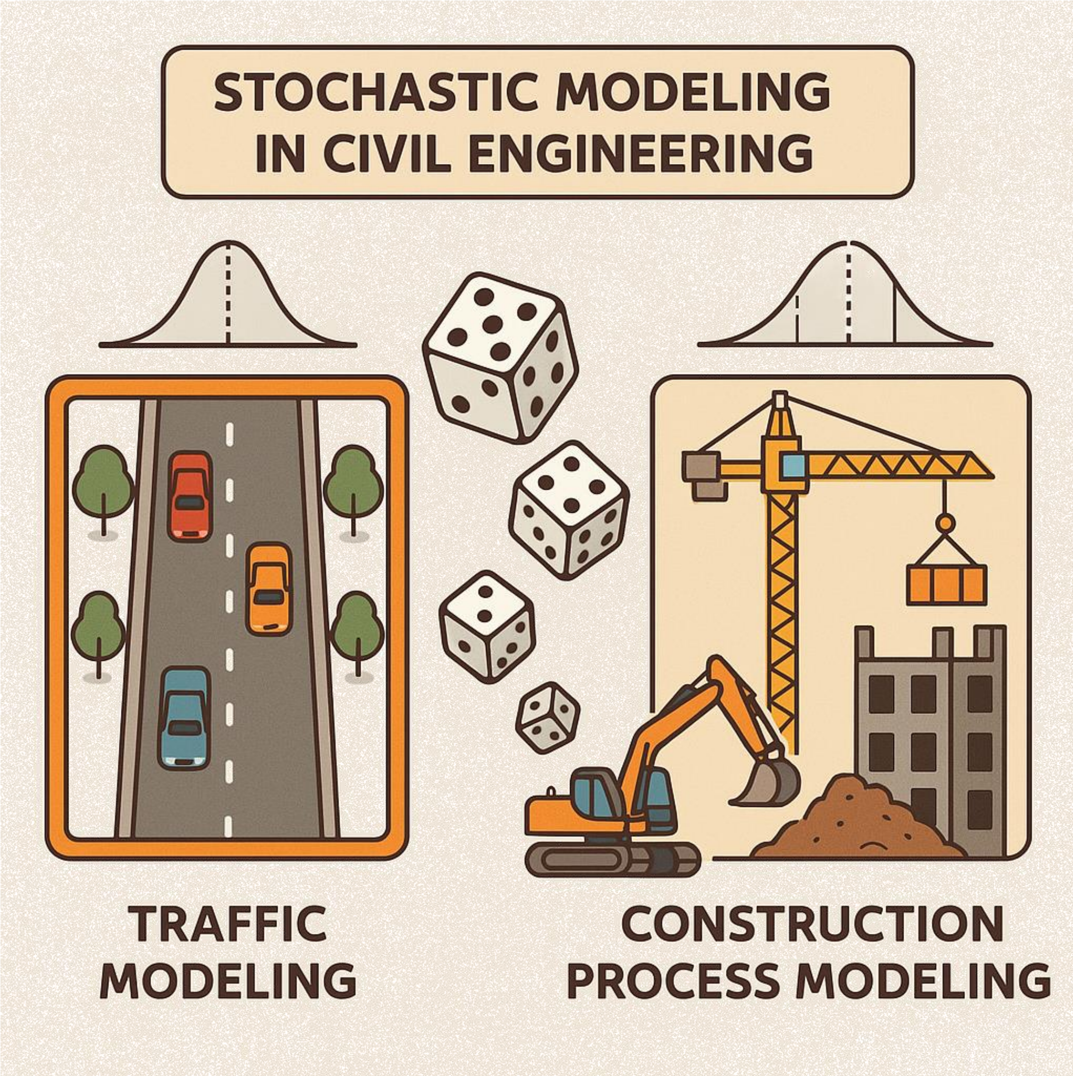
Manual for Module 8 of Bachelor program in Civil Engineering at University of Twente

Module 8: Simulation and Stochastic Modelling in Civil Engineering (202200229)



Bachelor program: Civil Engineering (CE), or in Dutch "Civiele Techniek" (CiT), quartile 2.4, study year 2023-2024, 15EC

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1 GENERAL DESCRIPTION

In our everyday life, we are surrounded by and interact with many events/processes that have certain levels of uncertainties. Think of your journey from home to UT on a normal day. The time that you wake up, the time it takes you to get ready, the trip to the train station, the train arrival time, and the trip from the station to the UT all have certain degrees of uncertainty. Of course, with proper planning, you can reduce some of these uncertainties but variation in how this process unfolds is inherently inevitable. Processes that have elements of uncertainty (i.e., probability) are commonly referred to as stochastic processes. As civil engineers, we constantly deal with many stochastic processes, e.g., traffic flow, formation of congestion, paving of new asphalt roads, earthmoving operations, etc. And again, as engineers, we try to avoid surprises by properly accounting for these uncertainties in the design, planning, construction, and management of our assets/projects.

The "**Simulation and Stochastic Modelling in Civil Engineering**" module aims to familiarize you with (1) what stochastic problems are, and (2) how to model these problems using simulation techniques. We focus specifically on four key knowledge domains, namely Stochastic Modeling, Traffic Flow Dynamics, Simulation of Traffic Flows, and Construction Process Simulation. Each subject can be encountered in everyday life. For example, stochastic modeling can be used to convert complex everyday problems into simple models that can provide insight into how these processes unfold and can be best managed. Traffic Flow Dynamics can be used for understanding the occurrence and dynamics of queueing and congestion. Simulation of Traffic Flows can be used for the evaluation of infrastructure design in combination with traffic management measures. Process Simulation can be used to model a wide variety of challenges, such as optimizing construction processes in terms of resources, cost, and time. In addition, you learn to select the appropriate tool to tackle a given problem, analyze the results of using the tool, and formulate recommendations to solve the problem.

With this background, the core objective of this module is to provide insights into how stochastic phenomena can be accurately accounted for in civil engineering, focusing specifically on traffic and construction process modeling. To this end, the module consists of the following three components (study units) and three Professional Skills workshops (first week, no EC's involved):

- 202200230 - Traffic Flow
- 202200231 - Process Simulation in Construction
- 202200232 - Integrated Project

2 MODULE STRUCTURE

The module is offered entirely by the Civil Engineering department. You need to follow all the study units mentioned in Section 1. The module has a very simple structure, as shown in Figure 1. The integrated project module will encompass elements of both theoretical units (i.e., Traffic Flow and Process Simulation). A more detailed description of the project can be found in Section 6. In essence, the module focuses on stochastic modeling in traffic and in construction process design, which is why the module has two main theoretical units.

