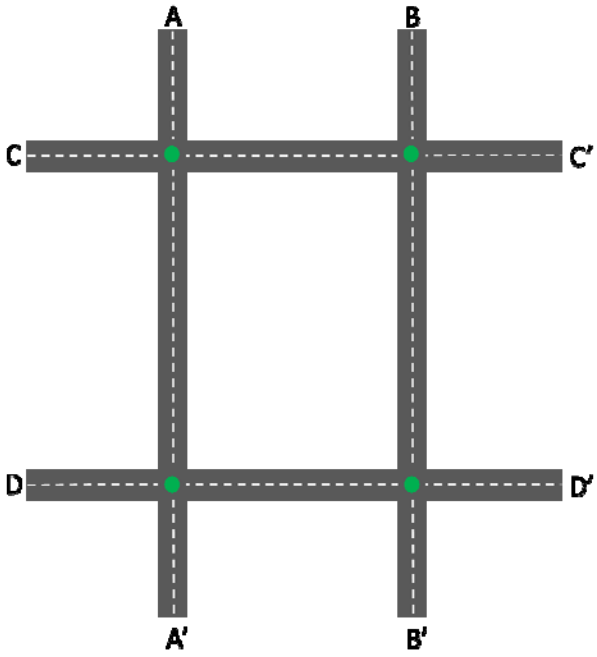
TLight: A traffic modeling and exploration tools

Requirements Definition

1 Introduction and Context

Understanding and optimizing traffic flow can be difficult, even in seemingly simple situations. For example, consider a small city area consisting of just two north-south streets and two east-west streets with traffic lights at all four intersections. See Figure 1. Obviously, poor timing of the lights will could slow the traffic flow, or even cause deadlock. However, optimizing traffic flow needs to take into account many variables such as: number of lanes; average speeds; vehicle frequencies; vehicle types with their size, acceleration capabilities, and turning patterns; accidents; and road obstacles. Using the map shown in Figure 1, assume that a large percentage of vehicles enter at point A and exit at points A' or D'. Effective time of the lights for this situation would be very different than for another situation where most of the traffic enters through C or D and exits at C'. In addition to vehicle frequencies, traffic patterns could be impacted by the expected size and type vehicle, because freight trucks, for example, accelerate much slower than passenger vehicles.

Figure 1 – Sample road layout with four intersections



This document describes the user goals and requirements for a software application, called *TLight*, that aims to help users model traffic problems and experiment with possible solutions. The target users of *TLight* include cartographers, traffic engineers, and analysis. Cartographers will use TLight to draw abstract street maps for the sections of a city that need to be studied. The traffic engineers will then use these maps to create various traffic models (i.e. simulations). Some of these models will try to emulate problems and other will describe solutions to those problems. The traffic engineers will be able to run any simulations multiple times. During each execution of a simulation, *TLight* will record key statistics and allow the user to save that data for further study and comparison by traffic analysts.

Section 2 describes the user and their goals in more detail. Section 3 describes functional requirements for a proposed set of software features that will satisfy these user goals. A suggested overall organization of the user-interface for these features is described in Section 4. The software will be built using an incremental development process, constrained by the non-functional requirements enumerated in Section 5.

Note that *TLight* is intended to be a lightweight tool that users of all level of computer skills should be able use. Furthermore, its features are intentional focused on the highest priority user goals and limited to those that can be completed in one month. Interesting features that cannot be included in the first version are listed in Section 6.

2 Users and Their Goals

The UML Use Case Diagrams in Figures 2-6 describe the key actors and user goals for *TLight.* The actors are color-coded by major area. Things shown in gray are secondary goals that do not have to be satisfied by the first version of the software.

