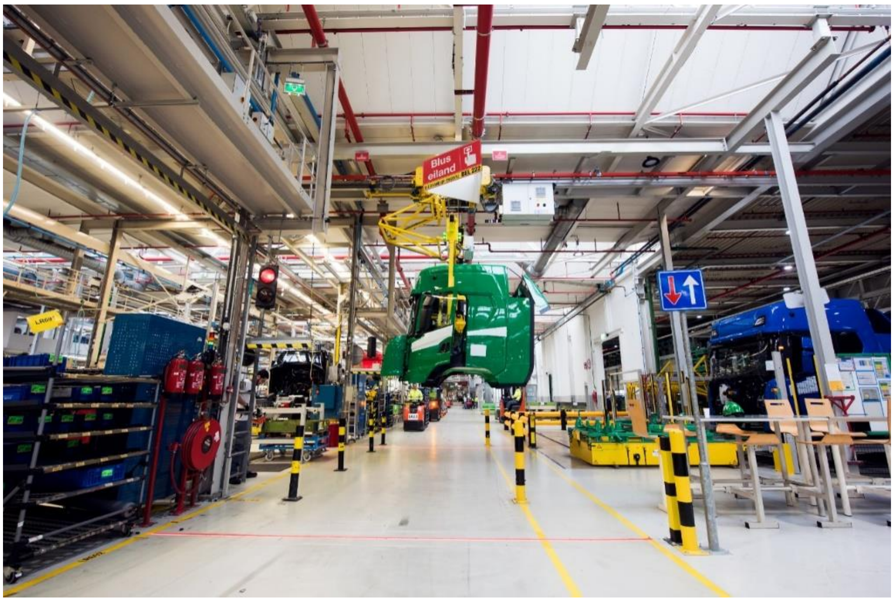

Increasing Traffic Safety in the Factory of Scania Zwolle

Solving a Complex Traffic-Flow Problem with Multiple Constraints in a Manufacturing Environment

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Industrial Engineering and Management
Master Thesis
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Colophon

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I hope this thesis will increase the reader's understanding of addressing traffic-related safety problems in a manufacturing environment!

Philip Borggreve, Zwolle, July 2024

Management Summary

This thesis is performed at Scania Zwolle. In Zwolle, Scania assembles most of the trucks they are making. The company has two main assembly lines in their factory, the Pollux and the Castor line, at which all the trucks are assembled. All the materials are brought to the two production lines with transporters like trains and forklifts from outside the factory. However, this process results in quite some problems regarding traffic safety in the factory. All kinds of traffic flow across each other, resulting in unsafe situations in the factory.

Scania is giving the KPI 'Safety' great value in the way it is making its policies. Therefore, it wants to focus attention on solving this problem. Nevertheless, with the eventual solution to the problem, it wants to maintain the performance of the production process in the factory. Therefore, the main goal of the thesis is the following: *Provide a strategy for Scania Zwolle in terms of factory layout, human behaviour, and vehicle routing to improve worker safety and the safety of all those utilizing the factory, all while taking into account the impact on production efficiency.*

At first, an analysis of the current situation is made. From this analysis, five types of traffic flows are the most important to consider. These are the flows from the 'blue’, 'green’, and 'purple' buildings, the flow from the 'Awnings’, and the flow of pedestrians. By looking at the routes, these traffic flows are mostly taking, and the resulting intensity of the traffic in the factory could be seen as the highest traffic intensity occurring in the upper part of the factory. Here, most of the flows are coming together. From direct observations, interviews, and statistical research, we determine that 'the PortiersLoge’, 'The Crossing at the Blue Building’, 'the EagleOvergang' and 'the Aorta' are the busiest places in the factory. Most of the traffic interactions are happening here. As a result, these points focused more on the remaining research.

From our literature review, it came forward that too high intensity of traffic, bad road design, and human behaviour are the main reasons for unsafe situations in traffic. We tested the following solutions in order to address the mentioned problems:

Table 1: Implemented Solutions

Reason Traffic Accident	**Way to solve the problem**	**How?**
High intensity of road users	Switch traffic flows	1 Change shift system, 2 Dynamic routing
Poor design of roads	Change road design	3 Bridges 4 Traffic barriers
Human behaviour	Introduce new Standard Operating Procedures to encourage greater responsibility from employees	5 New speed limits 6 Lower the speed limits at crossing points

To assess the performance of these solutions, we built a discrete event model of the Scania Zwolle factory. However, before developing the model for the Scania factory, we first decided what the conceptual model should look like. We started by determining the model's assumptions. One assumption is, for example, that there should only be a limited number of roads, destinations, and road users in the model. Another assumption is that road users should enter the factory with the same intensity as they would in the real world. After listing the assumptions, we chose the inputs for the model. The model's input included, for example, all roads i, road users l, destinations k, and arrival times λ. After listing the input, we designed the logic within the model to determine the model outputs. In order to calculate the values of the main KPIs, the interactions at crossings, the interactions at straight lines, the total travelled distance, and the total waiting time are counted.

Once we were aware of all the conceptual model's assumptions, inputs, outputs, and logic, we created the discrete event model that represents the current traffic situation in the factory of Scania. As a result, the model calculates the values of the four primary KPIs for our specific case. Meetings with important Scania stakeholders were held to validate the model. Based on the answers provided during the interviews, we concluded that we accurately replicated the traffic flows in the factory. We could test the solutions listed in Table 1 by adopting the discrete event model. The warm-up period and the number of replications were considered to obtain reliable results.

Based on testing the solutions, the following main conclusions can be drawn:

- The best strategies to reduce the number of interactions at crossings are to construct bridges at the three most busy pedestrian/vehicle points, install traffic barriers at the same places, and use Dynamic Routing (wait at depots and split pedestrian streams at Portiersloge). These solutions decrease the number of interactions at crossings by 52%, 40%, and 25%, respectively.
- Lowering the speed restriction is the best method for reducing the number of interactions on straight lines. Reducing the speed restriction to 7.5 km/h, 7.0 km/h and 6.5 km/h will reduce the number of straight-line interactions by 20%, 27%, and 39%, respectively.

We looked into nine hybrid solutions to see whether we might improve the positive effects of the individual solutions. We combined the three options for lowering the speed limit with the three most effective solutions to decrease the number of interactions at crossings. Table 2 shows the results of the three best hybrid solutions.