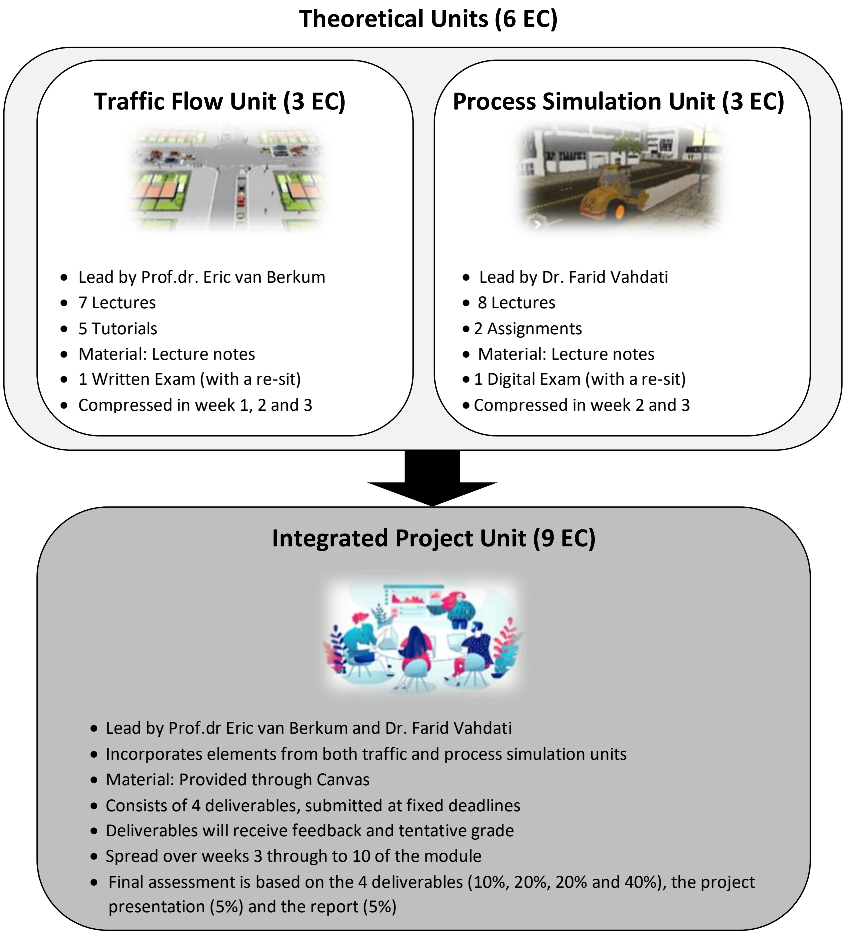

Figure 1. Schematic representation of the Module Structure

2.1 THEORETICAL UNITS

Each of the theoretical units accounts for 3 ECs; in total making up 6 ECs. **Please note that this module uses front-loading teaching strategy, where the theoretical units are compressed mainly over the first four weeks.** After the fourth week, you will have received all theoretical foundations required to for the integrated project.

The below paragraph provides an insight into the topics covered in each of these units:

- **Traffic Flow:** In this unit, you learn about the behavior of traffic flow from theory and also by simulation. Macroscopic flow characteristics such as speed, flow, and density, and microscopic characteristics such as speeds and headways play an important role as well as traffic flow phenomena such as queuing, shockwaves, delays, and intersection control. As a prerequisite for simulation, the goal is to learn about the principles of a so-called micro-simulation to be able to conduct a simulation study focused on traffic operations.

- **Process Simulation**: In this unit, you will learn about the principles of process simulation, i.e., why construction processes need to be simulated. This will be followed by a discussion of what process simulation means and what it entails, i.e., typical simulation methodology. You will also learn about the differences between deterministic and stochastic modeling. Next, with a focus on stochastic modeling, you will be familiarized with Queuing theory and Markov Chain principles. Also, you will learn about the basics of data collection and analysis, which is an integral part of any modeling practice. Consequently, you will learn about discrete-event simulation and how it can be applied to construction processes. Thereafter, you will learn about the basics of data-driven simulation, where the concept of machine learning and its application in civil engineering will be introduced. Finally, the unit will be wrapped up by looking at how a process simulation model can be leveraged in asset decision-making (i.e., basics of optimization). Tables 1 and 2 presents the overview of lectures and other details about each of these two modules.

Table 1. Overview of the content of Traffic Flow unit

Unit	Lecture Title	Date	Discussed topics	Material	Lecturer
Traffic Flow	Lecture 1: Introduction to Traffic Flows and Simulation	See Timetable	• Conceptual framework of a transport system • Types of simulation models • Driver-Vehicle Element • Pseudo random number generator	Lecture Notes	Prof. dr ir Eric van Berkum
	Lecture 2: Measurement and Externalities		• Macroscopic and microscopic traffic flow characteristics • Methods of measurement • Derivation of externalities from flow characteristics, e.g. traffic safety, air quality, emission of GHG	Lecture Notes	Prof. dr ir Eric van Berkum
	Lecture 3: Stochastic Properties and Route choice		• Arrival and headway distributions • Queueing • Discrete choice models for route choice	Lecture Notes	Prof. dr ir Eric van Berkum
	Lecture 4: Fundamental Diagrams and Car following behavior		• Relationship between flow, speed and density • Stationary and homogeneous processes • Fundamental diagrams • Capacity • Car following models • Stability	Lecture Notes	Prof. dr ir Eric van Berkum
	Lecture 5: Shockwaves		• Types of shockwaves • Shockwave speed • Examples	Lecture Notes	Prof. dr ir Eric van Berkum
	Lecture 6: Intersections and Roundabouts		• Types of regulations at intersections • Variables on the decision of type of intersection • Capacity of priority intersections and roundabouts	Lecture Notes	Dr Alejandro Tirachini
	Lecture 7: Traffic control		• Introduction to traffic signals • Capacity and delays of signalized intersections	Lecture notes	Dr Alejandro Tirachini

Table 2. Overview of the content of Process Simulation unit

Unit	Lecture Title	Date	Discussed topics	Material	Lecturer
Process Simulation	Lecture 1: Introduction to Process Simulation	See Timetable	• Description of the construction process • The role of simulation • Different types of simulation • Modeling methodology	Lecture Notes	Dr. Farid Vahdati
	Lecture 2: Stochastic vs. Deterministic modeling		• Deterministic modeling • Balance point in the system • Stochastic modeling • Monte Carlo Simulation • Random number generator	Lecture Notes	Dr. Farid Vahdati
	Lecture 3: Queuing theory and Markov chain		• Introducing queue and its relevance to construction processes • Queuing theory • Markov chain and its application in construction	Lecture Notes	Dr. Farid Vahdati
	Lecture 4: Principles of Discrete-event Simulation		• Discrete vs. continuous modeling • Definition of Discrete-event system • Warm-up period • Simulation clock • Flags and productivity measurements • DES modeling flowchart • Stochasticity in DES	Lecture Notes	Dr. Farid Vahdati
	Lecture 5: Examples of DES models of the construction process		• Several examples of DES models for construction processes • Tricks and tips for modeling complex phenomena in DES	Lecture Notes	Dr. Farid Vahdati
	Lecture 6: Data Collection and Processing		• Probability distribution functions • Histograms • A statistical representation of observed/measured data (mean, median, standard deviation, etc.) • Use of historical data in simulation • Distribution fitting	Lecture Notes	Dr. Farid Vahdati
	Lecture 7: System Dynamics		• System thinking • Causality and casual loops • Stock and flow diagrams • System Dynamics Modeling	Lecture Notes	Dr. Farid Vahdati
	Lecture 8: Agent-based Simulation		• Emergent phenomenon • Top-down vs. bottom-up modelling • Agent-based modeling	Lecture Notes	Dr. Farid Vahdati
	Lecture 9: Simulation-based decision making		• Decision variables vs. Objective functions • The notion of optimization • Single vs. multi-objective optimization • Exhaustive search	Lecture Notes	Dr. Farid Vahdati
	Lecture 10: Exam Review		N/A	Lecture Notes	Dr. Farid Vahdati

2.2 Integrated Project Unit

The Integrated Project unit is worth 9 ECs. You will be working on this project for six/seven weeks (i.e., depending on the year, the quartile length can vary). During these weeks, you will collect the required data, analyze/process the data, develop the required models, and analyze the models. Several tutorial sessions will be offered during this period to help you learn about the software/methods you are going to use in your projects. During the tutorial, a member of the teaching staff will walk you through the basics of different software and methods you need to use in this project (e.g., Vissim, Stroboscope, AnyLogic, etc.). There will be several project support sessions too. In these sessions, a staff member will be present to answer your questions about the project.