Figure 2 – Key Actors

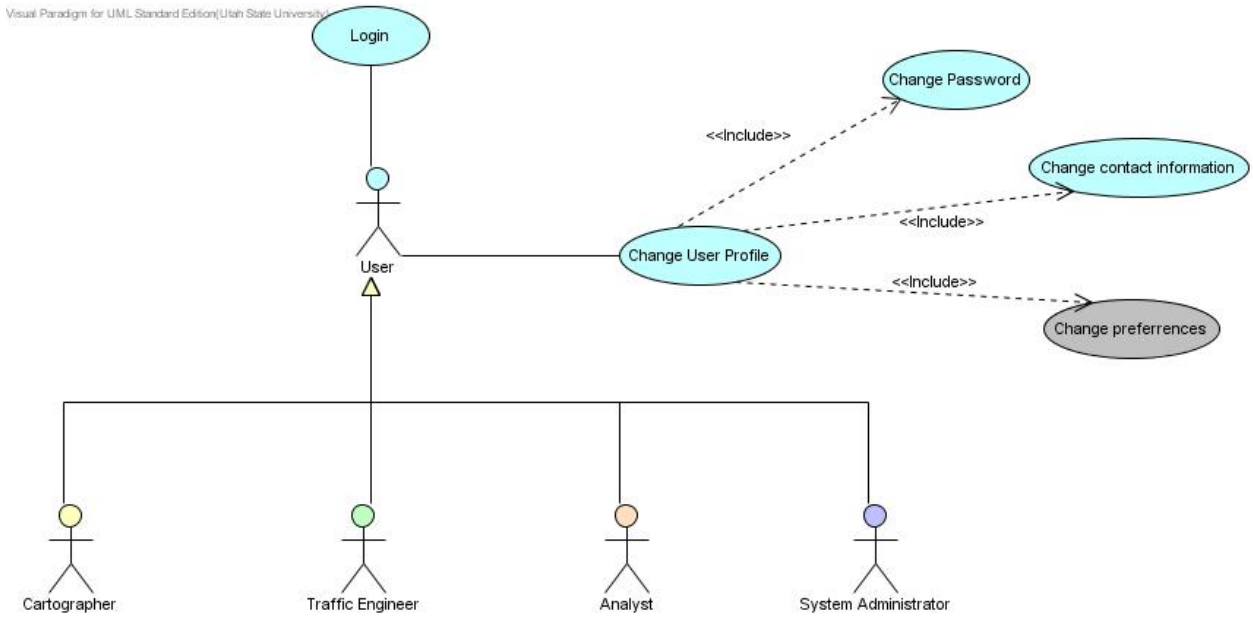


Figure 3 – Cartographer Goals

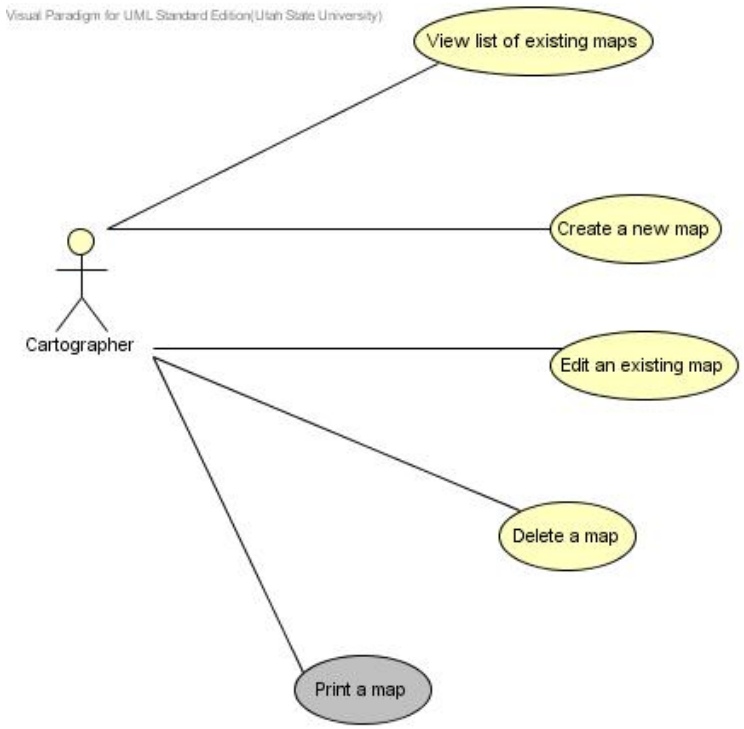


Figure 4 – Traffic-engineer Goals

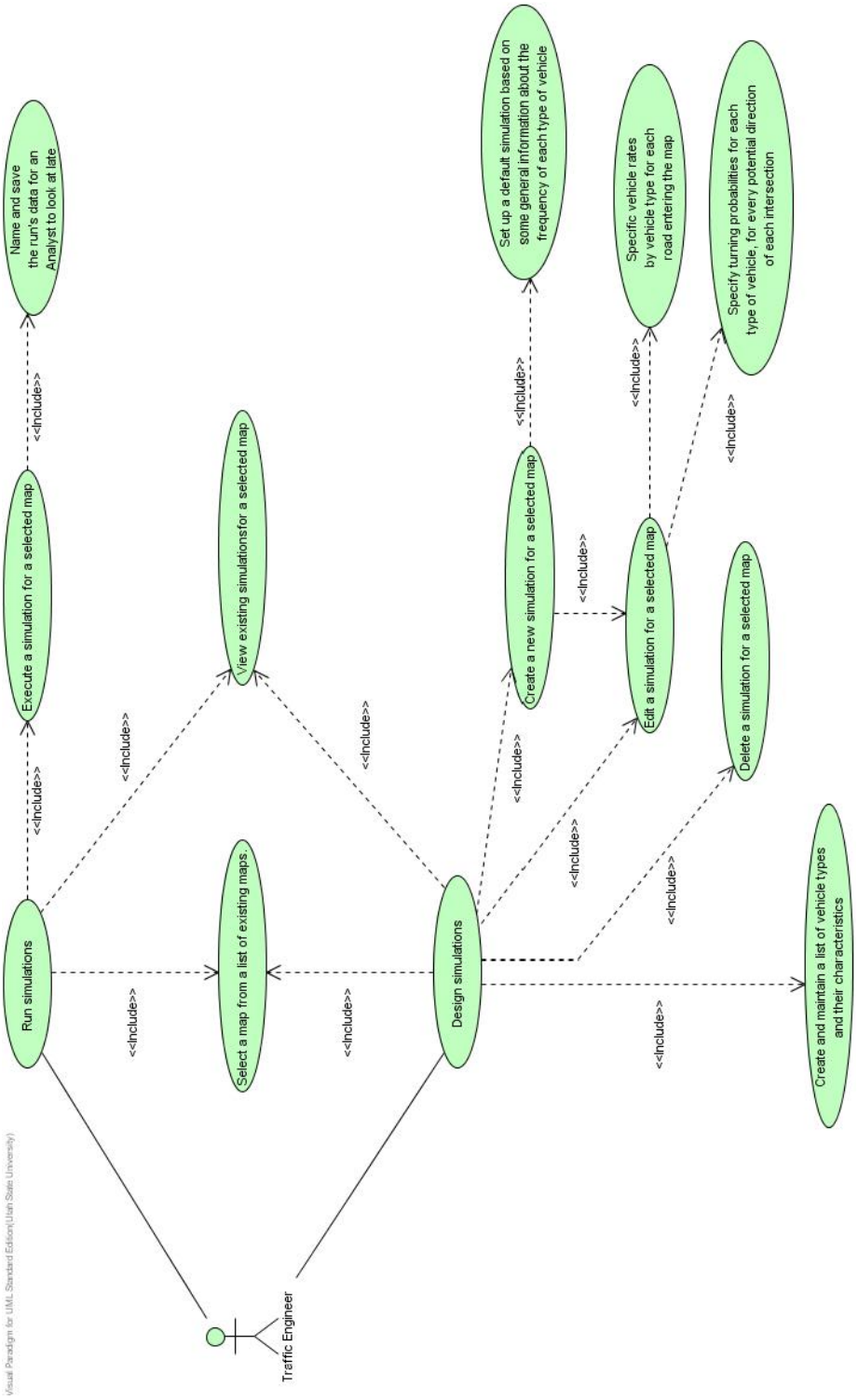


Figure 5 – Analyst Goals

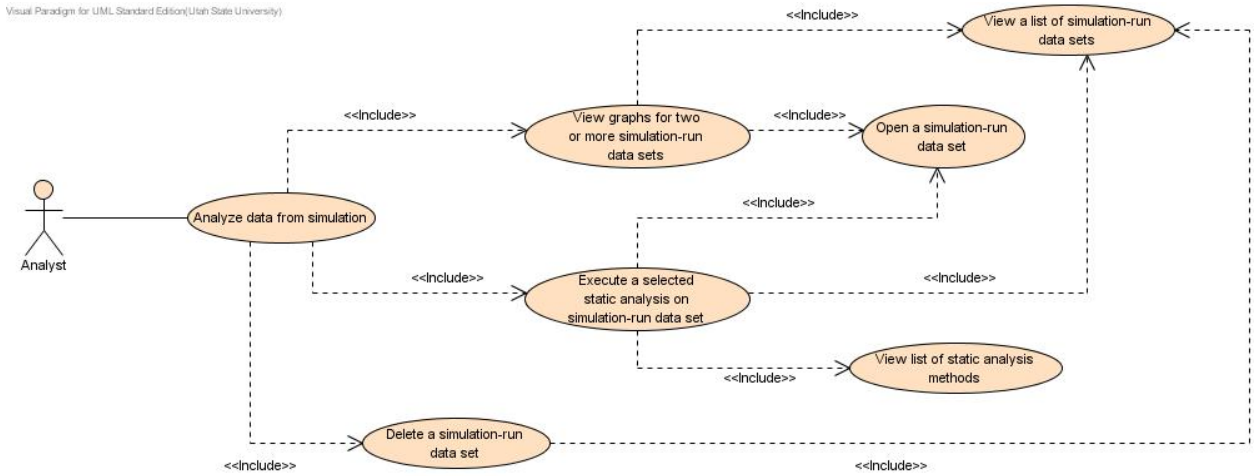
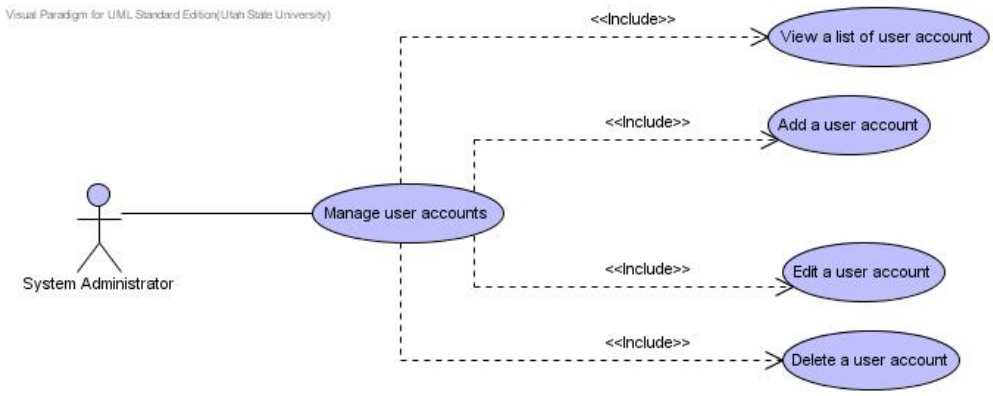


Figure 6 – Administrator Goals



The following table summarizes the actors' anticipated skill levels and attitudes.

Actor	Expected Skill Level	Anticipated Attitude(s)
User	In general, all users are familiar with using Windows and general computer-based tools for doing their jobs, such as email, a word processor, and spreadsheet	n/a
Cartographer	Expert users of other map-drawing tools, but are not too familiar with traffic engineering issues.	Somewhat apathetic about using proposed software. They see themselves being hired to draw maps and will do that with whatever tool they can use.
Traffic Engineer	Novice computer users who may be intimidated by new tools, but are very knowledge about the problem domain (i.e., traffic)	Excited to use about the prospects of a new tool that will help them solve tough traffic problem. These users will "live" in the software system for a relatively long time as they design and execute traffic simulations.
Analyst	Advanced computer users who may probably have high expectations for data analysts features	Are also optimistic about the new system, but cautiously so. They could be unsympathetic about weakness, missing features, or errors in the system.
System Administrator	Advanced user, in that he/she is already familiar with a variety of software systems that require user authentication and authorization.	Will want to get in, do their tasks (manage user account), and get out as quickly as possible.

Below are a few example scenarios that illustrative a couple of key user goals.