Table 2: KPIs Reduction per Solution

Solution	NrInteractionsCr	NrInteractionsSL	Total Distance	Total Waiting Time
Three Bridges + Speed Limit 6,5 km/h	56%	35%	9%	38%
Six Traffic Barriers + Speed Limit 6,5 km/h	48%	34%	7%	24%
Dynamic Routing S2 + Speed Limit 6,5 km/h	13%	41%	7%	43%

This research found the optimal (hybrid) solution to build bridges at the factory's three busiest pedestrian/vehicle locations and reduce the speed restriction to 6.5 km/h, as seen from the table. We also suggest Scania implement this hybrid solution. This solution positively impacts the total travel distance and total waiting time. Furthermore, most importantly, this solution decreases the total number of interactions.

Table of Contents

1 Introduction

The introduction to this research is covered in this chapter. In Section 1.1, the research problem is presented. We go into detail about the background of the problem, the assignment provided to us, the problem cluster related to this assignment, and the core problem that followed from this problem cluster. The research goal and research scope are then stated in Section 1.2. The research steps are explained after the research goal is indicated, giving the reader an overview of the actions taken to address the main problem. Finally, the data-gathering techniques required to carry out the research steps are explained in Section 1.3.

1.1 Problem Identification

This section introduces the research problem. After providing some background information about Scania, the assignment is explained. The core problem of this study is then addressed by discussing the problem cluster and problem context in further detail.

Background

Situated in Zwolle, The Netherlands, Scania Zwolle is a production facility component of the Scania Group, a well-known Swedish automobile manufacturer. The manufacturing of trucks is the main focus of this plant. Scania is well-known in the transportation sector for its dedication to sustainability and innovation, and the Zwolle site is no exception. The Logistics Department is the part of the company where this thesis is written. Ensuring the smooth transportation of Scania goods and trucks within, into, and out of the Zwolle factory is the primary responsibility of the logistics department. This thesis addresses a safety concern that the factory has about this department. Scania prioritizes worker safety. This is why Scania wants to create a safer work environment in the factory. In addition, Scania adheres to the LEAN methodology and pursues ongoing development.

The Assignment

Scania recognizes that the traffic intensity has increased over time in its factory and will increase even further soon. Therefore, a high number of pedestrians interfere with vehicle flows. These situations should be prevented, mainly because they can lead to dangerous situations within the factory. Therefore, the main goal is to address and reduce the safety problems brought on by the increased traffic volume and pedestrian-vehicle interactions. The following are the two primary components of this assignment:

1. Safety Assessment: Assess the factory's current traffic flow and safety hazards, considering vehicle and pedestrian movements. Identify specific areas or situations regarding transportation that pose a significant risk to the safety of the employees.
2. Propose Safety Solutions: Offer and implement practical solutions to prevent or reduce traffic-related safety incidents. This can entail changing the traffic flow, improving the infrastructure, adding signage, or taking other safety measures.

Problem Context

The factory of Scania has witnessed a significant rise in traffic intensity in the past few years due to an increasing demand for its products. It is anticipated that this tendency will continue, adding to the stress on the traffic within the facility. The main problem that needs to be addressed immediately is that a high volume of vehicles and pedestrians will interact with each other. The following factors contribute the most to the problem:

1. Two-shift production system: The factory uses a two-shift system, and there is one shift change during the day at 2:00 p.m. During these transitions, there is a large concentration of pedestrians coming in and leaving the factory, which leads to increased traffic density.

2. Pedestrians and vehicles move at the same time: Small trains and other industrial vehicles move at the same time as pedestrians' arrival and departure, for example, during the shift change. This can create an unsafe intersection, raising concerns about safety.
3. Lack of space in the factory: Since movement space is limited, pedestrians come close to moving vehicles while walking through the factory. Therefore, these employees are in danger of becoming injured. Potential risks include accidents and production delays.
4. Increased traffic over the years: As the factory grew and expanded its production, traffic increased inside the factory. Moreover, this may grow further in the future, which will increase already-existing safety concerns.

Consequences of the current situation are the following:

1. There is a higher chance of accidents and injuries.
2. A decrease in operational effectiveness can have an impact on production.
3. The effect that safety concerns may have on worker morale and job satisfaction.
4. Possible violations of safety regulations and related fines when Scania gets checked on the safety regulations.

The relationships between the causes and consequences of the problem are indicated in the problem cluster in Appendix A1.

The Core Problem

From the problem context, it can be seen that the core problem is the following: **"There are locations within the factory where the volume of traffic is excessive, sometimes during specific hours of the day. This excessive volume of traffic results in dangerous traffic conditions within the factory.** Therefore, what can be changed to improve the situation regarding the traffic intensity in the factory should be investigated. It is an option to look if the two-shift system can be changed. Another way to improve the situation could be to change the factory's layout and, for example, change the infrastructure around the crossing points in the factory. SOPs (Safety operating procedures) can also be used to manage the traffic intensity in the factory better.

1.2 Research Approach

This section describes the objective and scope of the research. First, the research objective is determined from the core problem and research scope. Then, the research approach is chosen based on this objective. After that, the steps that must be taken to accomplish the research goal are covered in detail. Finally, we examine the data collection techniques required for the research approach.

Research Scope and Objective

The Scania Zwolle factory is the main subject of the study. Pedestrians, trains, and vehicles are among the several types of movement that occur daily throughout the factory. Each of these movements should be considered. An essential factor that needs to be considered is the factory's production efficiency. Scania already produces more than 200 trucks daily and hopes to increase this number even further. Therefore, the number of trucks that can be produced in a given day should not be harmed. Material delivery delays, higher travel distances within the facility, and traffic congestion can all result in delays in truck manufacturing, which lowers the factory's production efficiency.

This study considers the following goal by the research scope and the identified core problem: *Provide a strategy for Scania Zwolle in terms of factory layout, human behaviour, and vehicle routing to improve worker safety and the safety of all those utilizing the factory, all while taking into account the impact on production efficiency.* Several approaches to improving factory safety are examined to meet this goal, including rearranging the facility's traffic flows, modifying the SOPs, and changing the two-shift system. Further discussion of these techniques is provided in Chapter 3.

Research Steps

The following main research question is generated from the description of the core problem, research scope, and research objective: What is the most effective strategy in terms of factory layout, human behaviour, and vehicle routing for Scania Zwolle to improve worker safety and the safety of all those who utilize the factory while keeping in mind the factory's production efficiency?

To answer this question, six research phases are defined. These phases are:

1. Investigating the current situation
2. Conducting the literature review
3. Model description
4. Designing the solutions
5. Testing the solutions
6. Concluding and providing recommendations

At each stage, a main research question is addressed with the assistance of several sub-questions. We explain for each step which data is required to address the questions and how it is collected.

Phase 1: Investigating the current situation

The main research question of phase 1 is: *What is the current situation of safety in relation to the logistics operations taking place at the Scania factory?*

The following sub-questions are answered in order to address this question:

1.1. Which logistical operations happen every day in the Scania factory?
1.2. Where in the workplace are most traffic interactions based on statistics?
1.3. From the employees' standpoint, where do most traffic interactions occur in the factory?
1.4 What are the current traffic rules in Scania's factory?
1.5 What does a safety-related project need to meet in order to be approved by Scania?

