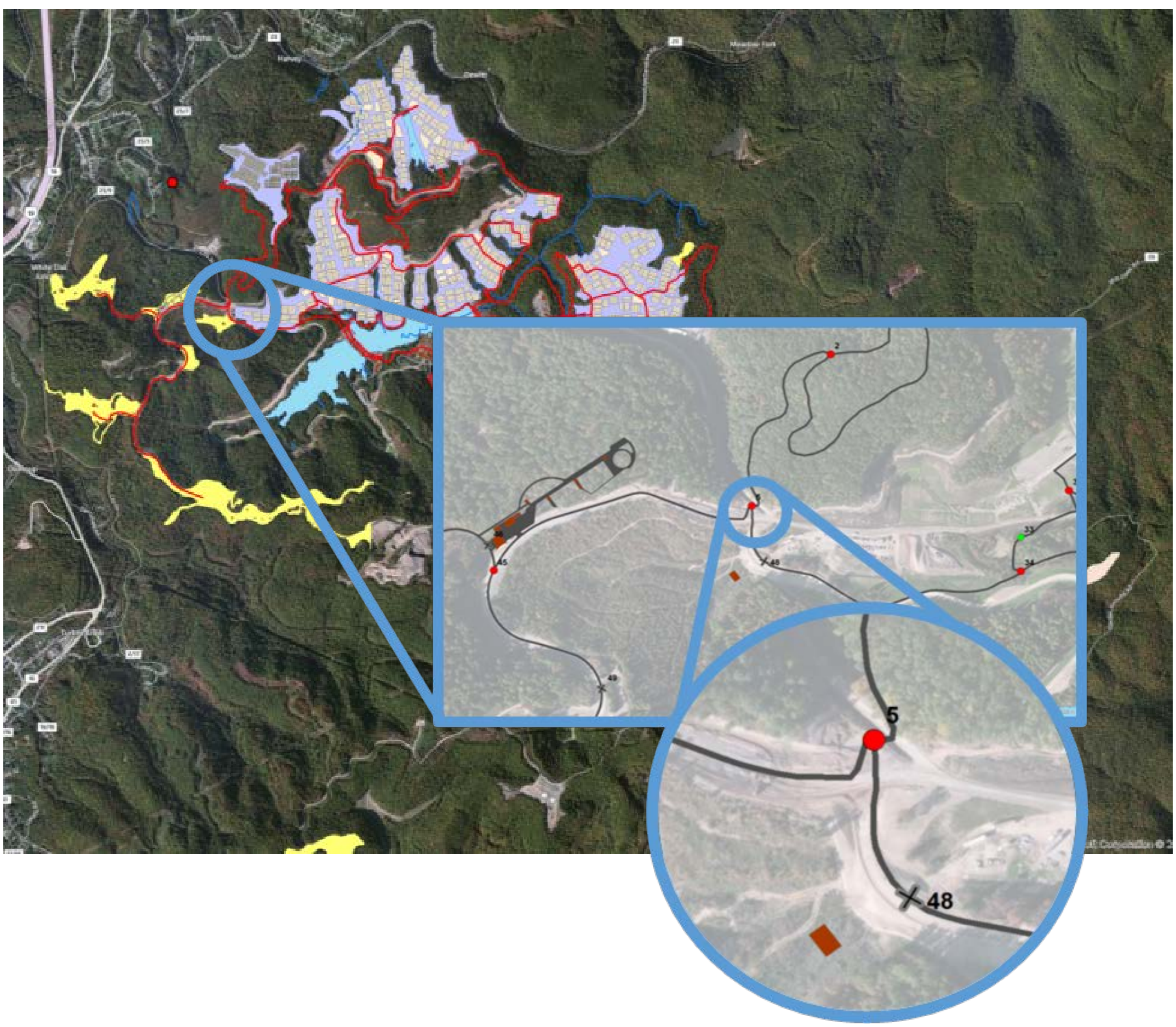
Figure 9: Computational Model Flow Diagram

Micro-scale Model

Micro-scale model is an agent-based microsimulation model operated in VisWalk, a component of PTV's VISSIM transportation simulation package. The microsimulation models estimate the pedestrian demands placed on each trail segment at each time step of an analytical period. These expected pedestrian demands can be compared with the pedestrian capacity for trail segments to evaluate whether or not demand for use exceeds a trail segment's capacity. These demand-capacity evaluations can be conducted based on a number of criteria, including those that prioritize the service quality of facilities and those that prioritize the experiential characteristics of pedestrians.

Micro-scale models are data and computationally intensive and, consequently, cannot be run for the entirety of a complex trail network. This challenge is addressed by identifying critical analytical areas that are of greatest potential or consequence for capacity challenges. A three-way intersection was identified as the critical analytical area. This junction is utilized by approximately half of the pedestrians modeled and there is not alternative routing possible for pedestrians to reach their desired destinations. Figure 10 illustrates this critical analytical area.

Figure 10: Critical analytical area three-way junction



With the critical analytical area identified, the relevant input data are selected, formatted and exported from the computational model. These include the expected pedestrian loads from for each trail segment included in the micro-scale model at each time step. The critical area is extended for two trail segments on either side of the three-way junction to allow agents to populate the trail segment before analysis is conducted. Five minute time steps were used.

The micro-scale microsimulation models require a number of inputs in addition to pedestrian loads by segment and time step. These include:

- Pedestrian composition by gender and body size: For the purposes of this model, equal ratios of male and female agents were used. The default body size distributions from the modeling software were used.
- Pedestrian walking behavior distributions: The basic walking behavior of desired speed was set as a uniform distribution of 1.8 miles per hour. Selection of this speed distribution was based on the advice of project collaborators to reflect the travel speed of the modeled agents. Program default settings for acceleration, deceleration, and social forces were used.
- Routing Decisions: Routing decisions are based on the relative proportions of each route drawn from the origin destination matrix generated by the macro-scale network model and its inputs.