Scenario #1

1. Joe, a cartographer, logs into the system using his username and password.

2. Joe sees a lists of existing maps, but chooses to create a new one for the center of town because one does not exist for that area yet
3. Joe buildings a map of the area, which consists of two north-south streets and two east-west streets. The map contains four intersections where the north-south streets cross the east-west streets. Three of the intersections have traffic lights. The remaining intersection has a four-way stop. There are no other roads or traffic devices in that area. The entry/exit points for the roads on the map are labeled like those some in Figure 1.
4. Joe saves the map as "Downtown Area"

Scenario #2

1. Mary, a senior traffic engineer, logs into using her username and password
2. Mary sees a list of existing maps and decides to work with the "Downtown Area" map
3. Mary selects that map and sees a that there are currently no simulations for that area, so she decides to create one
4. Mary starts a new traffic model and gives to the name "Moderate downtown traffic simulation" and specifies the following incoming/outgoing traffic patterns
    a. 15 car/minutes enter at Point A and A'
    b. 5 large truck/minute enter at Point A and A'
    c. 10 car/minutes enter at Point B
    d. 5 car/minutes enter at all other points
    e. 60% of the vehicles leave via Points A or A'
    f. 20% of the vehicles leave via Point B
    g. 40% vehicles leave through one of the remaining points.
5. Mary saves this model and starts a new one called "Heavy downtown traffic". This model is the same as the previous model expect that volume of vehicles is three times that of the moderate model.
6. Mary save this second model
7. Mary executes both models five times and save each simulation