In the project, you will be applying the theories you have learned in the theoretical units and apply it to a real project. The core objective of the integrated project is to give you an idea of how the simulation theories can be applied to a real decision-making process. Therefore, the focus is more on the application side of the theories.

As will be explained later, the project involves the simulation-based assessment of the existing traffic condition in a specific location, developing strategies to improve the traffic condition, and assessing the traffic flow after the improvement. Over the six weeks, you are required to submit certain deliverables. These deliverables each include part of the final content of the report. **In other words, the final report will be the aggregation of these deliverables, which is edited into a single report format.** Each group will submit a short summary of each deliverable and give a presentation about the deliverable to the teaching staff. Based on the submitted summary and the presentation, and you will receive verbal feedback and a tentative grade. The grade will only be an indication of how the part will be assessed if **it is written as presented and no further changes are applied.** However, you are free and highly encouraged to improve each deliverable based on the feedback you have received. This can result in the improvement of your grade with no limitation or cap. For example, Groups 1 and 2 submit a summary and give a presentation and receive feedback with tentative grades of 6, and 4, respectively. Group 1 decides to ignore the feedback and prepare the final report exactly based on the presentation. The will get a 6 for that deliverable. Group 2 on the other hand, takes the feedback and improve their deliverable substantially. They will get an 8.5 for their deliverable.

3 LEARNING GOALS

The learning goals of each component are as follows:

1) At the end of the **Traffic Flow unit**, you are expected to:

- Know the basic concepts of traffic flow theory, including data measurement
- Understand and explain some of the basic phenomena in traffic flows, including data measurement
- Analyze traffic management systems, in particular at road intersections
- Analyze the level of service of a traffic flow, based on measurements and/or simulation outcomes
- Be able to analyze and compare different traffic flow situations
- Know all objects in a traffic flow simulation, e.g., infrastructure, demand, traffic control, vehicle-driver-units
- To be able to explain the functioning of these objects

2) At the end of the **Process Simulation in the Construction unit**, you are expected to:

- Explain the role of process simulation in Civil Engineering
- Distinguish between deterministic and stochastic modeling approaches
- Explain the concept of the Monte Carlo Simulation
- Describe the principles of discrete-event simulation
- Use appropriate techniques to extract statistical information from site measurement
- Describe the principles of system dynamics simulation
- Describe the principles of agent-based simulation
- Deduce the notion of simulation-based optimization

3) At the end of the **Integrated Project unit**, you are expected to:

- Communicate and collaborate in a group with your peers
- Select appropriate modeling tools (from the set of tools provided in this module) for a large real-life problem in road construction and use them to model and solve the problem
- Interpret the outcomes of the before mentioned tools and formulate practical recommendations for system improvement
- Inform and convince the problem owner by means of a report and presentation
- Be able to model and interpret a simple traffic situation and transfer it to a traffic flow simulation experiment
- Be able to identify the impact of infrastructure, demand, and control in a simple traffic flow simulation experiment
- Be able to identify the causal relations in an experiment and develop solutions to improve the traffic situation
- Apply the principles of discrete-event simulation, system dynamics and agent-based simulation in real projects
- Use appropriate software and modeling methodology to translate a conceptual model into a functional simulation model
- Interpret the outcome of stochastic models
- Reflect on the outcome of the model and translate it into actionable strategies

4 REQUIRED PRIOR KNOWLEDGE

Students are expected to have the following prior knowledge.

- **Probability Theory and Statistics:** The student is familiar with random variables, cumulative distribution functions, probability density functions, and measures of distribution (mean, variance, standard deviation), which are covered in CE Module 3.
- **Traffic:** The student has basic knowledge of the supply side and demand side within a traffic system, design issues, data collection, and modeling traffic demand, which was covered in CE Module 3.
- **Programming:** The student understands the basics of programming (e.g., for and while loops, if – then statements).
- **Excel:** The student is familiar with Excel and knows the basic functions, such as multiplication, constructing a graph, data analysis, and several basic formulas (if, sum, count, etc.).

5 Assessment

Table 3 presents the overview of the assessment in this module. As discussed before, the theoretical units are each worth 3 ECs, and the project makes up 9 ECs. The assessment of each unit is explained below.

Table 3. Assessment components, weights, and the passing grade

Unit	Credit	Assessment Item	Weight	Passing grade
Traffic Flow	3 ECs	Final written exam	100%	5.5
Process Simulation	3 ECs	Final digital Exam	80%	5.5
		Group Assignment 1	10%	5.5
		Group Assignment 2	10 %	5.5
Integrated Project	9 ECs	**Deliverable 1:** Project area analysis	10 %	5.5
		Deliverable 2: Simulation of traffic flow in the current and improved state	40%	5.5
		Deliverable 3: Simulation of the intervention process	40%	5.5
		Presentation	5%	N/A
		Report	5%	5.5

5.1 Theoretical Units

The Traffic Flow unit is assessed through a written exam that covers all material from the 7 lectures. The Process Simulation unit encompasses three assessment items, namely a written digital exam (70%), and two group assignments (each worth 15%). The description of each assignment will be provided in separate documents and will be posted on Canvas.

All group assignments are done in the same groups as the project. **Please note that you need to receive at least 5.5 for each of these items. Regardless of the final average grade, if any item is assessed with a grade below 5.5, that item needs to be repaired/redone. If the second attempt is also not sufficient, the pertinent study unit will be scored insufficiently (regardless of the overall average grade).** You will have one chance to redo any of the assessment items. As far as the redos are concerned, while the re-sit of the written digital exam is not capped (e.g., you can receive an 8 in the re-sit exam) the repair of the group assignments is capped to a 6. Also, bear in mind that you can still decide to redo the written exam even if you had already passed the first exam but want to improve your grade. If you take the exam twice, the maximum of the two grades is considered.

5.2 Integrated Project Unit

You will do this project in groups. Each group consists of a maximum of 4 members. Groups are formed in the first week of the module. You use the same group formation throughout the module. The project consists of 3 deliverables that together make the final report. As explained before, you will submit a summary for each of the deliverables on the designated deadline (**Mandatory**). After the submission, you will present the deliverable content to a teacher on the designated date and time. The presentation will be 10 min max. After the presentation, the teacher will give you feedback (i.e., points for improvement and a tentative grade). The grade and feedback you will receive at this point are only for your information. As explained before, you are free to keep the deliverable content as is or improve it. If you decide to improve it, there is no cap on how high your final grade can be. If you decide not to improve it and the teacher determines that your final report is indeed aligned with your presentation, your final grade for the deliverable will be the same as the tentative grade. If the teacher decides that the presentation inflated the actual work done, the final grade can be less than the tentative grade. So, please make sure your presentation is fully aligned with the work done at the time of the deliverable deadline. The assessment of the final report is definitive, and no feedback is provided.