The main goal of Phase 1 is to assess the current level of safety at the Scania factory. An overview of the current state of the safety issues is produced by examining quantitative data about safety-related traffic interactions, mapping all logistical activities occurring in the factory, and interviewing Scania employees. All of this is done in Chapter 2. It is anticipated that after writing Chapter 2, it will be clear which parts of the factory have the highest number of safety-related traffic interactions and the main reasons for these occurrences. In order to increase the chance that Scania will implement our suggested solution, we will examine the general process for a project's acceptance at Scania as well.

Phase 2: Conducting the Literature review

The main research question for phase 2 is: *Which solutions are suggested by the literature to address the main common sources of traffic-related safety problems in manufacturing environments?*

The following sub-questions are asked in order to address this question:

2.1 What are the main reasons for traffic-related safety concerns in manufacturing environments?
2.2. What approaches does the literature suggest to address these reasons for traffic-related problems in manufacturing environments?

The primary goal of phase 2 is to get an overview of what the literature says about the primary causes of factory traffic-related safety concerns. With this information in hand, along with the results of phase 1, it is expected to arrive at a good understanding of the root cause of the safety-related problems at the Scania factory. Next, by providing an answer to question 2.2, an overview of potential solutions to the traffic-related issues in the Scania factory is generated. Chapter 3 includes a description of this literature review.

Phase 3: Model Description
We want to test the solutions that the literature suggests in Phase 2. Thus, we are interested in determining which conceptual model is suitable to simulate a traffic system in a manufacturing environment. Therefore, Phase 3's central research question is: *How should the conceptual model be made considering the traffic situation in a manufacturing environment we want to replicate?*

To answer this question, the following sub-questions are posed:
3.1 Which kind of model do we want to make?
3.1 Which model assumptions, inputs, and logic should the conceptual model contain?
3.2 Which KPIs should be included in the outputs of the model?

In order to replicate a traffic system in a manufacturing environment, the first thing we do in this phase is determine which model to create. In Section 3.1, we decide on this subject. After that, we create the conceptual model in Section 3.2. We discuss the assumptions of the model, its inputs, and its logic. In order to answer question 3.3, a review of the literature and interviews with significant stakeholders are conducted to identify the most crucial KPIs that need to be considered for the final solution. At this stage of the research process, understanding these KPIs is essential since measuring the primary KPIs is a base requirement for creating the (conceptual) model we utilize.

Phase 4: Designing the Solutions
The main research question for phase 4 is: *Which solution designs may be the best for Scania's existing circumstances, and how should these designs be adapted to the current situation of Scania's factory?*

To answer this question, we look at the following sub-questions:
4.1 How may the shift system be changed or dynamic routing be implemented to switch traffic streams?
4.2 How should bridges and traffic barriers be implemented in Scania's factory?
4.3 How can human behaviour be changed to improve the safety of the traffic situation inside the factory?

In this phase, the solutions from the literature suggested in phase 2 are changed to fit Scania's current traffic system. The literature proposes reducing the road intensity, improving the road layout, or changing human behaviour. Therefore, we elaborate on the solutions that can potentially realise these changes and describe how the solutions are implemented in the model from Phase 3.

Phase 5: Testing the Solutions
The main research question of phase 5 is: *What performance can be expected from the interventions proposed in phase 4?*

In order to address this question, the following sub-questions are posed:
5.1 Which experimental settings should be used during the tests?
5.2 How well are the solutions suggested in Phase 4 regarding safety and production efficiency?

Answering Question 5.1 enables us to select the experimental settings. Important KPIs, including the number of interactions at crossings and the total waiting time, are examined to answer Question 5.2. This enables us to find Scania's best potential solution. The primary result of this phase is a practical and efficient solution for Scania regarding the safety-related issues at the factory. Chapter 6 describes this phase.

Phase 6: Drawing Conclusions and Providing Recommendations
In the last phase of this research, the conclusions and recommendations about this research are proposed. The main research question is answered, and recommendations are proposed to Scania regarding how the company should implement the proposed solutions into practice. Also, options for future research are proposed. This is done in Chapter 7 of the thesis.

1.3 Data Collection Methods

This section examines the data collection techniques required for the intended research steps. We will briefly explain why we use a literature study, interviews, direct observations, and simulation as data collection techniques.

Literature Study:
A review of academic papers on traffic safety is conducted as part of this study. Academic journals, research papers, and industry reports are all used to create a thorough literature study. Additionally, we are looking for historical data on Scania, such as factory traffic patterns and safety incidents in the Scania factory throughout the years.

Interviews:
Interviews with stakeholders and employees are conducted to obtain an in-depth understanding of specific research questions, such as how employees feel about the current traffic situation at the factory. Employees to be interviewed are chosen based on their qualifications and applicability to the research questions. The interviews primarily take place one-on-one.

Direct Observations:
On-site observations are conducted to collect information on traffic patterns and safety issues. Using observational checklists, pedestrian-vehicle interactions, traffic flows, and safety concerns can be recorded.

Discrete Event Simulation:
A discrete event simulation model is used to simulate various scenarios and evaluate the effects of suggested changes to the factory's traffic patterns, shift systems, and safety rules. During the simulation process, data on several essential factors of this study, including the number of traffic interactions and production efficiency, are gathered. Section 4.1 provides the reasoning behind utilizing a discrete event simulation.

2 Current Situation

The current state of the safety concerns at the Scania factory is described in this chapter. First, we would like a detailed grasp of the current traffic situation at the Scania factory. The types of traffic flows in the factory are explained in Section 2.1. Section 2.2 explains the routes of the traffic flows and their intensities. Next, we examine the traffic rules followed by those participating in factory traffic in Section 2.3. It is crucial to be aware of these rules because, in their absence, we propose solutions in Chapter 5 that will ultimately be impractical.

Furthermore, we would like to know which areas of the production facility are most problematic regarding traffic-related safety issues. In Section 2.4, we first interview employees. With these interviews, we mainly want to determine where the employees think the factory's most hazardous areas are. Next, we quantitively examine the process in Section 2.5 to determine which manufacturing areas are statistically the most unsafe. Then, we examine the results of Sections 2.2, 2.4, and 2.5 in Section 2.6 to see whether the results are related. Once this is done, we can determine which areas of the facility are the riskiest and where the primary attention will be during the rest of the research. We also examine the requirements in Section 2.7 in order for the project to be approved in the end. A chapter summary is then included in Section 2.8 to wrap up the chapter.

