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TTM4110 - Dependability and Performance with Discrete Event Simulation

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Lab I
Smart City transportation service modelling

10031

Worked with 10040

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Task I.A: Quality of Experience and Influence factor

I.A.1 Description of situations

In the following I will describe two different situations where I need transportation. Each of the scenarios has different requirements.

- **Going to school:** The most common scenario for me is taking the bus to school. Since I live pretty nearby campus I don't use the bus too often. When I take the bus to school, it is usually because I woke up feeling lazy, and didn't feel like walking. Or perhaps the weather is terrible, and I choose to hop on a bus instead of arriving school soaked.

  If the bus is late or never arrives, I would probably get a little bit annoyed, but it is not the worst thing in the world, as I could just walk or even wait for the next one, since they arrive every 10th minute. When the bus is scheduled somewhat frequently, I'm more relaxed that one late bus won't ruin my day.

  Since it is a pretty short trip, I don't mind standing and it is okay if the bus is crowded. There is always room for one more person. It is still okay even if it makes "sild in tønne", because I know that it is only for a brief period. Thus, in a situation like this, I'm more flexible regarding comfort when I know the trip is over soon enough.

- **Going to the airport:** When I need to go to the airport I have more requirements for my trip. This journey feels more important since I am catching a flight, and timing becomes more critical.

  This is because the bus is just the first part of my trip. If the bus is late it could affect my overall journey., worst case leading me to miss my flight. In this case I rely on the service in another way compared to my trip to school.

  Additionaly, because this is a longer trip I would prefer to sit, as standing for the whole ride while juggeling a lot of luggage is frustrating and uncomfortable, and decreasing my QoE.

I.A.2 Human IFs

Two Human Influence Factors (HIFs) that can significantly impact the Quality of Experience (QoE) are "Level of Anxiety" and "Time Pressure".

1. **Level of Anxiety**
   - Descriptive state variable name: level of anxiety
   - Discretized state values: relaxed, calm, stressed, nervous

The users stress level is an important factor when going to the airport. When the user is stressed, every inconvenience may feel like a disaster.

2. **Time Pressure**
   - Descriptive state variable name: time pressure
   - Discretized state values: none, low, moderate, high, critical

   The amount of time pressure a user experiences will influence their QoE in how they react to delays or inconveniences.

I.A.3 System IFs

Two System Influence Factors (SIFs) that can significantly impact the Quality of Experience (QoE) are "Bus Punctuality" and "Bus Capacity".

1. **Bus Punctuality**
   - Descriptive state variable name: punctuality
   - Discretized state values: on time, late, early

   The punctuality of the bus will influence the QoE regarding to reliabilty. If the bus appears to always be late, it may affect the users view on the service. Worst case the user decides to use alternative transport.

2. **Bus Capacity**
   - Descriptive state variable name: capacity
   - Discretized state values: empty, medium, full

   The capacity could affect the QoE in how eager the user is to board the bus.

I.A.4 Context IFs

Two Context Influence Factors (CIFs) that can significantly impact the Quality of Experience (QoE) are "Overall Traffic Conditions" and "Time of Day".

1. **Overall Traffic Conditions**
   - Descriptive state variable name: traffic conditions
   - Discretized state values: flow, dense, congeted

   Traffic conditions are a factor that can influence the punctuality and overall travel time, effectively influencing the QoE.

2. **Time of Day**

   - Descriptive state variable name: time of day
   - Discretized state values: morning, noon, afternoon, evening, night

   The time of day has an impact on the bus, regarding to how the rest of the traffic operates and the amount of passengers on the bus.

I.A.5 System State Variable

- **Human Influence Factor**, ω_H = level of anxiety:

  When initiating a trip the user is calm. If there is a sudden change in traffic, leading to congestion, the users anxiety levels can increase leading to a change in ω_H, e.g. from "calm" to "stressed".

- **System Influence Factor**, ω_S = punctuality:

  At the beginning of a route, the bus is most likely to be on time. If the bus happens to come across roadwork or an accident, this would make an impact on the punctuality. Here ω_S could change from "on time" to "late". This would again influence the users QoE in a negative way, especially in time-sensitive scenarios.