As shown in Table 3, the content of each deliverable in the final report is weighed as follows, Deliverable 1 (10%), Deliverable 2 (40%), and Deliverable 3 (40%). In addition to the content, the quality of the report (structure, language, format, references, etc.) accounts for 5%. Finally, all groups need to prepare a final presentation of a maximum of 15 minutes. This presentation accounts for 5% of the total project grade. During the presentation, you will be examined on the project content (i.e., the teaching team will ask you questions about the project). You will get a grade for your presentation and will not receive formal feedback for improvement. Like the assessment of items in theoretical units, the passing grade for each deliverable is 5.5. You need to receive a sufficient grade for all and every item. Should you fail any of these items, the repair version needs to be submitted, with the grade capped at a 6.

6 INTEGRATED DESIGN PROJECT

The integrated design project is about the redesign of a specific road in Enschede. The project area will change every year since it is going to be based on an actual traffic improvement project by the municipality. The exact location of the project will be communicated with you through Canvas and through an introduction presentation.

Figure 2 presents an overview of the scope of the project. In a nutshell, in this project you need to analyze the current traffic situation using traffic flow simulation and data collection (i.e., data collected from observing the actual traffic situation on the site). You can use the data not only to feed the model (e.g., using realistic distribution functions) but also to calibrate the model and validate it after it is built. Based on the results of the model and data collection and considering the objective of the municipality for traffic improvement, you will develop an intervention strategy. The strategy should include some construction process (e.g., changing the intersection regulation with a roundabout) and therefore **it is not sufficient** to only limit yourself to improving the traffic regulations (e.g., changing the right of way, or re-routing the traffic). Then, you will use simulation to assess the traffic condition after the intervention is implemented. For example, if the intervention strategy is to build a new overpass, you need to simulate the traffic condition when the overpass is built. You need to use the results of the two simulations to substantiate your design choice and to convince the municipality that your intervention strategy indeed improves the traffic condition.

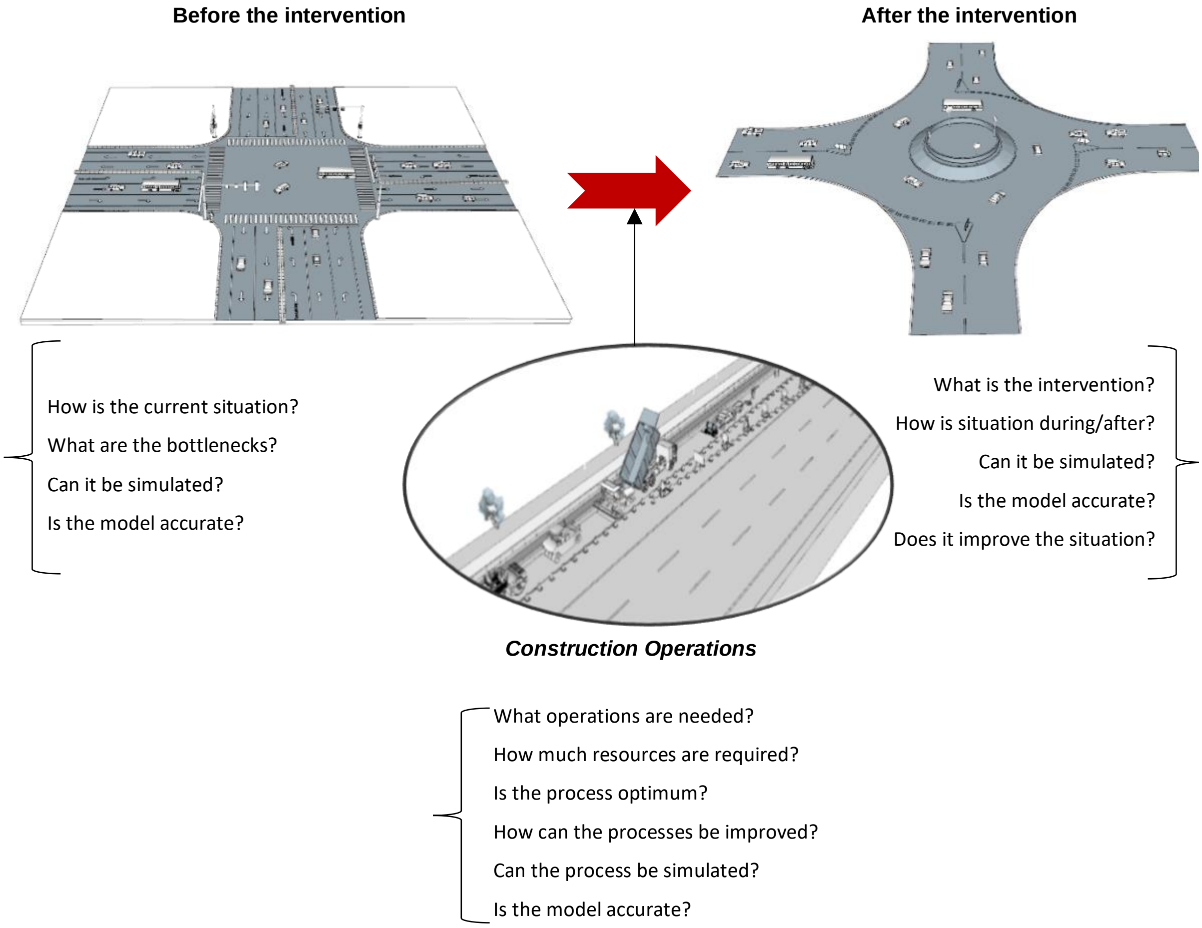

Figure 2. Schematic representation of the integrated design project

After completing the simulation-based pre- and post-intervention assessment, you need to use two different process simulation techniques (you are free to choose two out of the three simulation techniques, namely, discrete-event simulation, system dynamics and agent-based simulation) to model two construction processes of the intervention. **You do not need to model the entire construction project**. Instead, you will model two processes/operations. One operation can be selected by yourself (e.g., earthmoving, grading, etc.). The second operation must be the paving of the new asphalt layer. You develop the simulation model of these processes. Finally, you will use one of the two models to make decisions about the resources you need for that particular process. Out of the two processes you modeled, you are free to choose anyone of them for the resource optimization. For instance, if you choose the earthmoving operation, you need to determine how many trucks and excavators can best complete the operation. You need to define the **best** by yourself. This can be in terms of at least **two objectives** (e.g., minimizing cost, minimizing idle time of equipment, minimizing the construction time, etc.). You need to present the results of the optimization and justify your resource allocation strategy.

As mentioned before, this project is decomposed into 3 different phases (i.e., deliverables).

6.1 Deliverable 1: Project Area Analysis

In this deliverable, you first need to provide an overview of the project. You should explain the project as you see it (substantiated by the traffic data analysis) and present your plan for achieving the objectives of the project.