2.1 The Flows in the Factory

This section examines the many traffic flows within the Scania Zwolle factory. First, we examine where the traffic flows are coming from. Then, we examine the types of road users that are a part of the traffic flows. We try to comprehend the types of flows in the factory since this is crucial to comprehend the current state of affairs. However, first, we look at Scania Zwolle's production facility. Figure 1 shows a map of the facility. The facility is divided into several buildings. The function of these buildings is explained below.

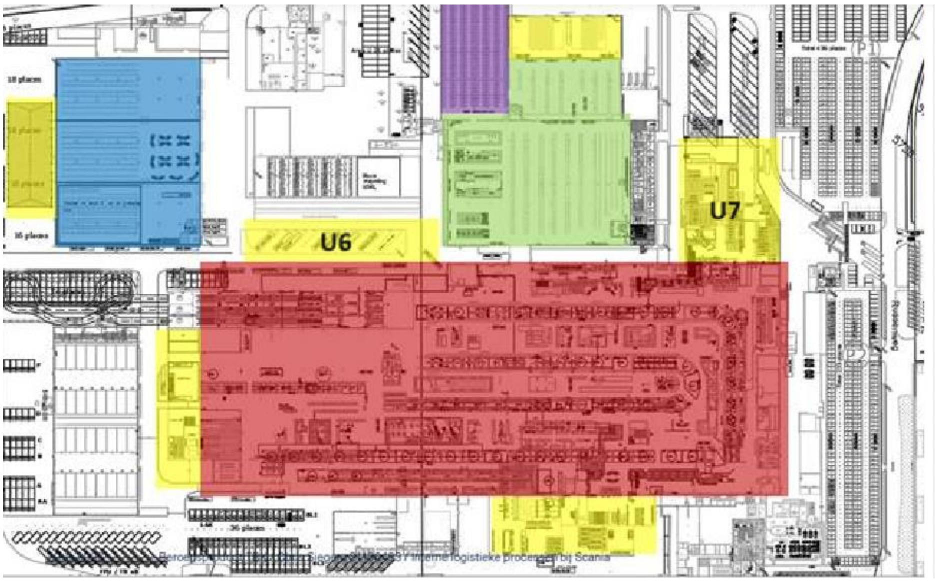

Figure 1: Overview of Scania Zwolle's facility

Red building: the factory

This is the plant's main building. The factory has two primary assembly lines, as shown in the picture. The "Castor" line, the outer line, is one type of assembly line. The trucks produced on this line have a more straightforward structure because they are more "standard" trucks. The “Pollux” line comes next. The more "specialized" trucks are produced in this smaller assembly line. It is possible that, for instance, these "specialized" trucks have a few extra features over a "standard" truck.

Because of the interference from both vehicles and pedestrians in this building, traffic in the red building is the least organized and most chaotic of all the buildings on the plant. Therefore, this building is also the one considered in this research. But in order to understand the factory's logistical processes completely, we also need to understand what is going on in the other buildings with regard to traffic.

Green building: inventory hall with high volume SKUs
One of the primary inventory halls of the facility is located in the green building, which is situated above the factory. The parts that are stored in this building are the parts that are frequently needed at the assembly line. Therefore, this inventory hall is near the factory. The components that are transported from this building can deviate from very tiny (a bolt or screw) to big (an engine of a truck, for example). This building's traffic has the most significant impact on the traffic inside the factory.

Blue building: inventory of pallets
The blue building is another large inventory hall. The pallets containing the materials are kept in this building. Several materials can be located on these pallets, from very tiny to enormous. The pallets from the blue building can be brought to the green building or the factory. Since the number of pallets that must be brought into the factory is smaller than the number of materials that must be brought in from the green building, the traffic flow from the blue building is smaller than that of the green building. However, given that the traffic flow of delivering pallets to the factory is still high, this is another crucial traffic flow to consider.

Purple building: inventory hall of low-volume SKUs
The purple building is the plant's final large inventory hall. All of the low-volume SKU inventory is kept in this building. The intensity of the flow from the purple building is smaller than that of the green building, but it is still essential for this research. As is the case with the green building, the components that are transported from this purple building can deviate from tiny (a bolt or screw) to big (an engine of a truck, for example).

Orange building: batch bins
The batch bins are stored in the orange building. However, since the building's flow does not directly enter the factory, this is not significant for this study.

Yellow buildings: awnings
The yellow buildings represent the awnings on the map. Different parts are stored and carried into the factory at these awnings. The intensity of the traffic flows from these awnings is quite low in general, but two traffic flows are quite important to consider in order to describe the current safety situation in the factory. These traffic flows have a high intensity and are described below.

- **Traffic flow from 'Awning U7'**. This traffic flow is delivering cabins to the Pollux and Castor lines. This flow is significant not just because of its high intensity but also because of its placement. It namely passes through several busy areas of the factory. Awning U7 is indicated in Figure 1 by 'U7'.
- **Traffic flow from 'Awning U6'.** This traffic flow is delivering grills to the Castor line. This traffic flow is significant for the same reasons as the previous flow: the traffic flow is high intensity and passes through several busy areas of the factory. Awning U6 is indicated in Figure 1 by 'U6'.

So, the blue building, the green building, the purple building, and the two awnings provide the main traffic flows. Moreover, pedestrians make up a significant portion of the traffic in the factory. For instance, employees working at the production line are pedestrians in the traffic system. This also counts for the employees that are working in the offices. Due to the factory's strategic location within the organization, many personnel must travel through the plant to get to their buildings. As a result, the factory's walking routes are crowded. Employees of Scania are required to cross the yellow paths indicated on the floor when moving through the factory. Consequently, this employee flow is denoted as the “Yellow Flow."

Now that we know all the essential types of traffic flows, it is critical to understand the ways of transportation that the different traffic flows apply to move goods from point A to point B. Although the methods of transportation used by each flow vary, the following are the ones that are generally applicable: 1 Reach Trucks, 2 Forklifts, 3 Trains, 4 Toyota Transporters, 5 Mafi Cars, and 6 Hanging Wires. Images of the different types of transporters and their usage are provided in Appendix B1. A small overview of the usage of the different transportation methods over the different flows is given below:

Green flow: Types 1, 3, 4
Blue flow: Types 1, 2, 5
Purple flow: Types 1, 3
Awnings: Types 1,2,6

Conclusion
This section clearly outlines five traffic flows that need to be considered for this research.
- The Yellow Flow: pedestrians moving through the factory.
- The Blue Flow: AGVs that move pallets from the blue building to the production line.
- The Green Flow: AGVs that deliver materials to the production line from the green building.
- The Purple Flow: AGVs that deliver parts to the production line from the purple building.
-Flows from Awning U7 and U6: These traffic flows deliver cabins and grills to the production line.
In the blue, green, purple, and awning flows, materials are transported using various vehicles, such as reach trucks, forklifts, and trains.