The microsimulation model is capable of estimating capacity and travel conditions for areas and individual pedestrians. Evaluation can be generated at the time-step level and aggregated for the analytical period. They include:

- Density ($^{area}/_{person}$)
  - Time step: the area of the analytical area divided by the number of pedestrians within the analytical area for each time step
  - Aggregated for the analytical period: the area of the analytical area divided by the average number of pedestrians with the analytical area for all time steps
- Flow Rate (($^{\#\ pedestrians}/_{time}$)$/_{width}$)
  - Time step: the number of pedestrians flowing through the perpendicular linear centroid of the analytical area, divided by the number of minutes between time steps, divided by the width of the length of the perpendicular linear centroid, for each time step
  - Aggregated for the analytical period: the number of pedestrians flowing through the perpendicular linear centroid of the analytical area, divided by the number of minutes between time steps, divided by the width of the length of the perpendicular linear centroid, averaged for all time steps
- Speed Delta (Desired Speed – Modeled Speed)
  - Time step: the difference between desired speed and modeled travel speed, after accounting for social force acceleration and deceleration, averaged for all agents within the area, for each time step
  - Aggregated for the analytical period: the difference between desired speed and modeled travel speed, after accounting for social force acceleration and deceleration, averaged for all agents within the area, averaged for all time steps

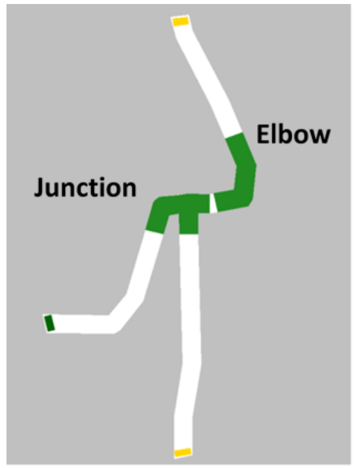
In addition to these numerical outputs, visual simulations can be generated in the form of video animations. While these animations do not contain detailed information, they provide context and richness of impression that the numerical outputs do not. Because of this, video animations can be particularly valuable outputs when communicating modeling results with lay audiences.

3. Results

The primary result of the work conducted under this grant is the development foundational expertise in adapting and applying integrated modeling techniques for transportation and recreation in parks and public lands. This foundational expertise is evidenced in the numerous externally funded research projects that grant recipients and cooperators have developed. Additionally, it is extended beyond the core work of the grant via graduate student education, the effectiveness of which is demonstrated in the awards and fellowships collaborating students have earned.

Results specific to the Bechtel Summit Reserve models evaluate the system function and experiential quality of critical pedestrian transportation facilities. These results are generated for two analytical areas of the critical three-way junction identified through the macro-scale network model. These areas, depicted in Figure 11, are designate the “elbow” and the “junction.”

Figure 11: Analytical areas in of the three-way junction



Numerical results for the output variables of density, flowrate, and speed, along with additional descriptive data of service quality, are generated for both areas. The condition of output variables are evaluated in comparison to the Levels of Service framework for pedestrian walkways as published in the Highway Capacity Manual and indicators and standards as applied in the field of park and recreation management.

Table 4 presents the results of microsimulation of average aggregated pedestrian volume demands placed upon the three-way intersection throughout the analytical period. These demands are the initially estimated by the macro-scale network model, processed through the computational model, and then simulated in time and space via the microsimulation model.

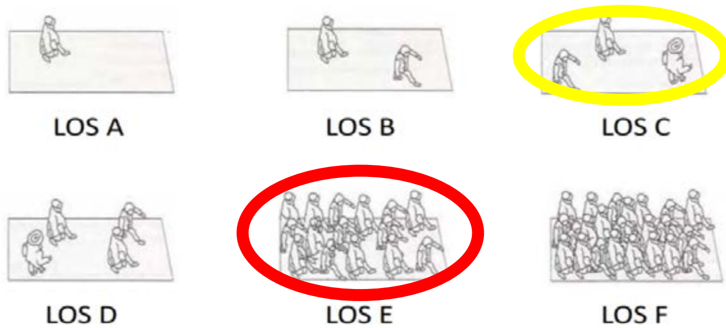
Based on all three output variables (density, volume, and speed), when evaluated against LOS criterial for pedestrian walkways, service and experiential quality for both the elbow and junction analytical areas is fair to poor. For the output variables of density (and its inverse space) and speed, LOS service quality is coded as E, or approaching system failure. Flow rate is evaluated at LOS C, the minimum acceptable service.

Figure 12 provides a standardized illustration of the conditions estimated by the microsimulation model.

Table 4: Results of three-way microsimulation analysis

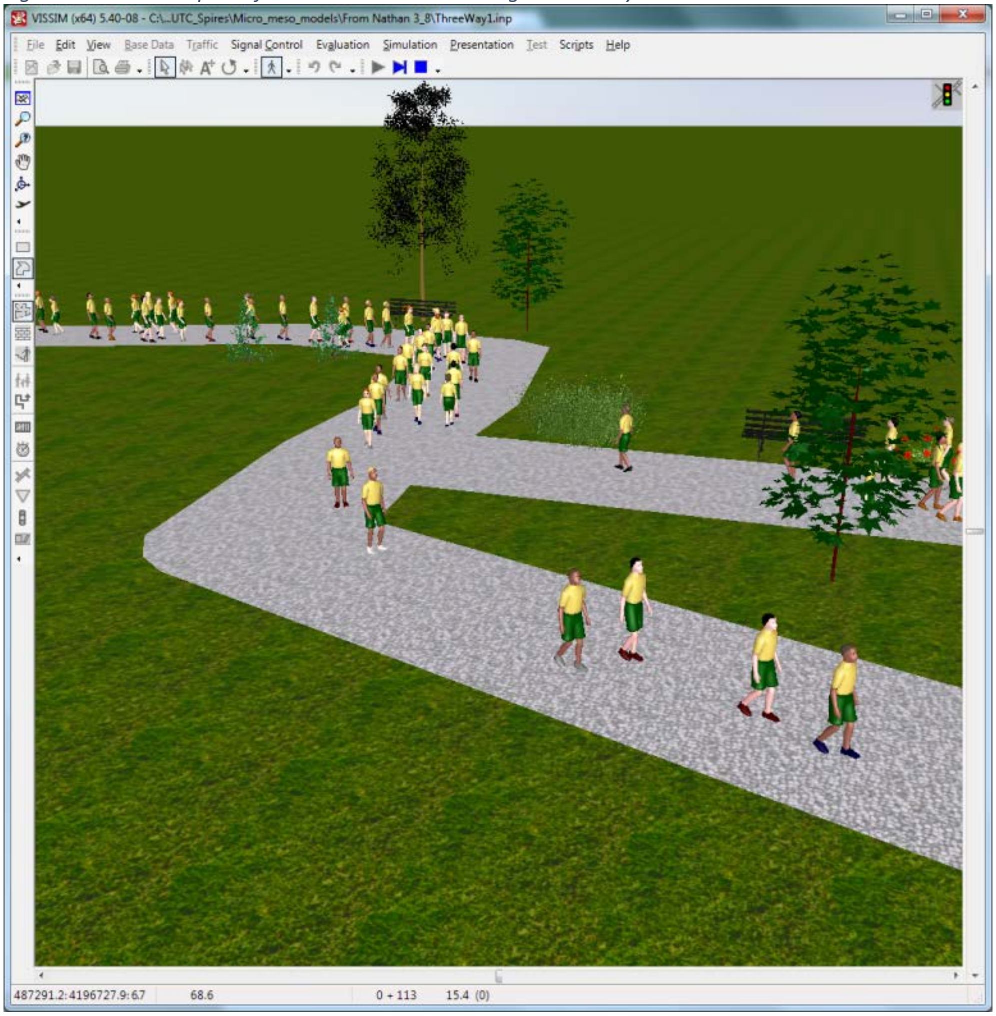
Variable	Units	Junction	Elbow	Flow Rate (n/min/ftwidth)	
Source Volume	N	14.18	9.63		
Pedestrians N	N	17.24	15.47	8.62	7.73
Density	n/m^2	0.24	0.22		
Space	ft^2/n	13.70	10.61	ft/s	
Desired Speed	km/h	4.49	4.56	4.09	4.16
Speed	km/h	3.71	3.69	3.38	3.36
Total Delay	ss	1.91	2.77		
Total Distance	ss	12.07	15.96		