You need to clearly specify the criteria you are going to use for the assessment of traffic situation (e.g., travel time, congestion, queue length, safety, etc.). You will be using these criteria later to develop your intervention strategy. Bear in mind that you do not need to limit the scope of the project to vehicle traffic. You can very well incorporate concerns for cyclists, pedestrians, and residents into your project. You just have to make this clear and then make sure to reflect on these concerns throughout the project.

Next, you need to go to the project area and observe the current traffic condition and collect data that can represent variations in the traffic condition over different periods of the day and week. We recommend all groups coordinate with each other and arrange the observation campaigns in such a way that each group will do a 3 to 4-hour shift. It is encouraged and recommended that groups share their collected data so that everyone can benefit from a large database covering a long period. During the data collection campaign, you can focus on the OD-flows (number and type of vehicles, movements at the intersection), queue lengths, arrival distributions etc. Figure 3 and Table 4 give you an idea of what and how to observe the area. Don't forget, you can also choose to include bike traffic count in your project. This is up to you. Also, you may choose to video record the traffic situation so that you can analyze it later at the comfort of your house. How you extract the necessary data is up to you.

In the deliverable, you need to translate the collected data into distributions that can be used to develop your traffic flow simulations in the subsequent deliverables. You can break down the data into an hourly representation of the traffic flow.

- What is this project about? What problems are you trying to solve? and what is your methodology?
- What are the criteria you will use to assess the as-is and to-be-improved situation?

- What is the scope of your project (i.e., who are you concerned with)?
- What is the current situation in terms of the traffic flow?
- How did you collect the necessary data?
- What are the bottlenecks?
- What statistical models can best represent the current traffic situation and why?
- How are you going to use this data in the next phases of the project?

Appendix A presents the rubric used for the assessment of this deliverable.

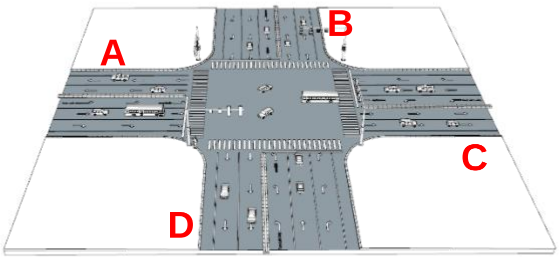

Figure 3. A layout of an example intersection

Table 4. Template for the vehicle data collection

				Destination			
				A	*B*	*C*	*D*
Origin	*A*	*Weekdays*	*Morning*				
			Afternoon				
			Evening				
		Weekends	*Morning*				
			Afternoon				
			Evening				
	B	*Weekdays*	*Morning*				
			Afternoon				
			Evening				
		Weekends	*Morning*				
			Afternoon				
			Evening				
	C	*Weekdays*	*Morning*				
			Afternoon				
			Evening				
		Weekends	*Morning*				
			Afternoon				
			Evening				
	D	*Weekdays*	*Morning*				
			Afternoon				
			Evening				
		Weekends	*Morning*				
			Afternoon				
			Evening				

6.2 DELIVERABLE 2: SIMULATION OF THE TRAFFIC FLOW

In this deliverable, you are asked to analyze the performance of the project area in terms of at least the traffic flow (capacity), travel time, and travel time reliability. You can add other performance metrics if you think they give important insights. The municipality also likes to know to what extent differences over time and directions of traffic are important for the performance measures. The models you create for this project should allow for these day-to-day and within-day variances.

Moreover, the municipality wants to construct a new neighborhood and is currently investigating possible locations of the new neighborhood. To get insights on what the effects of changes in traffic demands (i.e., higher or lower demand) is on the traffic system, the municipality would like to see a sensitivity analysis of traffic flow.

Furthermore, models are never fully correct. The municipality would like you to give an indication of the uncertainty of your model. You do not need to change all of your parameters, but choose the one(s) you think is or are most important or influential.

The municipality also would like to see how the project area can be improved by changing the layout from your basic design to something more sophisticated. Design one variant, explain your choice for the new layout, and show whether it improves the original situation. The budgets of the municipality and Ministry of I&W are not infinitely large and there are already other developments around the intersection, so make sure the measures are realistic.

Also, present your solution for the management of traffic during the implementation of the intervention (i.e., during the construction phase). Think of re-routing or phasing of the project. Use simulation to show how this traffic management strategy would affect the area during the construction.

In summary, this deliverable needs to answer the following questions:

- What is the perfect description of the model 'design' with the correct settings (e.g. right-of-way, speeds, signal times, a sufficient length of roads for queues)?
- What is the appropriate distribution of the traffic over the day?
- What are the assumptions?
- What is the statistical analysis of the delays and travel times in different directions with the distinction between different times of the day?
- What do graphs of the distribution of travel times/delays with main statistics (standard deviation, mean, median) look like?
- How do relevant variables (speed, travel time, or delay) for different directions/times/intersection types compare?
- What is the appropriate number of runs to sufficiently account for the stochasticity of the model?
- What can be concluded from this analysis (e.g., in terms of directions or times which are most remarkable and which are most useful in this case)?
- How can the situation be improved most effectively?
- What part of the intersection needs the most improvement and has the potential for the best flow (based on literature to make it perfect)?
- What is the impact of the intervention? (i.e., in terms of statistical difference between relevant quantities)

- What is the qualitative description of the advantages and disadvantages?

6.3 DELIVERABLE 3: SIMULATION OF THE INTERVENTION PROCESS

In this deliverable, you focus on the simulation of the intervention process. As mentioned before, you will **take one process of your choice and the mandatory paving process** and develop **<u>two models</u>** for these operations. For each process, use one of the three simulation technique (but it should not be the same technique for both process). In other words, you need to use two out of the three simulation techniques to model the two processes. Before taking any further steps in the modeling, you need to explain very clearly what types of decisions you want to make based on these models (i.e., the model scope) and what criteria you are using to assess different alternatives (i.e., the objective functions). **Be mindful that you need at least 3 decision variables and 2 objectives for each model.**

Subsequently, you need to present your conceptual model of each process. This includes a flowchart that presents the sequence of the tasks and the interaction of resources with different tasks (i.e., truck travels to the asphalt plant, excavator dumps soils, etc.). **Please bear in mind that each of your processes needs to have at least 15 tasks (if it is Discrete Event Simulation). If System Dynamics is your modeling of choice, then the model should include at least 5 different casual loops and 4 stock and flows. If you choose to use Agent-based Simulation, then the model needs to have at least 4 proactive or reactive agents (each agent needs to have at least 6 different states). That will help you determine the level of detail at which you need to model the processes.**

You, then, need to discuss all the assumptions and simplifications you are making in each model. For instance, you assume that a full truck needs to be at least 50 meters away from the excavator before the next truck is allowed to move to the loading location. You need to present a comprehensive list of all your assumptions and simplifications. Subsequently, you need to present your data (actual or assumed) in a table. If you assume certain data, you need to present the source of your estimate (e.g., YouTube videos). You should present the stochastic data in a table that shows what distribution functions are used and why.