2.2 Routes and Intensity of the Flows

Section 2.1 showed that there are many different kinds of traffic flows in the factory. Furthermore, there are many locations in the factory that road users have to visit. As a result, Scania employees use a variety of routes to go to different locations within the facility. We provide an overview of the main routes in this section. But first, we talk about the intensity of the traffic flows. This is even more important to consider than the routes themselves. The intensity, namely, determines the busyness in the factory.

Intensities of Entrances
To examine the traffic intensity in the factory, we started by observing the entrance intensities of all movements. We made direct observations of the pedestrian and vehicle intensities at each entrance. We turfed the number of pedestrians entering and leaving the Northwest and Logistic entry for thirty minutes. We spent an hour doing this at the PortiersLoge, Main Entrance, South East Entrance, South West Entrance, and at each assembly line. Additionally, direct observations were used to determine the pedestrian intensities during the shift change. During shift changes on various days, we went to each entrance and counted the number of employees entering and leaving. The intensity at the Pollux and Castor entrances is established by figuring out how many employees should leave the factory during the shift change and dividing these employees over the Castor and Pollux lines.

The vehicle intensities are also calculated using direct observations, just as with the pedestrian distributions. We visited each entrance where vehicles entered the factory and counted the number of movements at those locations. We stood at the main entrances for an hour and counted the movements. We stood for thirty minutes at each of the other entrances.

Direct observations, for example, revealed that the Main Entrance and Portiersloge are the busiest pedestrian entrances, with one person entering every minute outside shift changes. Eleven pedestrians enter the factory at the main entrance, and twelve enter through the Portiersloge during shift changes. With an average of one vehicle entering the factory every 30 seconds, the Aorta entrance is the busiest for vehicle entrances. Chapter 5 implements both the vehicle and pedestrian intensities in the simulation model.

Main routes of the Pedestrians (Yellow Flow)
Now that we know the entrance intensities of the different types of road users, we can look at how these road users move throughout the factory. Most pedestrians are moving around the factory's outside edges. Employees only move away from the outside edges of the factory when necessary to perform their duties on the assembly lines. Additionally, it became clear from the interviews that the highest intensity of pedestrians is around the shift change at 2 pm. Then, there is a very high intensity of pedestrians on the walking paths, mainly close to the main pedestrian entrances of the factory. There are two main pedestrian entrances on the right side of the building and two main entrances on the south side of the building. These entrances are indicated in Figure 2, with pink arrows.

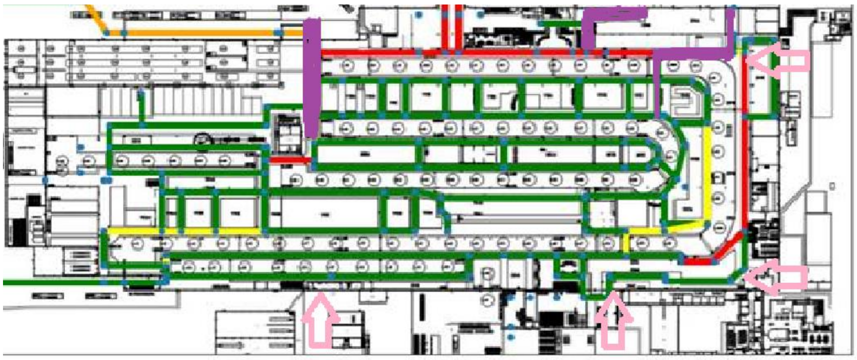

Figure 2: Traffic Intensity

Main routes in the Green, Blue, and Purple Flow
The traffic routes from the green, blue, and purple flows are now being examined. To explain the routes here, we primarily use Scania's historical data. Using this data, it was possible to determine which parts of the factory had the most frequently used routes for vehicles arriving from the warehouses. Figure 2 shows a heat map indicating the routes' directions.

The green, yellow, orange, and red lines indicate the following:

- Green lines: low route intensity of vehicles
- Yellow lines: low-average route intensity of vehicles
- Orange lines: average-high route intensity of vehicles
- Red lines: high route intensity of vehicles

Based on the lines, not many routes pass the green lines. Although more intense, the traffic near the yellow lines is still not concerning. As a result, when discussing traffic intensity, we should concentrate mainly on the areas where the lines are orange and red. First, a short red line is visible in the centre of the factory. The Pollux and Castor lines terminate here, and completed trucks pass over a busy traffic pathway. As a result, traffic is heavy in this area.

Additionally, a big red horizontal line can be seen at the top of the factory. This line is red because traffic flows from each inventory building and enters the factory from the upper side. The vehicles transporting the materials frequently follow the long, vertical red line on the right to go further into the factory, which explains why these specific factory zones have so much traffic.

Main routes of the Awnings (Blue and Orange Flow)
Figure 2 also indicates the routes of awnings U6 and U7 with purple lines. The purple line on the left indicates the singular route from awning U6. It brings grills to the same place at the assembly line every time. Awning U7 has two routes: one that brings the cabins to the Pollux line and one that brings the cabins to the Castor line.

Further analysis of the most crowded points in the factory
Figure 2 there can already be drawn a good image of the traffic intensity in the factory of Scania. Nevertheless, we still need quantitative data. To look at the traffic intensity in the factory, we thought the main KPI that indicates the traffic intensity at multiple points in the factory is the number of interactions between road users at multiple points throughout the factory. Since no data was available for the number of interactions at the crossings, we counted the number of interactions at the different crossings. We went to each crossing and looked for 30 minutes at how often a vehicle interacted with a pedestrian or another vehicle. Based on this analysis, it was determined that most of the traffic interactions take place at the "Aorta" crossing point. Table 5 in Section 5.1 indicates the precise number of interactions at each vital crossing in the factory.

Now that we have a general picture of all the traffic flows, their entry intensities, and the number of interactions at multiple points in the factory, we can identify the areas of the factory where traffic intensity is highest. Considering these variables, we identified four locations.
1. Crossing point: Green/Purple Building and main red pathway (The 'Aorta'). This is where vehicles from the green and purple buildings enter the factory.
2. Crossing point: Blue Building and main red pathway (CrossingBlueBuilding). This is where vehicles from the blue building and Awning U6 enter the factory.
3. Awning U7 and the central red pathway (The 'EagleOvergang'). At this point, the flow coming from Awning U7 crosses areas with strong pedestrian and vehicle traffic.
4 Entrance at the PortiersLoge. Two pedestrian entrances are located at places with high vehicle intensity (red line), including this one.