Figure 12: LOS representations for the resulting system function and experiential conditions for the three-way intersection



In addition to the numerical data generated by the coupled macro- and micro-scale modes, video animations representing service quality and experiential conditions are generated. While these animations do not contain detailed information, they do provide context and richness of impression that the numerical outputs do not. Because of this, video animations can be particularly valuable outputs when communicating modeling results with lay audiences. Figure 13 presents a representative frame of this video for the junction analytical area. This video depicts a levels of service in the C to E range.

Figure 13: Screen capture from the video animation generated by the microsimulation model



4. Implementation/Information Transfer

The research presented in this report formed the core of an expanded and continuing program of research to develop and apply simulation models for planning and management of recreation and transportation in tourism and outdoor recreation settings. This expanded and continuing research is made possible with the foundational expertise developed through the completion of the primary research funded by the UTC program. The techniques and conceptual understandings generated using UTC support enabled development of proposals for externally supported research, opportunities for student engagement and achievement, and service to recreation and transportation professional communities, including:

- Participation in National Socio-Environmental Synthesis Center (SESYNC) programs
- Monitoring and Evaluation of Recreation in the White Mountain National Forest
- Research to Support Visitation Estimation and Transportation Planning in Acadia National Park
- UVM Transportation Research Center Student Engagement and Achievement
- Transportation Research Board Public Lands – Pedestrian Modeling Liaison

SESYNC Programs

The National Socio-Environmental Synthesis Center (SESYNC) is a National Science Foundation funded interdisciplinary research center operated by the University of Maryland. Their programs bring together researchers and scholars from a diverse range of disciplines to work collaboratively to identify solutions to complex socio-environmental problems. Their approach focuses on synthesis that integrates disparate data, methods, and theories in novel ways to generate usable information and accelerate scientific understanding. The synthetic and interdisciplinary emphasis of SESYNC mirrors the collaborative and multidisciplinary effort of this research project.

The recreation and transportation modeling conducted as part of this UTC funded research project resulted in three distinct and complementary engagements with SESYNC, including: invitation to participate in a workshop called Visualization Technologies to Support Research on Human-Environment Interactions; participation in the Summer Computational Institute and Software Carpentry Bootcamp; and submission of a proposal to the Data-Intensive Modeling thematic pursuit within SESYNC. It is important to note that participation in SESYNC programs should be considered awards of high prestige. Invitation to SESYNC programs is highly competitive and, upon acceptance, SESYNC fully supports all costs of participation as well as supplying software, cyberinfrastructure, and technical support for participating individuals and projects.

Visualization Technologies to Support Research on Human-Environment Interactions

SESYNC hosted the Visualization Technologies to Support Research on Human - Environment Interactions Workshop in July of 2012 to focus specifically on the visualization and use of spatial datasets from the social and environmental sciences. The workshop discussed and identified some of the current visualization challenges and emerging opportunities in application of spatial datasets to the study of human-environment interactions. The meeting was a 'problem-solving' workshop wherein domain scientists from the social and environmental sciences were able to learn visualization tools and access resources for their work, and computational scientists were able to learn about the as-yet unmet visualization needs in the domain sciences. This description was provided by SESYNC.

The visualization workshop informed the development of alternatives for modeling approaches and scenario design, as well as approaches for displaying model outputs for maximum accessibility to and impact on research stakeholders including policy makers, recreation and transportation planners, and the public. Participation in the workshop directly preceded a site visit to the case study modeling site (Bechtel Summit Reserve) in West Virginia. The exercises and sessions of the workshop afforded project collaborators an excellent opportunity to immerse themselves in model data visualization techniques at a critical time just before visiting the case study site for model development planning.

Summer Computational Institute and Software Carpentry Bootcamp

SESYNC hosted small teams of researchers for a one-week Computational Summer Institute on conducting data-driven, socio-environmental synthesis research in July of 2014. The workshop offered participants hands-on training in managing the lifecycle of their data and code with a focus on using open source tools, including R. Topics included:

- best practices and techniques for collaborative code development;
- developing and testing code for data management, modeling, and analysis; and

- visualizing and disseminating results.

The beginning of the week consisted of a Software Carpentry workshop (http://software-carpentry.org/index.html). Software Carpentry is a set of related software programs and skills that facilitates flexible and open-ended management, querying, and analysis of large and asymmetric datasets.

Following the Software Carpentry bootcamp, PSL and ATR researchers worked with SESYNC computational scientists and database managers to streamline and standardize model structures and queries. These processes transformed the initial, site-specific model interfaces developed by the research team into generic data and model structures capable of adaptation to diverse research sites and contexts.

Data-Intensive Analysis & Modeling for Socio-Environmental Synthesis

In 2014, SESYNC solicited proposals for research in data-intensive analysis and modeling. The integrated transportation and recreation modeling approaches developed with support from the UTC grant are quintessential examples of data-intensive modeling designed to address socio-environmental problem solving. The UTC project resulted in a proposal submitted to SESYNC for consideration.

White Mountain National Forest

The White Mountain National Forest (WMNF) conserves several ranges of the east coast's most dramatic mountains. With forest districts in northern New Hampshire and western Maine, the WMNF is a quintessential multiple use forest. It protects rare and valuable landscapes, including the greatest extents of alpine habitat in the eastern United States. The forest supplies timber, water and wildlife and other resources of utilitarian value. The WMNF is perhaps best known and appreciated for the recreational opportunities it provides.

The WMNF is within a day's drive of nearly 60 million residents of the United States and Canada, including more than 3 million potential recreationists residing within 100 miles of the forest (WMNF, 2005a). A range of recreational opportunities are available to WMNF visitors. These include typical forest recreation activities including hiking, camping, nature viewing and dispersed motorized recreation. The WMNF also offers diverse developed recreational opportunities like scenic driving and picnicking. In addition to these typical recreation opportunities, the WMNF also offers characteristic and special recreation opportunities including rock climbing, alpine recreation, and a diversity of motorized, non-motorized, developed, and primitive winter recreation activities. Annual recreational visits for all of these activities combined total nearly 5 million (WMNF, 2005a).