- **Context Influence Factor**, ω_H = traffic conditions:

  Depedning on what time of the day it is, the traffic conditions could change during a trip. If rush hour begins, the conditions would propbably worsen leading to a potential change in ω_C from "flow" to "dense".

- **System State Variable**, $\omega = \{\omega_H, \omega_S, \omega_C\}$:

  The overall system state is a combination of the three factors above. It changes based on the interactions of each of them. Imagine the bus is late (ω_S) and traffic is dense (ω_C), this could lead to the user getting stressed, making a change in ω_H.

I.A.6 `MOS`

Original Definition:	**New Definition:**
• ω_H = {relaxed, calm, stressed, nervous} • ω_S = {on time, late, early} • ω_C = {flow, dense, congested}	• ω_H = {relaxed, stressed} • ω_S = {on time, late} • ω_C = {flow, congested}

The number of different states is equal to the number of combinations

$$\textbf{Original: } 4 * 3 * 3 = 36$$

$$\textbf{New: } 2 * 2 * 2 = 8$$

We have 36 different combinations with the original, and 8 combinations with the new definition. Quick maths, and the number of states in ω is reduced by 28.

`MOS` Score of System States

ω_H	ω_S	ω_C	`MOS` score
relaxed	on time	flow	5
relaxed	on time	congested	4
relaxed	late	flow	3
relaxed	late	congested	2
stressed	on time	flow	3
stressed	on time	congested	2
stressed	late	flow	2
stressed	late	congested	1

I.A.7 `MOS` and C Relation

I would say that lower the `MOS`, the higher the drop out probability C. In situations where the user has a very bad experience, and the `MOS` score is down at 1, the probability of leaving the bus stop is much higher. Resulting in a high drop rate. On the other hand, if the user has a good experience, the drop out rate will be much lower since the user has less reason to leave.

From my perspective, acceptable waiting time at the bus stop depends on how critical the trip is. As discussed in previous tasks, the importance of bus arrival when going to the airport is much higher, compared to going to school. I have less tolerance for the bus being late when I have a plane to catch, but I am also more willing to wait for a longer period of time since I really need to get to the airport.

Except the waiting time, other reasons to stop using the service could be negative past experiences, such as a long history of lateness and crowded busses. Additonally, the rise of a new and better service could lead to users choosing to switch to other services offering a higher `MOS`.

Task I.B: Model of a flexible and smart city bus

I.B.1 State Variables, Entities, and Resources

State Variables

The chosen state variables focus on factors that influence both passenger experience and bus efficiency. The variables are updated throughout the simulation.

- Available seats
- Number of passengers
- Passenger waiting time
- Passenger travelling time

Entities

The entities below are chosen since they are the main focus of the simulation.

- Buses
- Passengers

Resources

The chosen resources focus on supporting interactions between the entities. The bus stops are implemented in the bin, as a queue system. The roads are intended to be used for the ”travel”-activity.

- Bus stops
- Roads

I.B.2 Discrete Event Simulation model

Figure 1 shows the DES model for the simulation. It includes the two entites bus and passenger, and a passenger generator intended for the simulation. The purpose of the model is to enhance the interaction between a bus and a passenger. It also shows where in the simulation the different state variables is updated.

A bus gets a route and leaves a stop, which leads it to perform a ”travel”-activity at a given time length, before arriving the next stop. At each stop there will be a check of each passenger to see if they should disembark or not. After all passengers have left the bus, it checks if there are any stops left, if not it gets a new route and repeats the process. Otherwise it checks if there are any available seats in the bus. If there are available seats it allows passengers to board the bus, else it leaves the stop. A passenger arrives a stop and waits for permission to board, and does not leave until it is told.

I.B.3 Bus Utilisation

Bus utilisation can be defined as:

$$\text{Bus Utilisation} = \frac{\text{Number of passengers}}{\text{Number of seats on buss}} \tag{1}$$

This gives us a metric to show how effectively the use of the busses are in the system. We want the utilisation to be as high as possible, since that leads to good efficiency for the bus company and better service for the passengers. In the simulation, the goal is to calculate the utilisation every time the bus leaves a stop. This way it is possible to determine an average utilisation rate for a route.

I.B.4 Statistics for Utilisation and Travel Time

Various metrics are collected at different places in the model to calculate the utilisation and travel time, as one can see in Figure 1.