Scenario #3

1. Jane, an analyst, logs onto the system with the intent of analyzing traffic for the downtown area.
2. Jane sees a list of maps and selects the "Downtown Area" to work one.
3. Jane sees the two different traffic models for that map with their five simulations each and selected them all.
4. Jane creates a histogram of average delay times with separate bar sets for each the traffic models

The following table contains common terminology for this domain and their definitions:

Common Term	Definition
Road	A continuous route between two termini
Terminus	A place where a road begins or ends
Road Segment	A part of a road with distinctive characters, such as length, curvature, speed limit, and

	number of lanes. Examples of road segments include a .5 mile straight section of two-lane road between intersections with a speed limit of 45 mph, and a curved section over a 90 degree arc with a speed limit of 35 mph.
Traffic Device	Something that directs or controls traffic, e.g. a traffic light, stop sign, yield sign, speed bump, etc.
Road Alignment	A measure of how straight a road segment is.
MORE TO BE WRITTEN	

3 Classes of Objects and the Relationships

The following UML class diagrams describe the key object classes and their relationships.

Figure 7 – Maps and their components

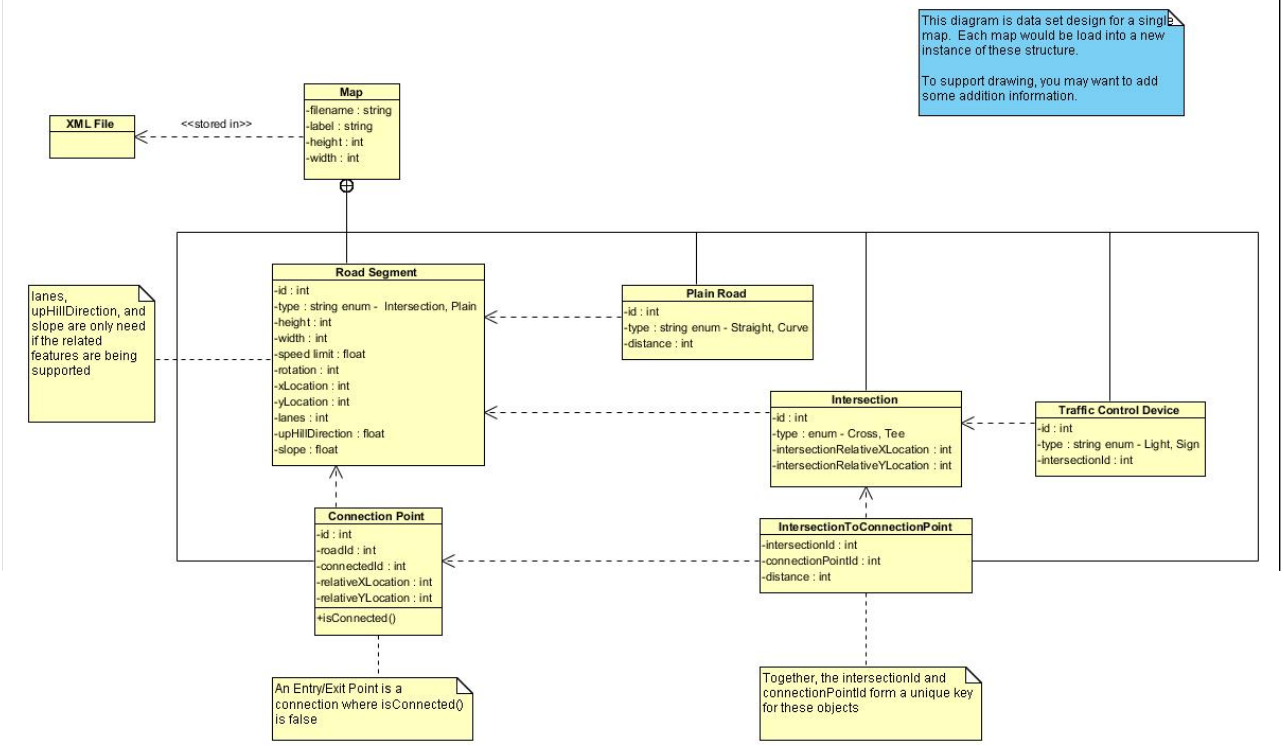


Figure 8 – Types of Vehicles

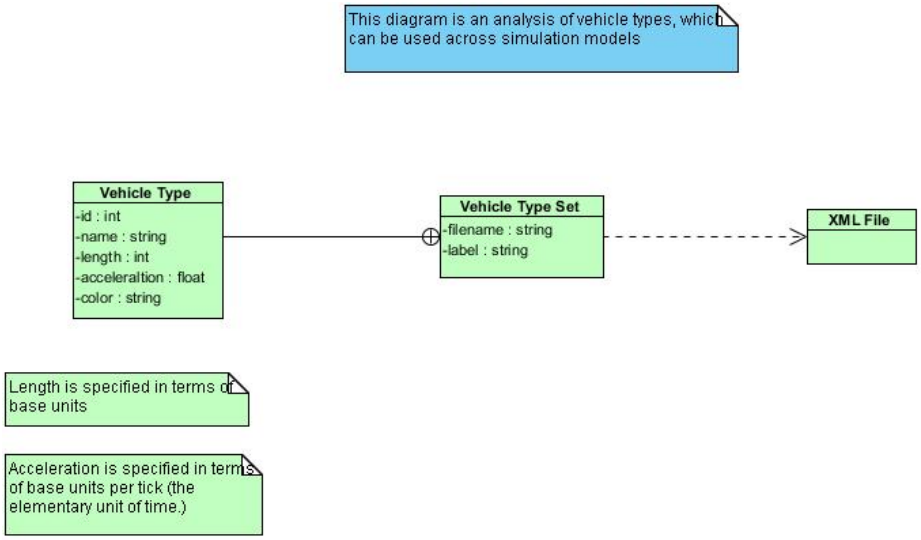


Figure 9 – Simulation Model

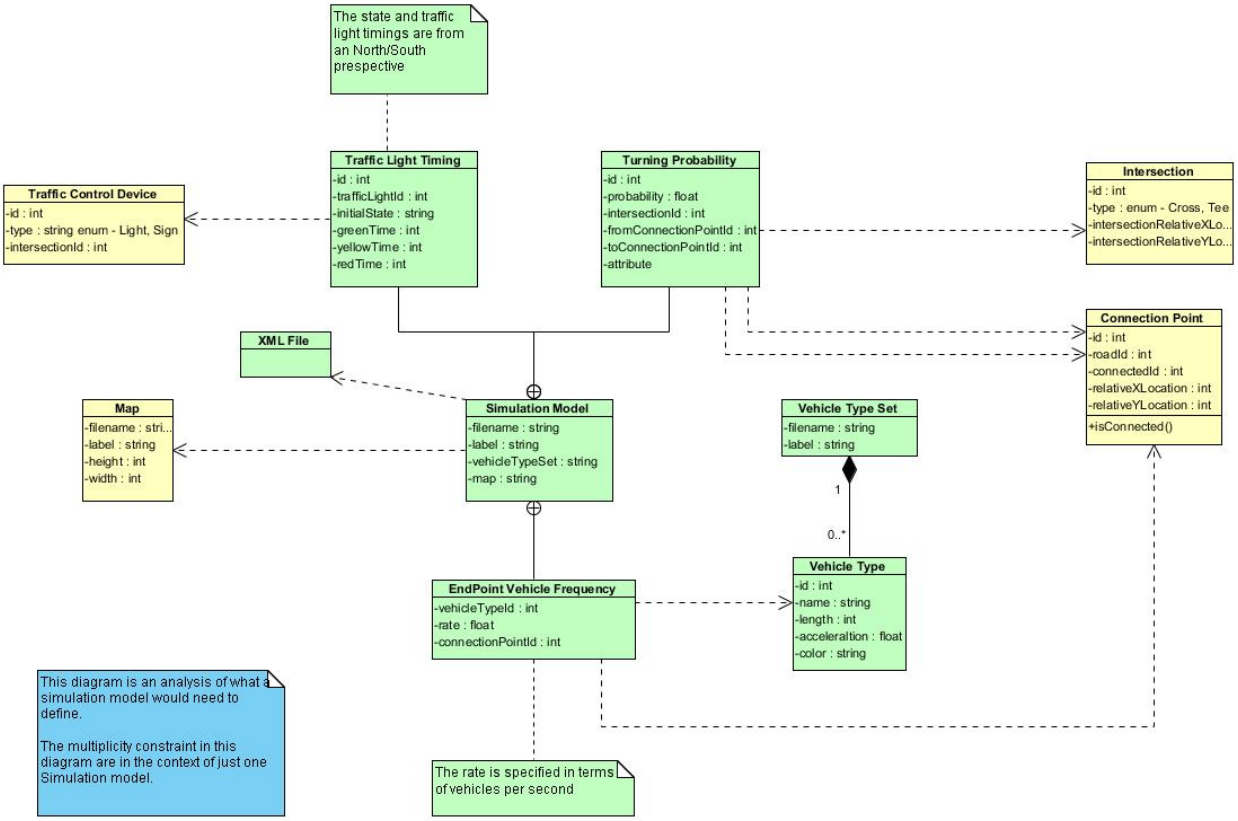
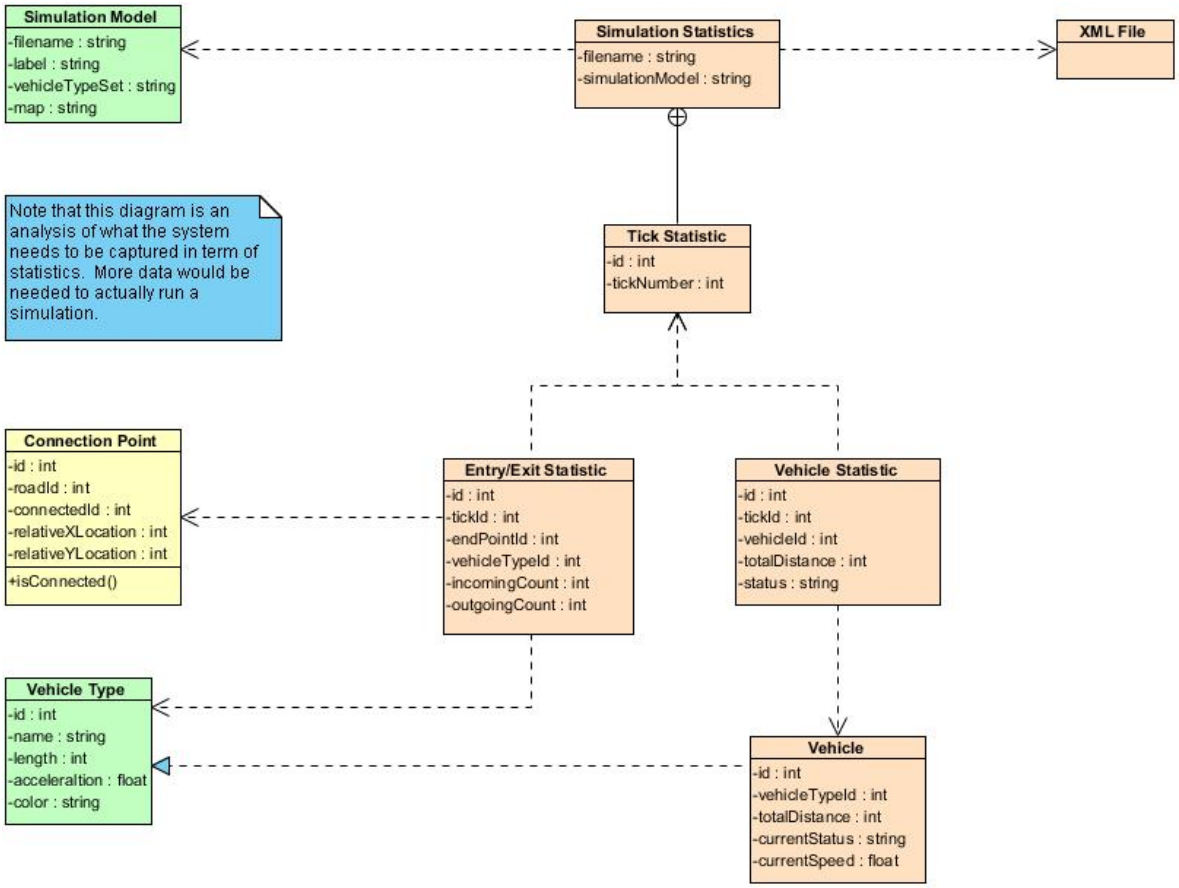