Figure 3 shows, from an eagle's perspective, where the factory's most busy locations are. The text within the figure can be forgotten.

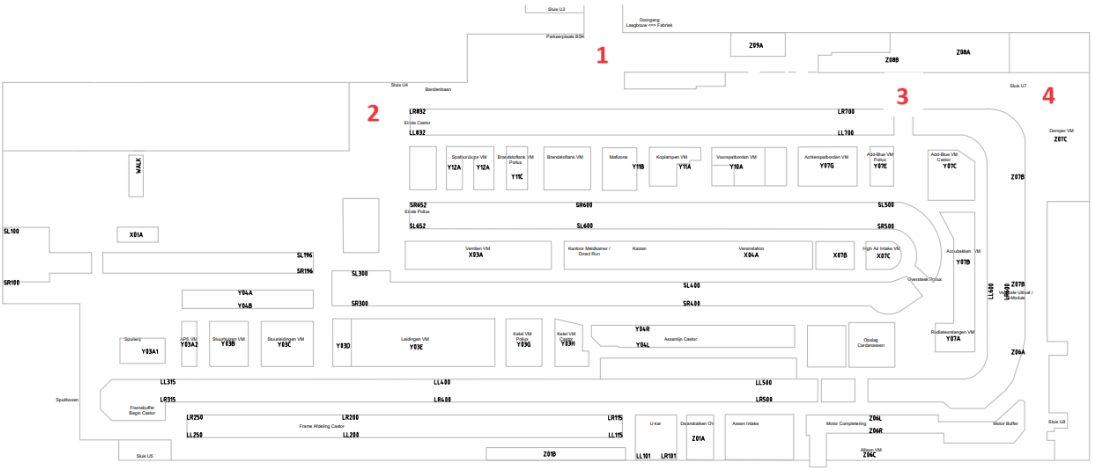

Figure 3: Most Crowded Points in the Factory

Conclusion
We can now determine which factory areas are the most crowded based on both route and traffic intensity data. Out of this chapter, four places have become the busiest in the factory.
1 The Aorta
2 The Crossing at the Blue Building/Awning U6
3 The EagleOvergang
4 The PortiersLoge

2.3 Traffic Rules in the Factory

Understanding the current traffic rules at the Scania factory is crucial to a good picture of the present traffic state. Employees must adhere to all traffic regulations in a busy factory, as unsafe situations could arise quickly otherwise. This section discusses the most significant traffic regulations currently in place in the Scania factory.

Scania complies with all safety regulations the Dutch government sets by following the "ARBO" recommendations. Employers must obey these rules to guarantee that their employees can work in a safe and healthy environment (Rijksoverheid, 2024). Furthermore, in addition to the ARBO regulations, Scania has implemented a number of safety regulations of its own to ensure the safest working environment for its personnel. This has resulted in an extensive list of regulations, of which the most significant are indicated below.

Rule 1: Safety vests + working shoes
All Scania employees are required to wear safety jackets inside the factory. These jackets ensure that Scania employees can be easily identified from other employees driving a vehicle or walking through the factory. Additionally, all Scania employees are required to wear safety shoes when working at the manufacturing line. Walking through the factory poses several safety dangers, including the possibility of a train running over employees' feet. The negative effects of a train running over feet are reduced when employees wear safety shoes.

Rule 2: Speed limits
Speed limits apply to all movements within the Scania production plant area. The speed limit for vehicles outside the factory is 15 km/h, and for movements within the factory, it is 8 km/h.

Rule 3: Safety Paths
Certain locations within the factory are suited for each type of movement that can occur. For instance, as seen in Appendix B2, pathways are indicated for pedestrians with yellow lines. Vehicles are forbidden from using these walking paths.

Rule 4: Priority in Traffic
Priority rules determine who gets to move first. The following rules apply at the Scania factory:
- Vehicles are always given priority over pedestrians.
- A pedestrian can only cross ahead of the vehicle when the driver signs to go ahead.
- Pedestrians are not permitted to cross at crossing locations marked with red, emphasized lines. A pedestrian can cross when the crossing places are not marked, but the pedestrian must still pay attention to ensure no vehicles are approaching.

Rule 5: Distance to a Vehicle
There should always be a "blue spot" towards a vehicle. This means there should be at least three meters between a vehicle and another vehicle or person.

Rule 6: Flighting routes

In an emergency, flight pathways need to be free. Consequently, parking is not allowed on these pathways.

Rule 7: Fences

At certain places throughout the factory, fences separate people and vehicles. People must always walk on the correct side of the barriers.

Conclusion

This section concludes that a primary traffic regulation in the factory is that vehicles always have priority over pedestrians. Another crucial regulation for the safety of the factory's traffic is the vehicles' top speed. These are also the primary restrictions we should consider while searching for a solution to the current problem.

2.4 Results of the Employee Interviews

Six Scania employees were interviewed to gain insight into the factory's most dangerous areas. This section includes the main conclusions drawn from the interviews.

About the Six Interviews

We interviewed the Head of Innovation Projects at Scania Zwolle, an employee of the Logistics Division, the Head of Facilities, an employee of the Logistics Safety Department, the Manager of Logistics, and the Manager of Engineering. They provided the following responses when asked which areas of the factory were the riskiest.

Shift of Employees at 2 pm

First, all the interviewees mentioned a time of day rather than a particularly hazardous location within the factory. The shift change that takes place at 2:00 pm. The employees from the second shift (2 p.m. to 10:30 p.m.) are taking over for the first shift's employees (6 a.m. to 2 p.m.). In the factory, every worker on the assembly line leaves the workplace by packing their personal belongings and leaving their stations. Compared to the rest of the day, this is by far the busiest time for the Yellow Flow (the flow of pedestrians), although the other processes are still in operation. This significantly raises the factory's overall traffic intensity, raising the possibility of safety hazards.

'The PortiersLoge'

The entry at the PortiersLoge is one place in the factory that every interviewee described as dangerous. In particular, the PortiersLoge is the entry that pedestrians use most frequently to enter the factory, together with the Main Entrance. In Figure 3, the PortiersLoge is indicated with number 4.

'The entrance at the main building'

Additionally, half of the interviewees noticed the factory pedestrian entrance from the main building. In Figure 2, this point is indicated by the lowest horizontal arrow. As indicated in Section 2.2, employees use this entry frequently to go into the factory.

'The entrances on the South Side'

50% of the interviewees indicated that the factory's southside employee entrances were dangerous. The locations of these entrances are indicated by pink arrows in Figure 2. Even though they are not used as often as the Portiersloge and the Main Entrance, many employees still use these entrances.