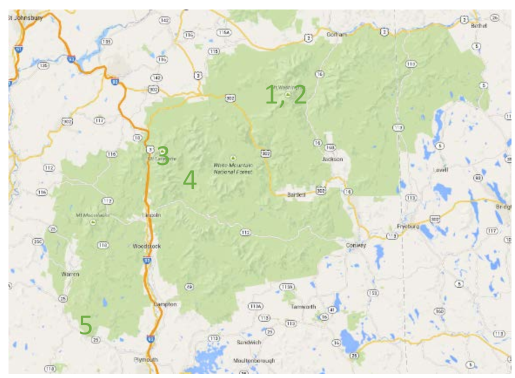
Recreation use, in particular use as intensive as that received by the WMNF, has potential to impact the quality of forest resources and visitor experiences. These impacts can be diverse, affecting natural, social and administrative elements of the WMNF. Natural resource impacts affect the quality of air, water, soils, vegetation, wildlife, soundscapes, scenery, and night skies, among other resources. Social impacts can include crowding among recreationists, conflict between recreationists, and depreciative behavior that intentionally or unintentionally propagates impacts. Forest infrastructure, including trails, roads, parking, campsites, and other facilities, can also be impacted by the magnitude, distribution or behavior of recreation use on the forest (Manning and Anderson, 2012). The full range of impacts from recreation occurs on the WMNF, and their extent is documented in the series of annual Monitoring and

Evaluation Reports available at http://www.fs.usda.gov/detail/whitemountain/maps-pubs/?cid=STELPRDB5187780.

While annual monitoring and evaluation reports provide extensive information on the quality of forest resources, including recreational resources, little is known about the experiential qualities associated with recreation on the WMNF (DuRocher, 2011). Of particular deficiency is monitoring and evaluation about the quality of social experiences (i.e. crowding, conflict, etc.) along trails, at population attraction sites, and within the forests' Wilderness areas. Monitoring of trail use, and consequent social quality, is described as "very rough," with visitor compliance with counting methodologies as low as 20% and quality control being conducted "sparingly." No monitoring or evaluation data are being collected about the perceived quality of recreation experiences, crowding, or use of rock climbing areas, and the data that are being collected about the use of forest trails and the satisfaction of Wilderness users' needs improvement.

The Park Studies Laboratory (PSL) in the Rubenstein School of Environment and Natural Resources at the University of Vermont is supporting implementation of recreation and wilderness monitoring and evaluation for the White Mountain National Forest (WMNF). Research conducted by the PSL will both fulfil the WMNF Monitoring and Evaluation Guide questions and inform future recreation planning and management efforts. Collaboration between PSL and WMNF staff identified a set of recreation areas and experiences for monitoring and evaluation. These locations and experiences were chosen because they represent exemplary, iconic, or characteristic recreational experiences in the WMNF, are of user capacity related management concern, and span a diverse range of geographies and recreational activities.

Site	Recreation Area	Recreation Experience Concern
1	Crawford Path	Trail crowding & conflict
2	Gulfside Trail, Mt. Jefferson	Trail crowding & conflict; Summit crowding & conflict
3	Franconia Ridge Trail, Mt. Lafayette	Trail crowding & conflict; Summit crowding & conflict
4	Pemigewasset Wilderness	Wilderness camping use & capacity
5	Rumney Rocks Climbing Area	Parking capacity & route displacement



The summer field season of 2014 was dedicated to documenting and quantifying recreation use occurring at the selected areas to help answer the visitor use questions of the Forest Monitoring Plan. This memorandum presents a summary of the field data collection effort from 2014, preliminary results from the season's recreation monitoring, and the next steps in analysis and reporting. The preliminary results presented here are summarized in three categories: trails, wilderness camping, and Rumney Rocks. The information provided in this memorandum illustrates the types of monitoring data gathered, initial analyses, and preliminary findings.

2014 Field Data Collection Effort

Field data collection for the 2014 recreation monitoring season began July 1 and concluded November 21. Primary data collection included the deployment of trail counters, calibration of trail counter, photography of trail use, counts of mountain summit use, collection of travel times and group sizes, counts of cars in parking lots at Rumney Rocks, self-reports of climbing displacement at Rumney Rocks, and counts of campers in the Pemigewasset Wilderness. This section briefly summarizes the data collection effort of 2014.

Trail counters were deployed in the three trail-based recreation sites (Crawford Path, Gulfside Trail, and Franconia Ridge Trail) and at Rumney Rocks. At trail-based recreation sites, trail counters monitored the volume of trail users. At Rumney Rocks, the trail counters supply a proxy for modeling and monitoring parking lot occupancy. Calibration counts were conducted for each trail counter. Calibration counts allow error in counter estimates to be corrected and provide direction of travel data.

Trail Counter Effort

Recreation Site	# of Counters	# of Counter Days	# of Calibration Periods
Crawford Path	2	104	259
Gulfside Trail	3	105	120
Franconia Ridge Trail	2	137	194
Rumney Rocks	5	143	154
Total	*12*	*1,512*	*727*

Photographs of trail use were collected at one minute intervals along defined sections of the three trail-based recreation sites. These photos provide data on crowding along trails in terms of both visual and spatial density. Similar data was observed directly for mountain summits at the Gulfside and Franconia Ridge Trails. Travel time and group size observations will be combined with trail counter data to model inter-group encounters and other measures of crowding and recreation quality on trails and mountain summits.

Photographic Observation and Summit Count Effort

Recreation Site	# of Photographs	# of Summit Counts	# Travel Speeds & Group Sizes
Crawford Path	1,398	N/A	192
Gulfside Trail	637	151	124
Franconia Ridge Trail	1,081	139	386
Total	*3,116*	*290*	*702*

Data collection efforts specific to Rumney Rocks included vehicle counts in parking lots and administration of climbing displacement self-reports. Counts of the number of vehicles in both Rumney Rocks parking lots were conducted 96 times. Self-report climbing displacement cards were returned by 357 climbing parties at Rumney Rocks.

Appalachian Mountain Club (AMC) staff at four tent camps in or adjacent to the Pemigewasset Wilderness collected 165 observations of tent camp occupancy. This data was collected in a format specified by PSL researchers. The contribution of AMC is greatly appreciated and was instrumental in the success of Pemigewasset Wilderness camping analysis.