Figure 10 – Simulation Data



4 Functional Requirements

The following functional requirements describe features that will satisfy the user goals listed in section 2.

Grading note: Projects just satisfying the stated requirements will receive an "average" score. To receive something more than an average score, you must extend the functional requirements to include more features of your own choice. Some ideas for such features are shown in italics.

1. User Authentication and Access Controls
   - 1.1. The system must require all users to authenticate themselves before giving them access to features of the system.
     - 1.1.1. On first login, the user must be able to enter the username and password that a system administrator created for that user
     - 1.1.2. Once the user has successful entered the initial username and password, the system must require the user to change the initial password to something of their own choosing.
     - 1.1.3. For any subsequent login, the user must be able to enter his/her username and current password. If entered correctly, the system must let the user access authorized features of the system. If entered incorrectly, the system should allow the user to try again or exit.
   - 1.2. User can be given any or all of the four access rights: Map Building, Simulation, Analysis, and Admin
     - 1.2.1. Users with Map Building rights should have access to all Map Building features. See FR #3.
     - 1.2.2. Users with Simulation rights should have access to all Simulation features. See FR #4
     - 1.2.3. Users with Analysis rights should have access to all Analysis features. See FR #5.
     - 1.2.4. Users with Admin rights should have access to System Admin Features. See FR #6.

2. User Profile Management
   - 2.1. The system will allow any authenticated user (one who is logged in) to modify his/her own contact information.
   - 2.2. The system will allow any authenticated user (one who is logged in) to modify his/her own password.
   - 2.3. The system should not allow user who doesn't have Admin rights to see or modify any other user profile.

3. Map Building Features
   - 3.1. The system should allow users with map-building rights to create new maps.
     - 3.1.1. When creating a new map, the system should allow the user to give it a label, a size, and then start drawing the map using any number of map elements. See FR 3.4.
       - 3.1.1.1. The size should be specified by the width and length of a rectangle area, specified in terms of *base units*[1].
     - 3.1.2. At time, the system should allow the user to save a newly created map using the "save" or "save as" features. See FR 3.5 and 3.6. Note, newly created maps are not associated with file prior to saving.
   - 3.2. A user should be able to open an existing map and edit it.

[1] To simply computation, the map is divided into units, called *base units*, that are equal to the length of a single passenger vehicle. Longer vehicles, such as freight trucks, may be three or four base units long. Road segments are also measure in terms of base units.

3.2.1. The user should be able to browse a list of existing maps and select one to edit.

3.2.2. When editing an existing map, the system should show the user the current contents of the map and then allow the user to add, delete, or manipulate map elements. See FR #3.4.

3.2.3. The system should allow a user to edit more than one map at a time.

3.3. A user should be able to delete an existing map.

3.3.1. The user should be able to browse a list of existing maps and select one to delete.

3.3.2. When deleting an existing map, the system should confirm the request action with the user before performing the delete.

3.4. Map Drawing Features

3.4.1. The system should allow to user to place any of the road elements shown in Figure 11 onto a map. *Consider adding more types of road elements.*

3.4.1.1. The system should warn the user if one road element overlaps another. (Overlapping road elements don't mean the roads intersect; rather, they situations where one passes over or under another.)

3.4.1.2. The system should recognize when a road element just placed on the map connects to a previous element, and give the user appropriate notification or feedback. Note the notification could be subtle because the feeling of closure is relatively small.

3.4.1.3. The system should keep track of and label enter/exit points on the map, i.e., unconnected connection points of the road elements.

3.4.1.4. Each road element has a bounding width and height, and a drivable length all defined in terms of base units.

3.4.2. The system should allow the user to rotate any road element by 90, 180, or 270 degrees. *Consider allowing other types of rotation.*

3.4.3. The system should allow the user to change the speed limit (in base units/tick) of the road characteristics. *Consider adding other road characteristics, such as:*

3.4.3.1. Number of lanes

3.4.3.2. *Grade (slope)*

3.4.4. The system should allow the user to place any of the following traffic control devices on an intersection or T-connection. *Considering adding of traffic control devices such as speed bumps, lane closures, or "caution" signs.*

3.4.4.1. Traffic light

3.4.4.2. Stop sign

3.4.5. The system should allow the user to remove any road- or traffic-control element from a map.

3.5. The system should allow the user to save a map at any time.

3.5.1. If the map is already associated with a file, then the system should save the map to that file.

3.5.2. If the map is not already associated with a file (such is the case for newly created files), then the system should ask the user for the file name.