'The Aorta'

In three of the six interviews, 'The Aorta' is mentioned as a significant bottleneck in production. The Aorta is frequently a location where much traffic is coming together due to the large flow of vehicles that must pass from the green building into the factory. Furthermore, many pedestrians have to pass this point. Therefore, there are some safety concerns at this point in the factory. Figure 3 shows where the Aorta is located.

'Crossings at Awnings'

According to information from one-third of the interviewees, there is a risk to safety in the areas where the traffic flow from awnings U6 and U7 enters the plant. In Figure 2, the streams from these awnings are indicated. Because of the heavy pedestrian and vehicle traffic that the streams from awnings U6 and U7 flow through, there is a greater chance of accidents occurring at these crossings.

Conclusion

This chapter has demonstrated what the Scania employees consider the most dangerous locations within the plant. The factory has several points that were recognized. The points that the employees indicate as the most dangerous are the following:

- 'The Portiersloge'
- 'The Entrance at the Main Building'
- 'The Entrances on the South Side'
- 'The Aorta'
- 'Crossings at Awnings'

We now investigate whether the statistics in the next section align with the interviewees' assessments of the level of safety at different factory locations.

2.5 Statistical Busy Points in the Factory

This section examines the locations in the factory that data indicate as unsafe. To retrieve the relevant statistics regarding traffic safety in the factory, we discussed with Scania's Logistics Safety department what statistics it possessed regarding this issue. Over the years, the department collected important information about the state of traffic safety in the factory. The most relevant data on this topic is shown in this section. We start by looking at the number of accidents and then at which places these accidents have happened.

Accidents at Scania: The Numbers

Scania's safety logistics department kept track of the total number of incidents that occurred in 2023. Scania has a system that requires the factory supervisors to report incidents, including the time and location of incidents. This has led to the following numbers regarding the accidents that happened in the factory:

- There were more than 90 recorded accidents.
- Out of these accidents, 2/3 have documented locations. The locations of the other accidents in the factory were not adequately indicated.
- Out of the recorded incidents, 5/6 occurred at different locations.
- More than 150 vehicles were involved in the accidents. This indicates that some of the incidents involved multiple vehicles and were two-sided.

Places of Recorded Accidents in the Factory

In 2023, Scania recorded a number of accidents where, in the factory, the accidents were occurring. Figure 4 shows the outcome of this. Red dots indicate the factory locations where accidents happened.

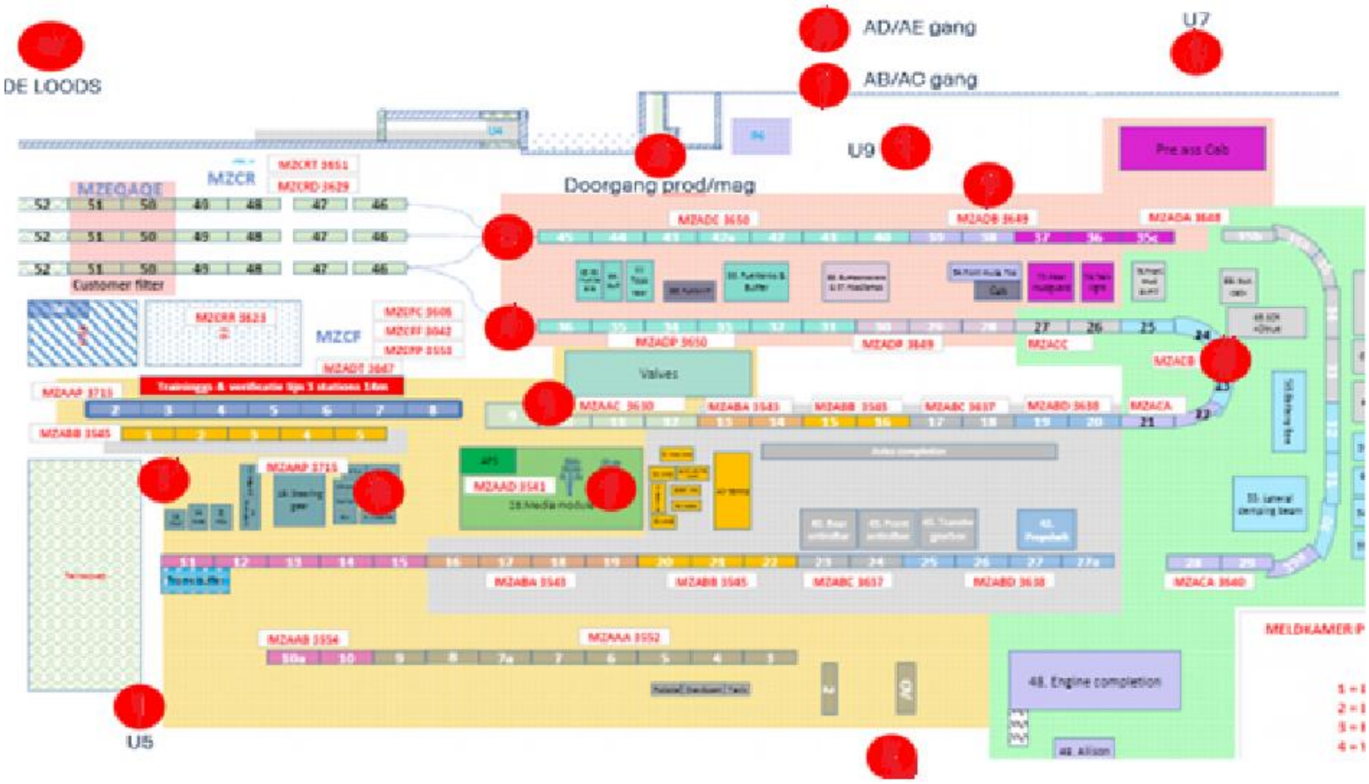

Figure 4: Locations of Accidents

Based on the location of the accidents in the factory, it becomes clear that there is a pattern that could be seen regarding where the accidents are happening in the factory. Most incidents occurred along the lines' edges, where the traffic is the busiest (see Figure 2). For example, locations where accidents occurred were where the awning flows enter, such as Awning U6 and Awning U7. In Figure 4, the place of Awning U7 is indicated with 'U7', and the place of Awning U6 is indicated with 'Doorgang prod/mag'. Furthermore, the 'Aorta' is another place where accidents happen. Figure 4 indicates this place with the 'AD/AE gang' and the 'AB/AC gang.'

Next to data from 2023, Scania also collected data regarding unsafe places in 2022. In Figure 5, locations are indicated where unsafe situations were reported. As can be seen, some places indicated in Figure 5 are the same as those indicated in Figure 3.

Figure 5: Safety Concerns Map

Using Figure 4 and Figure 5, we can also say which type of interactions (interactions on crossings or at straight lines) had the most significant influence on the number of accidents. These figures lead us to the conclusion that crossings were the location of most incidents. In the interviews with Scania employees, the crossing locations were also mentioned as the factory's most dangerous locations.