2014 Preliminary Results

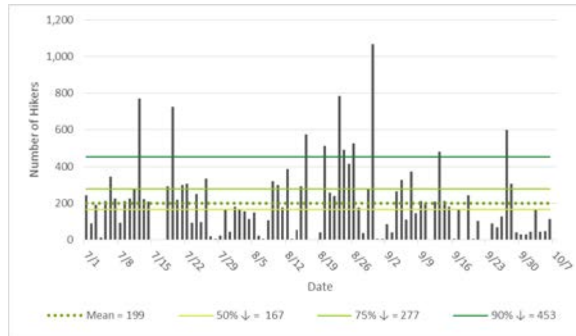
Trails

Trail-based monitoring and evaluation include the Crawford Path north of the Lakes of the Clouds, Gulfside Trail south of Mt. Jefferson, and the Franconia Ridge Trail south of Mt. Lafayette. This memo presents daily counts of hikers on each trail section, average numbers of hikers by day-of-week and hour-of-day, and the pattern of attenuation of large groups along trail segments.

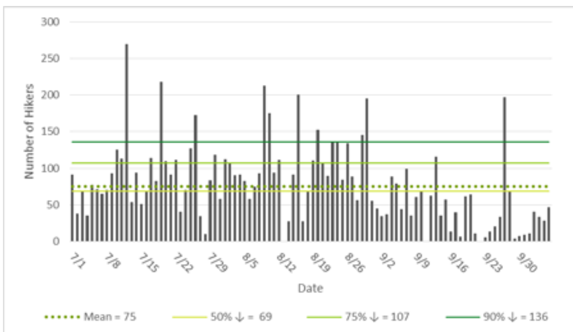
Daily Trail Use

In general, use of trails can be highly variable, dependent upon daily weather, day of the week, and time of the year. The Crawford Path and Franconia Ridge Trails both received maximum use levels of approximately 1,000 hikers/day. On the busiest 10 % of days, more than 450 hikers use the Crawford Path, nearly 400 people hike the Franconia Ridge, and more than 135 people hike on the Gulfside Trail south of Mt. Jefferson. Use of trails can also be highly concentrated, in time. Crawford Path and Gulfside Trail receive peak hiking use during the summer months, while Franconia Ridge peak use extends into the early fall.

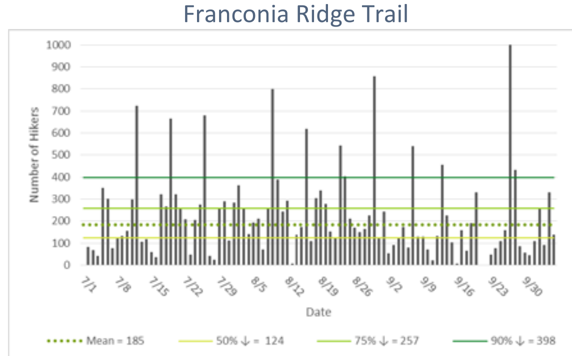
Crawford Path



Gulfside Trail



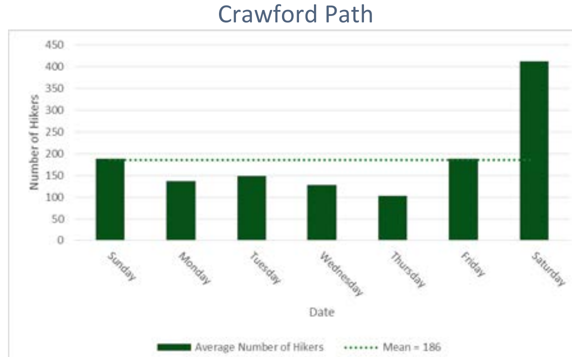
Franconia Ridge Trail



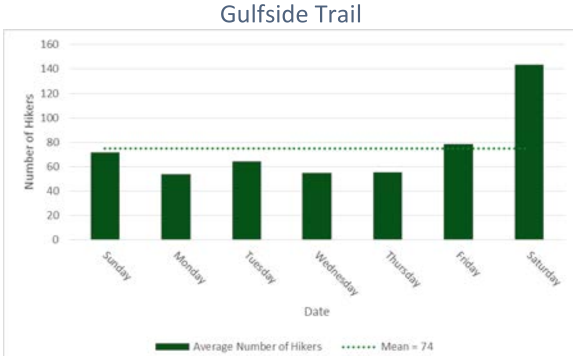
Trail Use – Average by day-of-week

Saturdays exhibit the highest average daily trail use, often more than doubling the average number of hikers for other days of the week. Saturday use on the Crawford Path and Franconia Ridge Trail averages more than 400 hikers/day. Sunday hiking use on the Franconia Ridge trail is substantially higher than weekday trail use. Sunday trail use on the Crawford Path and the Gulfside Trail is similar to Friday levels, as well as mid-week use levels. The Crawford Path and Franconia Ridge Trails have similar average daily usage, with the Franconia Ridge Trail receiving greater average usage on Saturdays and Sundays.

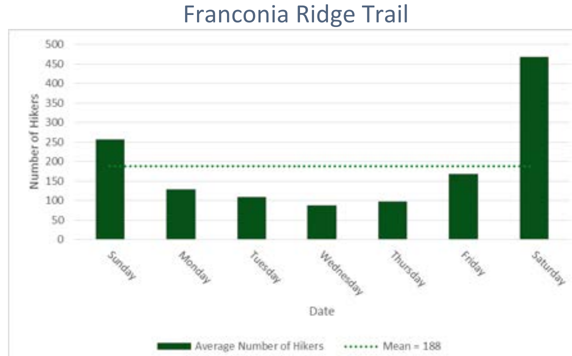
Crawford Path



Gulfside Trail



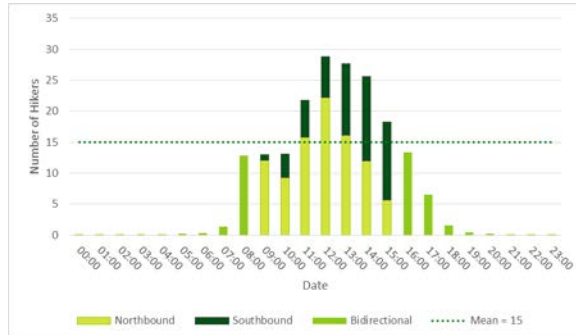
Franconia Ridge Trail



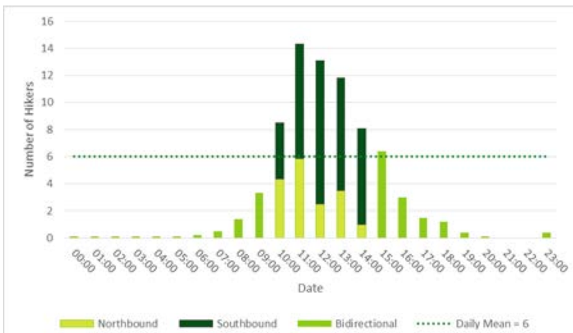
Trail Use – Average by hour-of-day

All three trails exhibit a similar pattern of use throughout the day, increasing through the morning, peaking at mid-day, and decreasing in the afternoon. Peak use on the Franconia Ridge Trail reaches 40 hikers/hour. Peak use on the Crawford Path peak is somewhat lower (25 – 30 hikers/hour), but last longer (3 – 4 hours). On the Crawford Path most hikers travel north in the morning and south in the late afternoon, most likely due to overnight use at the Lakes of the Clouds. Most Gulfside and Franconia Ridge Trail hikers travel in a single direction.