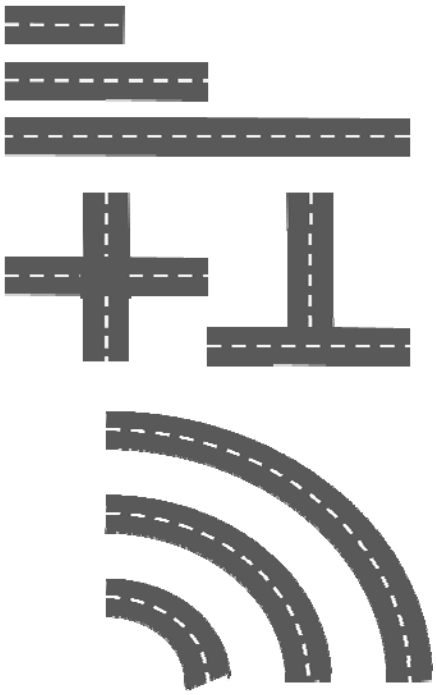
3.5.2.1. The system should allow the user to browse the current file name to select an appropriate name

3.5.2.2. The system should warn the user if the user enters the name of an existing file and then give the user the option to overwrite it or go back and enter a different file name.

3.6. The system should allow the user to save a previously existing map to a different file (i.e., the system should provide a "Save as…" feature.)

3.7. If the user tries to leave the map-drawing feature and some work has been done on the map, the system should warn the user and ask if he/she wants to save the map before leaving that feature

Figure 11 – Basic road elements



4. Simulation Features
   - 4.1. The system should allow a user with simulation rights to select a map for which he/she wants to build or execute simulations.
   - 4.2. Once the user has selected a map for simulation work, the system should allow a user to create a new simulation model.
     - 4.2.1. When creating a new simulation model, the system should allow the user to give it a label and then start adding simulation model elements. See FR 4.5.
     - 4.2.2. At time, the system should allow the user to save a newly created map using the "save" or "save as" features. See FR 3.5 and 3.6. Note, newly created maps are not associated with file prior to saving.
   - 4.3. A user should be able to open an existing simulation model and edit it.
     - 4.3.1. The user should be able to browse a list of existing simulation models and select one to edit.
     - 4.3.2. When editing an existing simulation model, the system should show the user its current contents and then allow the user to add or delete map elements. See FR #4.5.
     - 4.3.3. The system should allow a user to edit more than one simulation model at a time.
   - 4.4. A user should be able to delete a simulation model.
     - 4.4.1. The user should be able to browse a list of existing models and select one to delete.
     - 4.4.2. When deleting an existing simulation model, the system should confirm the request action with the user before performing the delete.
   - 4.5. Simulation-model Building Features
     - 4.5.1. The system should allow the user to define vehicle types and their characteristics, such as type name, length (in base units), and acceleration (in base units/tick). *Consider adding other characteristics, such as average-speed relative to the road's speed limit, propensity for accidents, lane shifting frequency, preferred inter-vehicle spacing, etc.*
     - 4.5.2. For each entry/exit point on the map, the system should allow the user to define the traffic that enters that point in terms of the type of vehicle and its expected frequency.
     - 4.5.3. For each traffic light, the system should allow the user to define its initial state and cycle. *Consider allowing the user to specify that one traffic light's is dependent on another traffic light's cycle*.
     - 4.5.4. For each intersection, the system should allow the user to specific a turning probability for each type of vehicle.
   - 4.6. Simulation-execution features
     - 4.6.1. When executing a simulation, the system should provide the user with a real-time visualization of the map and the traffic.
     - 4.6.2. The system should allow the user to stop the execution of a simulation at any time.
     - 4.6.3. When executing a simulation, the system should allow the user save the simulation data to an output file.

4.6.3.1. If the output file already exists, the system should warm the user and give an option for either overwriting that file or going back and entering a new file name.

4.6.3.2. In selecting an output file, the system should allow the user to browse the current file system.

5. Analysis Features
   5.1. The system must allow users with analyst privileges to select one or more existing simulation data files (simulation data sets) to analyze.
   5.2. To help a user study a simulation data set, the system should be display the following kinds of summary statistics:
      5.2.1. Total through vehicles entering the system per tick (which can be aggregated to second, minute, etc.)
      5.2.2. Total through vehicles exiting the system per tick (which can be aggregated to second, minute, etc.)
      5.2.3. *Average speed*
      5.2.4. *Number of 10+ second delays (number of cars stuck in traffic for more than 10 seconds)*
   5.3. To help a user study multiple simulation data sets, the system should be able create a bar graph showing vehicle entry and exit counts for all selected data sets, over user specified time intervals. *Consider other interval-based statistics.*
   5.4. The system should allow the user to customize the appearance of the graphs, e.g., labels, colors, scale, and time frame. *Consider other customizations like graphs styles.*

6. System Administration Features
   6.1. Configuration Features
      6.1.1. The system should allow users with admin privileges to view and change system configuration parameters, including:
         6.1.1.1. Default map directory
         6.1.1.2. Default simulation model subdirectory
         6.1.1.3. Default simulation data subdirectory name
   6.2. User Account Administration Features
      6.2.1. The system should allow users with admin privileges to create, edit, and delete user accounts.
      6.2.2. The system should allow users with admin privileges to reset or change user passwords.

5 Non-functional Requirements

Still to be written, but below are some initial ideas.

1. The system will be developed using an increment development process, where approximately 1/6 to 1/4 of features will be designed and implemented each week for the duration of the project.