Average travel time can be calculated as:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i, \tag{2}$$

where x_i is the travel time for each individual passenger, and n is the number of passengers. In the model x_i is denoted as t_{travel}

Before calculating the standard error, we need calculate the sample variance. This is calculated by using the average travel time and the travel time for each passenger.

$$S^2 = \frac{1}{n-1}\sqrt{\sum (x_i - \overline{X})^2} \tag{3}$$

When we have calculated both average travel time and standard error, we can calculate the standard error of the sample mean using eq. (4).

$$SE(\overline{X}) = \sqrt{\frac{S^2}{n}} \tag{4}$$

When the goal is to find a 95% CI, we set $\alpha = 0.05$. Since we already determined the standard error, we can calculate the confidence interval using eq. (5).

$$CI = \overline{X} \pm t_{\frac{\alpha}{2}} * \sqrt{\frac{S^2}{n}} \tag{5}$$

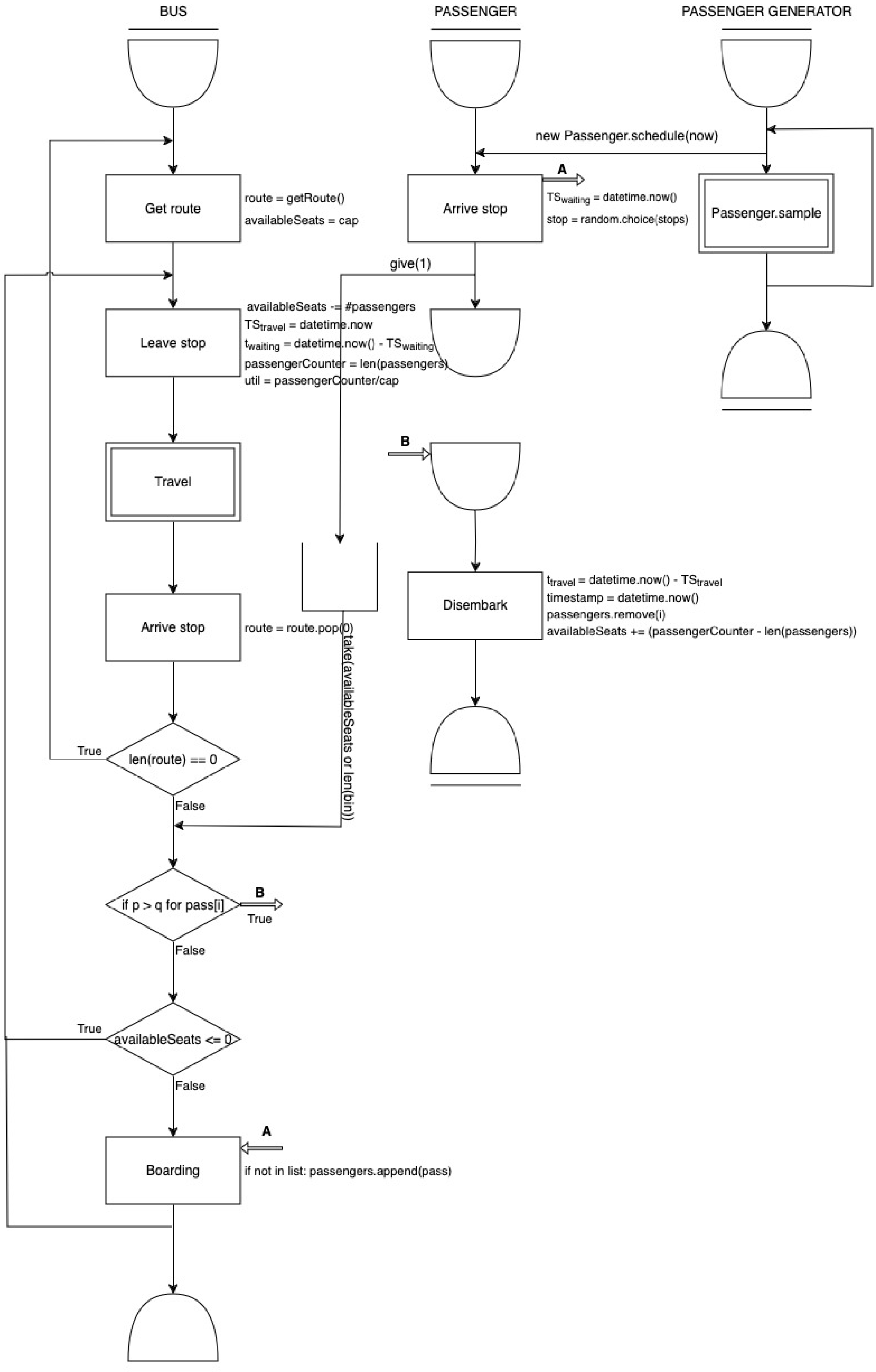

Figure 1: DES model of city bus system

I.B.5 Bus Routes Between End Stations

ID	Route	Stops	Roads
1	$E_1 \leftrightarrow E_3$	S_1, S_4, S_6	R_1, R_5, R_8, R_{13}
2	$E_1 \leftrightarrow E_4$	S_1, S_4, S_7	R_1, R_5, R_{10}, R_{15}
3	$E_2 \leftrightarrow E_3$	S_2, S_5, S_6	R_3, R_7, R_9, R_{13}
4	$E_2 \leftrightarrow E_4$	S_3, S_7	R_4, R_{12}, R_{15}

I.B.6 Rules for Selecting Bus-Routes

When a bus has arrived an end station, it has two alternatives for the next route. This is not included in the definition of the rules, since it is clarified here. The bus can choose the same route it just operated, or the alternate route from the current end station. To help choose, the system needs to implement some rules that determine the next route based on factors such as number of waiting passengers and the time they have waited. Additionally, it is important to prioritise the rules to minimise the risk of conflicts. Here the most important rules are listed first.

Rule 1: Route with the most passengers:

$$\text{Select Route } R_i \text{ if } \sum_{S_j \in R_i} P(S_j) = \max_R \left(\sum_{S_j \in R} P(S_j) \right),$$

where $P(S_j)$ is the number of passengers waiting at stop S_j. $\sum_{S_j \in R_i} P(S_j)$ represents the total number of passengers waiting at all stops on route R_i. The route R_i is selected if the total number of passengers waiting on this route is equal to the highest overall passengers count.