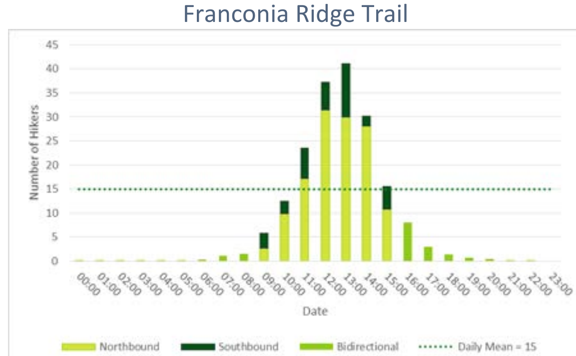
Crawford Path



Gulfside Trail



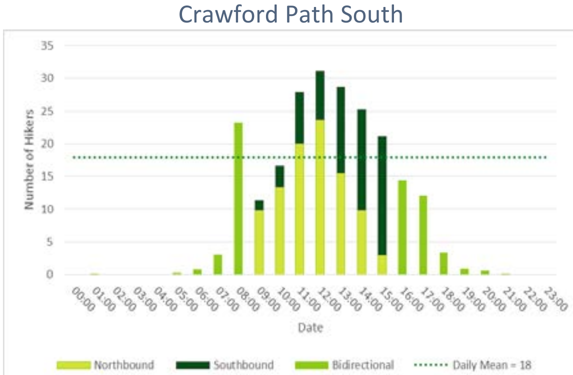
Franconia Ridge Trail



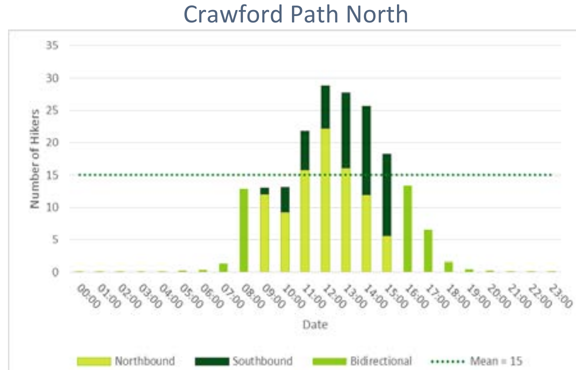
Trail Use – Attenuation of large groups

The pattern of overnight use of the Lakes of the Clouds Hut has potential to generate large pulses of trail users. These pulses are a product of the number of hikers staying at the hut and the scheduled programs the hut offers. A characteristic of these pulses is evident in the hourly average number of hikers passing the Crawford Path South counter during the 8:00 hour. This pulse is likely the result of the hut's breakfast schedule, served at 7:00, and hikers' desire to begin their ascent of the Crawford Path shortly afterward. These pulses, however, may quickly attenuate over relatively short distances. Hourly average counts from the Crawford Path North counter, 0.7 miles north along the trail from the Crawford Path South counter, suggest that the concentrated pulse of hikers generated by the Lakes of the Clouds Hut disperses over the distance between the two counters.

Crawford Path South



Crawford Path North



Wilderness Camping

Wilderness camping use and capacity was monitored for four back-country camps in the Pemigewasset Wilderness: Liberty Springs, Garfield Ridge, Guyot, and Thirteen Falls. Each of these camps has a number of tent platforms that are sized to accommodate either a single backpacking tent or two tents. It is assumed that a standard backpacking tent can accommodate two people, thus a single tent platform has a capacity of two people and a double platform has a capacity of four people. Guyot and Garfield Ridge also have shelters that can accommodate overnight users.

Tent camper capacity ranges from a minimum of 16 tent campers at Guyot to a maximum of 26 at Liberty Springs. These tent sites have a total capacity of 84 tent campers per night.

Tent Camper Capacity by Camp in the Pemigewasset Wilderness

Camp Name	Tent Sites		Tent Camper Capacity
	Double	Singles	
Liberty Springs	3	7	26
Garfield Ridge	5	2	24
Guyot	2	4	16
13 Falls	0	9	18
		TOTAL	*84*

Average tent camper occupancy is the average number of tent campers observed in each camp, divided by the number of observations collected. Note, the number in parentheses after each camps' name is the design capacity for each camp based on the number and size of tent platforms.

Average Tent Camper Occupancy

	Liberty Springs (*26*)	Garfield Ridge (*24*)	Guyot (*16*)	Thirteen Falls (*18*)	*Pemigewasset Wilderness* (*84*)
Sunday	21	6	22	9	*58*
Monday	26	10	28	8	*72*
Tuesday	21	27	31	10	*89*
Wednesday	24	22	29	14	*89*
Thursday	25	28	31	10	*94*
Friday	20	27	37	14	*98*
Saturday	49	34	50	26	*159*

The percent of nights observed over tent camper capacity is the percentage of nights where the number of tent campers at each site exceeded the capacity of each camp. All camps, with the exception of Thirteen Falls, exceed capacity every Saturday night. Guyot tent camping use was in excess of capacity every night on which observations were collected.

Percent Night Observed over Tent Camper Capacity

	Liberty Springs	Garfield Ridge	Guyot	Thirteen Falls
Sunday	20%	0%	40%	0%
Monday	33%	17%	60%	0%
Tuesday	0%	40%	75%	13%
Wednesday	40%	33%	80%	25%
Thursday	40%	67%	80%	13%
Friday	20%	67%	100%	25%
Saturday	100%	100%	100%	75%

The percent of tent camper capacity presents the average number of tent campers per camp as a percentage of each camp's capacity. For example, average tent camper use at Liberty Springs on Saturday nights is 188% percent of the camp's tent camper capacity. Percentages greater than 100% indicate that a camp's average use is in excess of its designed capacity. In general, tent camping use in the Pemigewasset Wilderness is in excess of the wilderness's designated site capacity.

Percent of Tent Camper Capacity

	Liberty Springs	Garfield Ridge	Guyot	13 Falls	*Pemigewasset Wilderness*
Sunday	81%	25%	138%	50%	*69%*
Monday	100%	42%	175%	44%	*86%*
Tuesday	81%	113%	194%	56%	*106%*
Wednesday	92%	92%	181%	78%	*106%*
Thursday	96%	117%	194%	56%	*112%*
Friday	77%	113%	231%	78%	*117%*
Saturday	188%	142%	313%	144%	*189%*

Rumney Rocks

Vehicle parking and climbing route displacement are the two elements of recreational use that were monitored at Rumney Rocks.