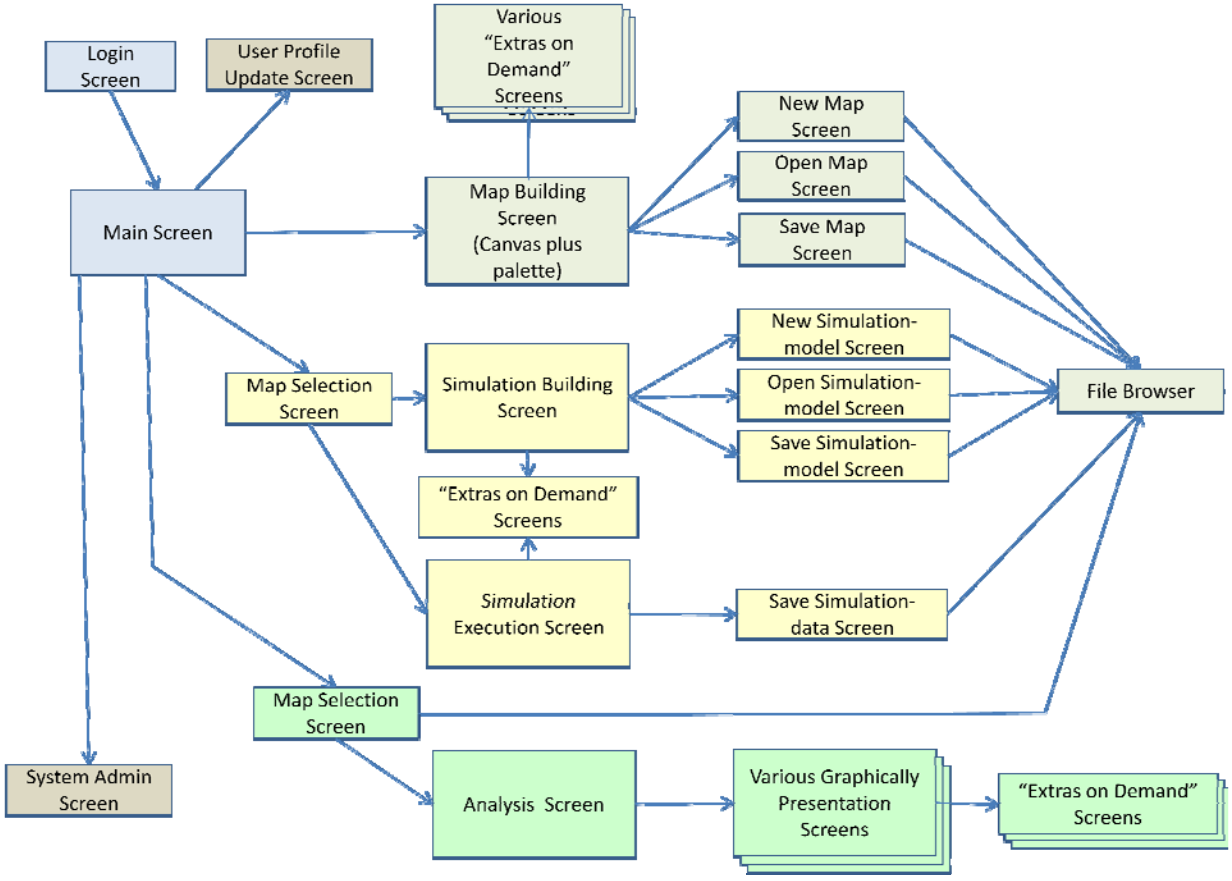
2. Application-level logic will be tested using NUnit.

3. Significant parts of user interface code will be tested using NUnitForms

6 User Interface Organization

Figure 12 illustrates an initial (and incomplete) user-interface organization. This is to be considered a starting point for design, not a definitive list of screens and possible navigations.

Figure 12 – User Interface Organization



Screen	Purpose / Content
Login Screen	Allow a user to login with a username and password. Contains branding and welcome devices. See Req. Def. 1.1.
Main Screen	Allows the user to navigate to the three main areas of functionality. Contains menu and maybe other kinds of context and navigational aids
User Profile Update Screen	Allows the users to update their contact information, change their password, and edit their preferences. See Req. Def. 2.
Map Building Screen	Allows users to build a map from standard road segments and map components. Contains a drawing canvas and a palette of things that can be dropped on the map. See Req. Def. 3., and in particular 3.4.
Map Building "Extras-On Demand" Screens	Allow users to access features and options for building maps.
New Map Screen	Allow the users to create and name a new map. Req. Def. 3.1.
Open Map Screen	Allows the user to open an existing map. See Req. Def. 3.2. It should also allow a user to delete an existing map. See Req. Def. 3.3
Save Map Screen	Allows the user to save a map. See. Req. Def. 3.5, 3.6, and 3.7
File Browse Screen	A basic file browsing screen. The screen can be used by the open and save screens.
Map Selection Screen for Simulation Buiding	Allows the user to select an existing map for which simulation will be built. See Req. Def. 4.1
Simulation Building Screen	Allows the user to construct or edit a simulation. See Req. Def. 4, and in particular, Req. Def. 4.5.
Simulation Building "Extras On Demand" Screens	Allow the user to access advanced simulation modeling features.
Simulation Model New Screen	Allows the user to create a new simulation model for the selected map. See Req. Def. 4.2
Simulation Model Open Screen	Allows the user to open a simulation model for the selected map. See Req. Def. 4.3. This screen also allows a user to delete an existing model. See Req. Def. 4.4
Simulation Model Save Screen	Allows the user to save simulation model for the selected map.
Simulation Execution Screen	Allows the user to execute a simulation for the selected map. See Req. Def. 4.6
Simulation Data Screen	Allows the user to view and save data created from a simulation's execution so it can be analyzed later by traffic analysts. See Req. Def. 4.6.3
Map Selection Screen for Data Analysis	Allows the user to view a list of maps and for each map a list of simulation data sets. It also allows the user to select a map and one or more data sets for analysis. See Req. Def. 5.1.
Analysis Screen	Provide the user with tools for analyzing the simulation data. See Req. Def. 5.2.
Various Graphically Presentation Screens	Present abstraction of the data so the analyst can visualize the characteristics of the traffic patterns that occurred in the simulation. See Req. Def. 5.3.
Various Presentation On-Demand Screens	Allow the users to access advanced presentation features. See Req. Def. 5.4.
System Admin Screen	Allows administrators to view a list of users, add user accounts, edit user accounts, and delete user accounts. When editing user accounts, it also allows administrations to grant user accounts access rights. See Req. Def. 1.2 and 6.

7 Future Features

Below is a list of ideas for future features.

1. Importing of a GIS shape file as starting point for a map
2. Background images for maps
3. Map decorations, such buildings, signs, landscapes, etc.
4. 3D visualizations of simulations