- **Pros:** We have high efficiency and utilisation when there are a lot of passengers waiting throughout a route.
- **Cons:** Could lead to starvation of less popular routes.

This rule overrides all other rules if the total number of passengers waiting throughout this route is more than 40% of all passengers in the system.

Rule 2: Route where passengers have been waiting the longest:

$$\text{Select Route } R_i \text{ if } \sum_{S_j \in R_i} t(S_j) = \max_R \left(\sum_{S_j \in R} t(S_j) \right),$$

where $t(S_j)$ is the total waiting time of passengers at a stop. $\sum_{S_j \in R_i} t(S_j)$ represents the total waiting time of the stops at route R_i. The route R_i is selected if the total waiting time of a route is equal to the highest total waiting time of a route in the system.

- **Pros:** Every route will eventually get served.

- **Cons:** Ignores passengers count, can not guarantee high utilisation.

This rule overrides all other rules if passengers have been waiting for more than a given t_{max}.

Rule 3: Stop with the most passengers:

$$\text{Select Route } R_i \text{ if } \max_{\text{stops}}(P(S_j)) = P(S_k),$$

where $P(S_j)$ is the number of passengers waiting at stop S_j. Thus, route R_i is selected if the number of passengers waiting at stop S_k along this route is equal to the maximum number of passengers waiting at any stop.

- **Pros:** Removes a lot of passengers from a stop.
- **Cons:** Main focus on one point, not automatically very efficient.

This rule overrides all other rules if the number of passengers at one stop is more than 20% of all passengers in the system.

Rule 4: Stop where passengers have been waiting the longest:

$$\text{Select Route } R_i \text{ if } \max_{\text{routes}}(t(S_j)) = t(S_k),$$

where $t(S_j)$ is the total waiting time of passengers at stop S_j. Thus, route R_i is selected if the total waiting time at a particular stop S_k is equal to the maximum total waiting time at any stop.

- **Pros:** Makes sure every stop eventually will get served.
- **Cons:** Inefficient as it ignores the passenger count.

This rule overrides all other rules if passengers have been waiting for more than a given t_{max}.