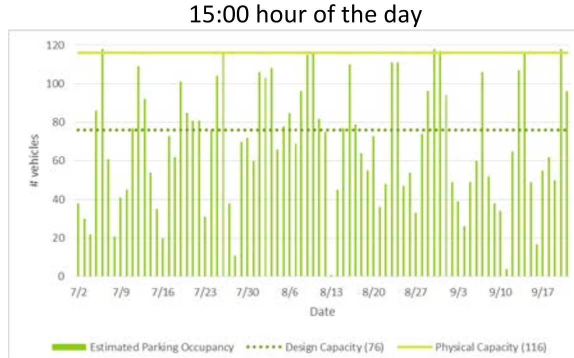
Vehicle Parking

Vehicle parking at Rumney Rocks has capacity and occupancy dimensions: parking capacity is the number of vehicles Rumney Rocks parking lots are designed to accommodate; parking occupancy is the number of vehicles parked in the Rumney Rocks lots at one time. These can be thought of as supply of and demand for parking. Parking capacity is determined by physical space (shape and size) and administrative policy. The WMNF INFRA database shows that Rumney Rocks has a capacity of 76 vehicles: 16 in the main cliff lot (west) and 60 in the main (east) lot. The 60 vehicle capacity for the main lot is substantially lower than the physical capacity of the lot. This capacity may not have been updated since the lot was expanded with new parking on the lot's eastern end. A conservative estimate for this expanded lot is 100 vehicles: 60 in the old section and 40 in the new section. To reflect this discrepancy, two capacities are used for analysis, one called Design Capacity that reflects WMNF's administrative guidance of 76 vehicles, and one called Physical Capacity (116 vehicles; 76 from the original design capacity plus 40 from the newer main lot expansion) that reflects an estimate of the total physical capacity of Rumney Rocks parking lots.

	Parking Occupancy and Capacity	**10:00**	**15:00**
	Total number of days	82	82
Parking Occupied	Average estimated parking occupancy	34	69
Parking Occupied	Median estimated parking occupancy	28	70
Parking Occupied	75th percentile estimated parking occupancy	49	96
Parking Occupied	90th percentile estimated parking occupancy	65	111
Parking Capacity	Number of day in excess of capacity	4	34
Parking Capacity	Percent of days in excess of capacity	5%	41%
Parking Capacity	Average number of excess vehicles when capacity is exceeded	79	100
Parking Capacity	Average percent of capacity when capacity is exceeded	4%	131%

Parking occupancy at Rumney Rocks was modeled using automated trail counters installed along the trails leaving parking lots to access climbing routes. Regression modeling defines a strong relationship between the number people hiking climbing access trails and the number of vehicles parked in Rumney Rocks parking lots ($y = -0.0003x^2 + 0.377x$; $R^2 = 0.9041$). Consequently, automated trail counters can be used to model and monitor parking occupancy.

<table>
<tr><th colspan="2">Parking Occupancy & Capacity at Rumney Rocks</th></tr>
<tr><td>At 10:00, parking occupancy is estimated to seldom reach design capacity (76 vehicles) and never approaches the physical capacity (116 vehicles) of the lots. Parking occupancy is highest on weekends.</td><td>10:00 hour of the day

</td></tr>
<tr><td>At 15:00, parking occupancy is estimated to regularly exceed the design capacity and often reach the physical capacity of the lots. Parking occupancy occurs on the weekends. Weekdays also exhibit estimated parking occupancy in excess of the lots' design capacity.</td><td>15:00 hour of the day

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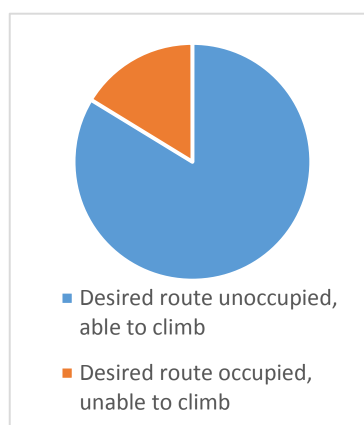
</table>

Eighty-two days of parking occupancy data are included in this summary. The table to the right presents a summary of estimated parking occupancy, and compares estimated parking occupancy with parking design capacity (76 vehicles). Data are presented for both the 10:00 and 15:00 hours.

During the 15:00 hour, parking occupancy in the Rumney Rocks lots averaged 69 vehicles. 70 or more vehicles are estimated to have occupied the parking lots on half of the days monitored. 25% of days had 96 or more vehicles. 10% of days had 111 or more vehicles in the lots. Based on these values, parking occupancy exceeded parking capacity on 34 out of the 82 days (41%). On these days, an average of 100 vehicles occupy the parking lots, or24 in excess of design capacity. 100 vehicles is 131% of design capacity and 86% of physical capacity.

Climbing Route Displacement

Displacement occurs in recreation when individuals or groups are not able or choose not to visit a recreation location because the conditions have become unsatisfactory. Displacement often occurs because of crowding or conflict. When climbers at Rumney Rocks cannot climb a desired route because it is occupied, displacement occurs. Climbers cope by waiting for the route to be free or moving on to an alternate route. Of 375 self-reported attempts to climb a desired route, 61 instances of displacement were reported. This represents a 16.3% preliminary displacement rate among self-reported observations.



Summary

These preliminary results will inform a second phase of analysis that will employ the simulation modeling approaches developed at the Bechtel Summit Reserve. Specifically the trail use data, along with parking lot use estimates and camping capacity evaluations, will be combined with simulation models of trail use to estimate the service and experiential quality along trails in the White Mountain National Forest. These models will enable monitoring of trail and recreation conditions, as well as evaluation of recreational satisfaction and forest visitors carrying capacity.

Acadia National Park Visitation Estimate

Acadia National Park is perhaps the most intensely visited unit of the National Park System when both the volume of use and the land area of the park are considered. Consequently, Acadia park managers have ongoing concerns with the demands visitor use places on the park's transportation network, particularly with respect to carrying capacity, system function, and experiential quality. The University of Vermont and its collaborative partners at RSG Inc have submitted a proposal to help Acadia evaluate, plan for, and manage coupled visitor use and transportation systems in the park. The foundational expertise necessary to complete this work was developed through execution of this UTC grant. The proposed research includes development of coupled transportation and recreation spatial, statistical, and simulation models based on the approaches pioneered at the Bechtel Summit Reserve. These models will address transportation and recreation quality at three sites: Cadillac Mountain, Ocean Drive, and Jordan Pond.