Then, you present your models. This includes the snapshots of your model from the software. You need to explain how different elements of your assumptions and flowchart have been translated into the corresponding modeling syntax. **<u>You should also submit your models together with the report</u>**. You need to explain how you accounted for the stochasticity in the processes and how you capture variability and irregularities in the processes (e.g., through flow stoppers). If you must resort to specific modeling techniques to model complex situations (e.g., using dummy resources to regulate traffic), you need to explain them. Also, you need to explain what strategies you applied to reduce the impact of randomness in stochastic modeling on your decision-making. You should then discuss your verification strategies. Basically, you need to show how the model really corresponds to your conceptual model.

- For Discrete-Event model: focus on the following elements:
    - **Model logic:** *Your abstract explanation of the process in terms of sequences of tasks and interaction between resources and tasks (present an schematic visualization of the process or a flowchart)*
    - **Model network**: *How you translate the abstract description to the language (i.e., syntax of the DES) (present the snapshot of the model and explain different parts of it)*

- **Elements of stochastic modeling:** *What are the distributions of the durations of different activities, what are the parameters of each distribution, and where did you get the data (use a table for this)*
- **Initial conditions:** *Present the starting state of different resources (use a table for this)*
- **Assumptions: P***resent the list of assumptions, why did you make these assumptions and how they are translated into modeling choices (use bullet points for this)*
- **Results:** *Present your quantitative results. The results are in terms of the previously-set objectives of the model. For instance, if you are looking at the duration and cost of the project, you need to present these two values for the initial condition you described in the earlier step. Present the outcome of the Monte Carlo analysis and explain how many runs are found sufficient (considering the variance of the average of model outputs vis-à-vis the number of the simulation run).*
- **Verification strategy:** *Explain how did you make sure the model is sufficiently stable and good. Present the extreme case analysis, sensible critical behavior, review of the simulation log and the expected start, intermediate and end state of the model, etc.*

* For System Dynamics model: focus on the following elements:
    - **Stock and Flow Diagram:** *present all the stocks and flows. Present mathematical function of the flow and sequence of the stocks (present a separate diagram that only shows stocks and flows)*
    - **Casual Loops**: *explain different casual loops that are modeled in the process. Each loop needs to be presented in a separate drawing and you need to explain how each loop interacts with the other loops. Also, discuss whether the loop is balancing or reinforcing.*
    - **Elements of stochastic modeling:** *What are the distributions of the durations of different activities, what are the parameters of each distribution, and where did you get the data (use a table for this)*
    - **Initial conditions:** *Present the starting state of different resources (use a table for this)*
    - **Assumptions: P***resent the list of assumptions, why did you make these assumptions and how they are translated into modeling choices (use bullet points for this)*
    - **Results:** *Present your quantitative results. The results are in terms of the previously-set objectives of the model. For instance, if you are looking at the duration and cost of the project, you need to present these two values for the initial condition you described in the earlier step. Present the outcome of the Monte Carlo analysis and explain how many runs are found sufficient (considering the variance of the average of model outputs vis-à-vis the number of the simulation run)*
    - **Verification strategy:** *Explain how did you make sure the model is sufficiently stable and good. Present the extreme case analysis, sensible critical behavior, review of the simulation log and the expected start, intermediate and end state of the model, etc.*
* For System Agent-based model: focus on the following elements:
    - **Sequence Diagram:** *Present the overview of different agents and how and when they interact using a sequence diagram*
    - **State Diagrams**: *for each agent (separately) present a state diagram that shows different states, the condition of the transition between different states, interaction with other agents/environment and the internal parameters and variables*
    - **Modeling of the Environment**: *schematically show and explain the set of the environment. Discuss how different agents are populated, where they are placed in the simulation environment, how they interact with the environment and how the environment changes*

- **Elements of stochastic modeling:** *What are the distributions of the durations of different activities, what are the parameters of each distribution, and where did you get the data (use a table for this)*
- **Initial conditions:** *Present the starting state of different resources (use a table for this)*
- **Assumptions: P***resent the list of assumptions, why did you make these assumptions and how they are translated into modeling choices (use bullet points for this)*
- **Results:** *Present your quantitative results. The results are in terms of the previously-set objectives of the model. For instance, if you are looking at the duration and cost of the project, you need to present these two values for the initial condition you described in the earlier step. Present the outcome of the Monte Carlo analysis and explain how many runs are found sufficient (considering the variance of the average of model outputs vis-à-vis the number of the simulation run)*
- **Verification strategy:** *Explain how did you make sure the model is sufficiently stable and good. Present the extreme case analysis, sensible critical behavior, review of the simulation log and the expected start, intermediate and end state of the model, etc.*

Next, **you need to choose one of the two model** and try to determine the optimal configuration for a given number of objective functions (at least two). You need to use exhaustive search method. So, you will explain the constraints of the model. The constraints should be defined in such way that at least 100 runs are required to cover the entire solution space. You have to explain your search strategy and decision-making process. You need to **present your Pareto** front and explain how an actual decision-maker can use this output. You also need to reflect on the limitations and shortcomings of your models. Think of conditions under which these models may not be applicable. In other words, reflect on the generalizability of the models.

In a nutshell, this deliverable should answer the following questions:

- What operations are modeled and what do these operations look like?
- What kind of decisions need to be made about these operations?
- How can an improvement in the operation be quantified/measured?
- How can these operations be modeled different modeling techniques?
- What assumptions and simplifications are needed to make different modeling possible?
- Do the models do what you want them to do?
- What are the optimum operations? How to best utilize the resources?
- What methods are used to find these optimum solutions?
- What are the limitations of the models?
- How generalizable are the models?

Appendix D presents the rubric that will be used to assess this deliverable.

6.4 Submission of the Summary of Deliverables and the Interim Presentations

At the designated deadline, you will submit a summary of what you have done in this deliverable and a 10-min presentation. The summary should be maximum of 5 pages. You can skip the editorial/report details (e.g., elaborate introduction, problem statement, etc.). Just present the core methodology (i.e., the steps that you have taken), the overview of the model, the results, and conclusions. Appendixes are excluded in the 5-page limit. You also submit the presentation file, which you will be later on asked to present in the designated time slot. A the presentation session, the teacher will listen to your presentation (maximum of 10 minutes), reflect on your summary and ask you questions about your deliverable. Ultimately, you will get some tips on how to improve your deliverable and a tentative grade. As mentioned before, the tentative grade only indicates the grade that you will get if you decide to completely ignore the feedback and submit this deliverable in the final report as is. If improvement is made to the deliverable (and this is clearly explained in the rebuttal) the tentative grade can change without any cap. In an unlikely and extreme case where the teacher picks up outstanding anomaly between the interim presentation/summary and the final result, the final grade can be lower than the tentative grade.

6.5 Final Report

The final report is essentially the assembly of Deliverables 1 to 3. Each of the deliverables will a chapter in the final report. Please include a general Introduction (Chapter 1) and a general Conclusions & Discussions (Chapter 5) in the report. **It is very important to include a rebuttal table as an appendix to the report**. You will be penalized if this is not included in the final report. The rebuttal report is basically a table where you mention each feedback point you received during the module, how you reacted/responded to the feedback, and where the changes can be found (e.g., Paragraph 2 on Page 23 Or the new Figure 3). Use Appendix E as a template. **Unless you fail the report, you will not receive feedback on the final report.**

6.6 Final Presentation

At the designate time slot, in the last week of the module, each group will give a presentation (max 15 minutes) to the teaching team in a closed session. The presentation will be followed by a Q/A about the project. All students are expected to be familiar with all and every part of the project. If the teacher asks one student to answer a certain question and the student fails to respond to the question, the whole group will be penalized. No structured feedback will be provided in this session. The presentation grade will be given to each group at the end of the session.

7 Professional Skills

Professional skills in Module 8 is about preparation for the internship in Modules 11 and 12 and the job market after you've completed either your Bachelor's or Master's programme. To help you on your way, the first week of Module 8 will feature three workshops: writing your Curriculum Vitae (CV), writing an application letter, and creating a LinkedIn page.

7.1 Workshop 1: writing a Curriculum Vitae

In this workshop we will go over the various components that make up your CV or resume. To facilitate this, you are also asked to reflect on your education thus far: what are the skills you excel in and what are the skills in which you would like to improve? After that you are given the opportunity to work on your CV and ask questions. I will also introduce the company visit assignment in this workshop.

7.2 Workshop 2: writing an application letter

Where the CV is a kind of a fact sheet about your skills and interests, the application letter is your opportunity to offer a further elaboration. In this workshop we will discuss how you can emphasise how your various skills and traits make you a good fit, and how the company is a good fit for you.

This is a good opportunity to write an application letter for a company where you'd like to intern during your Bachelor Thesis assignment.

7.3 Workshop 3: building a LinkedIn page (optional)

In this optional workshop, I will guide you through the process of building a LinkedIn page in a step-by-step fashion. I will elaborate on the various elements of the page and how you can use it effectively to find and connect with other people in the field.

7.4 Professional Skills assignment: company visit

The best way to get an idea of the kinds of job you can get after graduation, is to go out there and experience it. To encourage you to seek out this experience, you are asked to team up with one or two fellow students and arrange a company visit at a company of your choice. Not only does this experience allow you to learn more about a potential field of work, it can also be the first step to finding your internship spot.

8 List of Software and Programming Languages

You need the following software suites for this project:

- Excel
- Visio (this will be provided by the department)
- Stroboscope (use this link)
- Anylogic
- Vissim (help on downloads in lectures in week 17 and 18)
- Python (used for machine learning and optimization)

9 Timetable

9.1 Deadlines

The deadlines for the exam, assignments, and deliverables are presented in Table 4.

Table 4. Deadlines in the module

Unit	Assessment Item	Deadline
Traffic Flow	Final written Exam	26/05/2025
	Resit written Exam	23/06/2025
Process Simulation	Final digital Exam	05/06/2025
	Resit digital Exam	30/06/2025
	Group Assignment 1	14/05/2025
	Group Assignment 2	28/05/2025
Integrated Project	Deliverable 1: Project area analysis	22/05/2025
	Deliverable 2: Simulation of the traffic flow	06/06/2025
	Deliverable 3: Simulation of the intervention process	20/06/2025
	Presentation	03/07/2023
	Report	04/07/2024

10 Organization and Supervision

In this module, different persons and groups are actively participating. We list the following:

Coordinators

Name	Room	Phone	E-mail address
Eric van Berkum	HR Z216	4886	e.c.vanberkum@utwente.nl
Farid Vahdati	HR Z220	2242	f.vahdatikhaki@utwente.nl

Lecturers

	Name	Room	Phone	E-mail address
Professional Skills	Cor van den Berg	BH	9127	c.l.vandenberg@utwente.nl
Traffic Flow	Eric van Berkum	HR Z216	4886	e.c.vanberkum@utwente.nl
	Alejandro Tirachini	HR Z217	1771	Alejandro.tirachini@utwente.nl
Process Simulation in Construction	Farid Vahdati	HR Z220	2242	f.vahdatikhaki@utwente.nl
Vissim	Luuk de Vries			luukorlando@gmail.com

Student Assistants

Name	Course	E-mail address
Loes Hazenberg	Tutorials Traffic Flow, Support Traffic Flows in Integrated Project	l.w.hazenberg@student.utwente.nl
Welmoed Spanjer		w.b.spanjer@student.utwente.nl
Qinshuo Shen	Tutorials Construction Simulation, Support Construction Simulation in Integrated Project	q.shen@utwente.nl
Amir Hassan Beykian	Tutorials Construction Simulation, Support Construction Simulation in Integrated Project	a.beykian@utwente.nl

APPENDICES

APPENDIX A: RUBRIC FOR THE ASSESSMENT OF DELIVERABLE 1

Table 5. the assessment criteria and weights for Deliverable 1

<table>
<tr><th>Project Requirements</th><th>Inadequate
(0~5)</th><th>Satisfactory
(5.5~6.5)</th><th>Good
(7~8)</th><th>Excellent
(8.5~10)</th></tr>
<tr><td rowspan="2">Project Description (10%)

• Background
• The problem addressed in the project
• The objectives of the project
• Improvement criteria
• Project scope
• Methodology and plan
• Introducing the problem area
• Breakdown of the report</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Comment:</td></tr>
<tr><td rowspan="2">Description of the data collection campaign (20%)

• The reason why data needed to be collected
• Explanation of the collected data
• Data collection strategy</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Comment:</td></tr>
<tr><td rowspan="2">Presentation of the data (40%)

• Analysis of the collected data
• Translation of the data into relevant distribution functions</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Comment:</td></tr>
<tr><td rowspan="2">Reflection and conclusions (20%)

• Limitations of the data collection campaign
• Strategy for the use of the data in the simulation of traffic flow</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Comment:</td></tr>
<tr><td rowspan="2">Report Style (10 %)

• Completeness
• Consistency
• Cohesion
• Clarity
• Format
• Style
• References and citations</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="4">Comment:</td></tr>
<tr><td colspan="5">Additional Comment:</td></tr>
<tr><td colspan="5">Overall Grade (Tentative):</td></tr>
</table>

APPENDIX B: RUBRIC FOR THE ASSESSMENT OF DELIVERABLE 2

Table 6. the assessment criteria and weights for Deliverable 2

Project Requirements	Inadequate (0~5)	Satisfactory (5.5~6.5)	Good (7~8)	Excellent (8.5~10)
Introduction (10%) • Analysis of the problem • The goal of intervention strategy • Discussion of the goal of the simulation • Discussion of the simulation methodology • Breakdown of the structure				
	Comment:			
Analysis of the current situation (25%) • Presentation of the traffic distributions • Assumptions • Statistical analysis of delays and travel times • Graphs of travel time distributions • Comparison of variables • Sensitivity analysis				
	Comment:			
Description of the intervention strategy (10%) • Identification of the area of improvement • Description of the intervention strategy • Hypothesis about the expected impact • Analysis of traffic management strategy during the construction				
	Comment:			
Analysis of the Improved situation (25%) • Presentation of the traffic distributions • Assumptions • Statistical analysis of delays and travel times • Graphs of travel time distributions • Comparison of variables • Sensitivity analysis • Strategies for the traffic management during the construction work				
	Comment:			
Conclusions (20%) • Description of the bottlenecks • Analysis of uncertainty in the model • Identification of the areas of the improvement				
	Comment:			
Report Style (10 %) • Completeness • Consistency • Cohesion • Clarity • Format • Style • References and citations				
	Comment:			
Additional Comment:				
Overall Grade (Tentative):				