Cadillac Mountain Model

Cadillac Mountain is identified as a high priority management issue in every dimension of the transportation data needs assessment: safety and congestion, visitor experience, natural and cultural resources, transportation geometry and large vehicles, demand and capacity. The Cadillac Mountain transportation system includes the Cadillac Mountain Road, parking at the summit, the summit loop trail, and the hiking trails leading to the summit. Several interconnected transportation and visitor use management issues are occurring on Cadillac including road congestion and safety hazards, parking capacity challenges, and visitor experience and resource protection problems on the mountain's summit.

Model Element	Management Challenge Addressed	Information Delivered
Road	▪ Congestion ▪ Safety ▪ Visitor Experience	▪ Vehicle volume, class, speed ▪ Traffic patterns ▪ Levels of Service
Parking	▪ Capacity ▪ Congestion ▪ Resource impacts	▪ # vehicles in parking lots ▪ Vehicle to capacity ratios ▪ Temporal and spatial patterns
Summit	▪ Crowding ▪ Soil & vegetation impacts	▪ Indicators & Standards for crowding ▪ Off-trail hiking rates

An interconnected set of road, parking, and pedestrian models will be delivered to address management challenges on the mountain road, in the parking lots, and along trails in the summit area. Statistical and simulation models are combined to provide a flexible tool capable of testing many road, parking, and pedestrian management alternatives. The information delivered from these models will characterize current road, parking, and summit transportation and visitor experience indicators. These indicators will be evaluated in comparison to standards established the body of social science conducted by the park, and with other standards. The Cadillac Mountain model will inform solutions for high priority safety, congestion, visitor experience, and park resource challenges.

Ocean Drive Model

Ocean Drive provides primary access to several of Acadia's most iconic features, including Thunder Hole, Sand Beach, and Gorham Mountain. Ocean Drive itself is a key element of most visitors' park experiences. Congestion on Ocean Drive, and its consequent impacts to visitor experiences and safety as well as transportation system performance, are identified as high priorities in both the transportation planning and the foundation document needs assessments.

Management of Ocean Drive begins with identification of desired visitor experiences for the road itself and the recreation sites to which the road provides access. The models proposed for Ocean Drive will help identify the transportation alternatives that best achieve these objectives. They will do this by estimating the visitor use levels and traffic patterns at key recreation sites and sections of Ocean Drive, given alternative road, vehicle, traffic, and parking configurations. These estimates of visitor use levels will be evaluated against standards for crowding, safety, and experiential quality from earlier park social science and from other sources. In doing so, the models will provide a powerful tool for integrated development and implementation of transportation and visitor use management plans.

Model Element	Management Challenge Addressed	Information Delivered
Road	▪ Congestion ▪ Safety ▪ Visitor Experience	▪ Vehicle volume, class, speed ▪ Traffic patterns ▪ Levels of Service ▪ Visitor road crossing safety
Parking	▪ Capacity ▪ Congestion ▪ Resource impacts ▪ Safety	▪ # vehicles in parking locations ▪ Vehicle to capacity ratios ▪ Temporal and spatial patterns ▪ Extent of unauthorized parking
Gorham Mountain & Beehive Trails	▪ Crowding & visitor experience	▪ Hiking encounters on the trail
Thunder Hole	▪ Crowding & visitor experience	▪ Indicators & standards for crowding

Jordan Pond Model

Traffic congestion and parking demand in excess of capacity are primary management issues for the Jordan Pond area. These issues are identified as high priority needs within the transportation plan needs assessment. Specifically, physical capacity for parking in the Jordan Pond area is substantially less than the demand for parking from current visitation. The excess demand manifests in visitor safety and experience concerns, as well as resource protection concerns from parking in undesignated areas.

The models proposed here are statistical models of vehicles on roads in the Jordan Pond area and their connection to parking demand and parking occupancy in both designated and undesignated areas. As parking demand builds through the day, visitors park in more distant and experientially marginal parking areas. Sometimes this marginal parking can be associated with safety concerns as visitors walk on roads to Jordan Pond facilities or resource protection concerns as soils and vegetation are impacted by undesignated parking and unimproved parking access trails. These models will allow monitoring and evaluation of parking related visitor experience, safety and resource protection impacts as they result from alternative traffic and parking scenarios.

Model Element	Management Challenge Addressed	Information Delivered
Road	▪ Congestion ▪ Safety ▪ Visitor Experience	▪ Vehicle volume, class, speed ▪ Traffic patterns ▪ Levels of Service ▪ Visitor roadside safety
Parking	▪ Capacity ▪ Visitor experience ▪ Resource impacts ▪ Safety	▪ # vehicles in parking locations ▪ Vehicle to capacity ratios ▪ Temporal and spatial patterns ▪ Extent of unauthorized parking ▪ Parking related visitor experiences

5. Conclusions

In building foundational research expertise in simulation modeling for integrated transportation and recreation management, this research contributed both to UVM's mission and the Spires of Excellence Initiative, particularly the complex systems spire, as well as to advance the state of research and practice in the transportation and recreation fields.

The primary work of the grant supported development of a new, integrated, and pioneering approach to pedestrian modeling for recreation areas and public lands. Previous approaches to pedestrian modeling in these settings were insensitive to the spatial effects of recreation and public land facilities and behaviors. The new modeling approach developed here is spatially explicit at both the macro- and micro-scales. Additionally, the modeling platform builds on previous work by addressing both transportation system function, in terms of service quality and transportation efficiency, and recreational experiences, in terms of pedestrian experiential quality and normative acceptability. Both analytical perspectives are made operational at multiple scales including network-wide, critical site, and individual agent.

The integrated modeling approach developed during the primary work phase of this grant enabled development of a robust and diverse program of externally supported research. This research program developed new and interdisciplinary collaborations as well as advanced application core research clients. The collaborations with SESYNC advanced the technical capacity of our team in data and output visualization as well as data storage structure and model programing. The research programs developed for the White Mountain National Forest and Acadia National Park afforded applications of the modeling techniques that refined our approach and demonstrates its utility to recreation and transportation managers.

The foundational expertise developed through this grant was extended beyond its application to research projects – it helped students to learn and forward their careers. The theoretical and computational approaches to integrated modeling formed the basis for a PhD research fellowship that extended their application from remote and wild public lands to diverse urban and suburban tourism and recreation settings. Further, the significance and quality of the primary work conducted for this project was acknowledge by the University of Vermont's University Transportation Center with a Student of the Year award.

The development and demonstration of expertise in integrated transportation and recreation simulation modeling is a unique and desirable capability among universities. The technical capabilities built through this UTC grant enabled UVM researchers to pursue and secure externally supported research projects, facilitate outstanding student engagement and achievement, and provide service to the recreation and transportation professions.

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