Appendix D: Rubric for the Assessment of Deliverable 3

Table 8. the assessment criteria and weights for Deliverable 4

Project Requirements	Inadequate (0~5)	Satisfactory (5.5~6.5)	Good (7~8)	Excellent (8.5~10)
Introduction (10%) • Justification of the use of process simulation • Introduction of the processes • Introduction of the decision variables and objectives				
	Comment:			
Conceptual Models (10%) • Conceptual models of the processes • Interaction between resources and tasks • Detailed description of level of details of the model • Assumptions and simplifications • Quantification of the model objectives				
	Comment:			
DES Model Development (25%) if chosen • Model logic • Model network • Elements of stochastic modeling • Initial conditions • Assumptions • Results • Verification strategy • Appended models to the report				
	Comment:			
SD Model Development (25%) if chosen • Stock/flow diagram • Causal loops and the rationale behind them • Elements of stochastic modeling • Initial conditions • Assumptions • Results • Verification strategy • Appended models to the report				
	Comment:			
ABS model (25%) if chosen • Sequence diagram • State diagrams • Modeling of the environment • Elements of stochastic modeling • Initial conditions • Assumptions • Results • Verification strategy				
	Comment:			
Reflection (20%) • Decision making process and optimization strategy • Near optimum solutions • Pareto front and explanation of how it can be interpreted • Limitations and generalizability of the models				
	Comment:			
Report Style (10 %) • Completeness • Consistency • Cohesion • Clarity • Format • Style • References and citations				
	Comment:			
Additional Comment:				
Overall Grade (Tentative):				

Appendix E: Template for the Rebuttal in the Final Report

Content	Feedback	Reaction	Location in the Report
Deliverable 1 (Chapter 2)			
Deliverable 2 (Chapter 3)			
⋮	⋮	⋮	⋮

Appendix D: Timetable

2024-2025		17	18	19	20	21	22	23	24	25	26	27	28
Day	Hour	21/Apr	28/Apr	05/May	12/May	19/May	26/May	02/Jun	09/Jun	16/Jun	23/Jun	30/Jun	07/Jul
Monday	1	Holiday		Holiday			Traffic Flow	Unsupervised	Holiday	Unsupervised	Traffic Flow	Construction	
	2	Easter Monday		Liberation Day	Data Collection				Whit Monday				
	3		Traffic Flows			Traffic Flows	Exam	Project Session		Project Session	Resit Exam	Simulation Resit	
	4		P-Vissim			L7-control							
	5												
	6		Traffic Flows			T4 Construction	Unsupervised	Q&A		Unsupervised	Unsupervised		
	7		P-Vissim		Data Collection	Simulation		Deliverable 2					
	8						Project Session	Unsupervised		Project Session	Project Session		
	9							Project Session					
Day	Hour	22/Apr	29/Apr	06/May	13/May	20/May	27/May	03/Jun	10/Jun	17/Jun	24/Jun	01/Jul	
Tuesday	1	General					Unsupervised	Unsupervised	Unsupervised	Unsupervised	Unsupervised		
	2				Data Collection								
	3	Traffic Flows	Traffic Flows	Traffic Flows		Q&A	Project Session	Project Session	Project Session	Project Session	Project Session		
	4	P-intro	P-Vissim	T2-FD		Traffic Flow Exam							
	5												
	6	L1 Construction	Traffic Flows	L7 Construction		Q&A	Supervised	Supervised	Supervised	Supervised	Supervised		
	7	Simulation	P-Vissim	Simulation	Data Collection	Deliverable 1	Project Support	Project Support	Project Support	Project Support	Project Support		
	8	Traffic Flows					Supervised	Supervised	Supervised	Supervised	Supervised		
	9	L1-intro&sim					Project Support	Project Support	Project Support	Project Support	Project Support		
Day	Hour	23/Apr	30/Apr	07/May	14/May	21/May	28/May	04/Jun	11/Jun	18/Jun	25/Jun	02/Jul	
Wednesday	1					Unsupervised		Unsupervised	Unsupervised	Unsupervised	Unsupervised		
	2				Data Collection								
	3	Prof Skills	Traffic Flows	Traffic Flows		Project Session	Q&A Construction	Project Session	Project Session	Project Session	Project Session	Review	
	4	Workshop	L3-stoch & routes	L5-SW			Simulation Exam					Traffic Flow Resit	
	5												
	6	L2 Construction	L4 Construction	L8 Construction		Unsupervised	Presentations	Unsupervised	Unsupervised	Unsupervised	Unsupervised	Review Constr	
	7	Simulation	Simulation	Simulation	Data Collection							Simulation Resit	
	8					Project Session	Deliverable 1	Project Session	Project Session	Project Session	Project Session		
	9												
Day	Hour	24/Apr	01/May	08/May	15/May	22/May	29/May	05/Jun	12/Jun	19/Jun	26/Jun	03/Jul	
Thursday	1					Unsupervised	Holiday	Construction	Unsupervised	Unsupervised	Unsupervised	Project	
	2						Ascension Day						
	3	Prof Skills	Traffic Flows	Traffic Flows	Traffic Flows	Project Session		Simulation Exam	Project Session	Project Session	Project Session	Presentations	
	4	Workshop	T1-measurement	T3-SW	T4-intersections								
	5												
	6	Traffic Flows	L5 Construction	T1 Construction	T3 Construction			Supervised	Supervised	Supervised	Supervised	Project	
	7	L2-measurement	Simulation	Simulation	Simulation			Project Support	Project Support	Project Support	Project Support		
	8					Deadline		Supervised	Supervised	Supervised	Supervised	Presentations	
	9					Deliverable 1		Project Support	Project Support	Project Support	Project Support		
Day	Hour	25/Apr	02/May	09/May	16/May	23/May	30/May	06/Jun	13/Jun	20/Jun	27/Jun	04/Jul	
Friday	1					Unsupervised	Holiday	Unsupervised	Presentations	Unsupervised	Presentations		
	2						Bridging Day						
	3	Prof Skills	Traffic Flows	Traffic Flows	Traffic Flows	Project Session		Project Session	Deliverable 2	Project Session	Deliverable 3		
	4	Workshop	L4-FD&CF	L6-intersections	T5-control								
	5												
	6	L3 Construction	L6 Construction	T2 Construction	Traffic Flows	Unsupervised		Unsupervised	Review	Review Constr	Unsupervised		
	7	Simulation	Simulation	Simulation	P-Vissim			Project Session	Traffic Flow Exam	Simulation Exam			
	8					Project Session		Deadline	Q&A	Deadline	Project Session	Deadline	
	9							Deliverable 2	Deliverable 3	Deliverable 3		Final Project	

dl. = Deadline
rep. = Repair
rev. = Review
Q&A = Question & Answer session

= Traffic Flows (Lec+Tut)
= Project-Traffic Flows (praktikum & supervised support)
= Construction Simulation (Lec)
= Project-Construction Simulation (Tut+supervised sup)
= Project unsupervised
= Exams and deadlines this module
= presentations & assessment deliverables
= Intros, Q&A's and Reviews
= holidays
= outside activities
= Professional Skills Workshop

~~**) All project deadlines are at 11:59AM (so at noon, not midnight).~~
**) All project deadlines are at 11:59PM (so at midnight, not at noon).