Conclusion

This section concludes that a significant number of accidents occur at the Scania factory each year based on statistics. Considering the areas of the factory where most accidents occur, the factory's edges are statistically the most risky. Many incidents occur around the building's entrances, particularly those with significant traffic volumes, such as those near the awnings and the Portiersloge. "The Aorta," which connects the Green Building to the factory, is another location where safety concerns exist. Finally, historically, more accidents happen at crossings than in straight lines.

2.6 Perception of the Employees VS Statistics

To see whether any locations inside the factory are mentioned in all three sections, 2.2, 2.4, and 2.5, we compare the outcomes of these three sections in this section. The locations mentioned in each section are the ones we wish to concentrate on the most in the remaining research. We interviewed several significant stakeholders about the safety concerns at Scania, as indicated in Section 2.4. We examined the traffic situation inside the factory statistically in Section 2.2 and Section 2.5. From the outcome of these sections, the following overview can be made:

Table 3: Locations of Safety Concerns

Name	Mentioned in Section 2.4	Mentioned in Section 2.2 and Section 2.5	Mentioned in both sections
1 ‘The Portiersloge’	X	X	YES
2 ‘The Entrance at the Main Building’	X		NO
3 ‘The Entrances on the South Side’	X		NO
4 Crossings at Awnings: ‘The EagleOvergang’	X	X	YES
5 Crossings at Awnings: ‘The Crossing at the Blue Building/Awning U6’	X	X	YES
6 ‘End of the Castor- and Pollux Line’		X	NO
7 ‘The Aorta’	X	X	YES

Both the statistical analysis and the interviews highlight the traffic circumstances at ‘The Aorta,' ‘The PortiersLoge,' 'The Crossing at the Blue Building and Awning U6', and ‘The EagleOvergang.' Therefore, during the rest of this research, we primarily concentrate on these traffic points.

Conclusion

This section observes four points that were mentioned in both the statistical research and the stakeholder interviews. These traffic points are located at 'the Aorta,' ‘the Portiersloge,' ‘the Eagleovergang,' and 'the Crossing at the Blue Building and Awning U6'. These are the critical points for the rest of the research concerning increasing traffic safety.

2.7 Standard Procedure for Project Management at Scania

For a project to be approved by Scania, the company follows a predetermined framework to outline the procedure. This procedure is explained in this section, and Appendix B3 illustrates it. Every project stakeholder should be included in phase 1 or 2, often known as the "Initiation" or "Pre-Study" phase. Scania ensures that the stakeholders are willing to work with the project's outcome in this way. To involve all the stakeholders, we talked about who to notify at this project stage with our supervisor. As a result, the list of stakeholders is as follows:

- The Head of the Health and Safety Department: Since this project influences traffic safety in the factory, its outcome falls within the working restrictions of this stakeholder.
- The Head of Logistics: The Head of Logistics is responsible for every movement from and towards the assembly line. He/she eventually decides whether changes in the logistic processes are approved.
- The Head of Line Feeding: This employee works within the restriction of the Head of Logistics, previously mentioned. The task of this employee is to regulate the transport to and from the assembly line.
- The Head of Engineering and the Head of Projects: These two stakeholders have allocated this project together. Therefore, it is crucial to consider these employees.

Conclusion

In this section, we determine how Scania typically manages its projects. The project process is divided into numerous parts, and the most significant stakeholders are included from the beginning. This ensures that the stakeholders are open to working with the solution. The information from this chapter is included in the remainder of this research to enable the solution to be worked out and approved.

2.8 Chapter Summary

This section serves as a summary of Chapter 2. This chapter includes an overview of the current traffic situation in the Scania factory. We started by examining the different traffic flows. We determined that there are five primary traffic flows. The primary traffic flows are the pedestrian, and the purple, blue, and green flow comes from the awnings. Based on Section 2.3, it can be concluded that the main traffic rule in the factory is that vehicles always have priority. The maximum speed limit for vehicles is another essential rule for the safety of factory traffic. When looking for a solution to the current problem, these are the most critical safety rules we should consider. We examined the factory's most risky locations in Section 2.2, Sections 2.4 and 2.5. After conducting interviews with significant stakeholders and examining relevant statistical data in these sections, it becomes clear that the factory's most hazardous locations are the traffic points located at "The EagleOvergang," "The Portiersloge," "The Aorta," and "The Crossing at the Blue Building and Awning U6". This means these points should be addressed during the rest of the research. The last takeaway from this chapter is that it is essential to involve the key stakeholders in this project from the beginning onwards for the solution to be approved.

3 Literature Study

This chapter aims to answer the following question: *Which solutions are suggested by literature to address the primary sources for traffic-related safety problems in manufacturing environments?* A few sub-questions must be addressed in order to provide an answer to this question. The primary causes of traffic-related safety issues in manufacturing environments are examined in Section 3.1. Next, Section 3.2 investigates which solutions the literature recommends to address these traffic-related safety issues. In Section 3.3, we provide a summary of the chapter.

3.1 Main Causes for Traffic Issues in Manufacturing Environments

There are many different kinds of traffic issues within factories. Even in cases where traffic safety has improved, accidents happen often. After consulting a wide range of sources, we discovered a pattern in the explanations provided by these sources for traffic issues in manufacturing environments. The key findings are provided in this section.

Too many movements at the same place/time

Traffic issues frequently happen in general, both inside and outside factories. The main reason for traffic safety issues is the large number of diverse road users and pedestrians using a limited space. Additionally, there is a higher risk of safety accidents when multiple traffic flows interfere, particularly in chaotic environments where interference occurs frequently (Tollazzi, Guerrieri, Jovanovic, & Rencelj, 2020) (Zakaria, Abdullah, & Norudin, 2012). An excellent example of such a chaotic environment can be a manufacturing facility. Because factories strive to use the space as efficiently as possible, space is frequently restricted. As a result, there are frequently several movements in a limited space. This raises the possibility of traffic accidents (Kircher, 2015).

When discussing the relationship between traffic intensity in a factory and traffic accidents, it is also critical to consider the time of day the accidents occur. According to data, most crashes happen during peak hours (Rizwan, Ejaz, Iqbal, Iqbal, & Khan, 2018). This is a crucial issue, particularly in manufacturing settings where traffic volume can fluctuate significantly (Ashok, 2006).

Poor quality of the road's layout

Traffic accidents do not get worse in every situation. We may suppose that traffic has become more chaotic and that there have been more accidents as a result of the fast-growing number of motor vehicles in and outside factories, which interact more with people, such as pedestrians. However, this is not true. The number of accidents has declined in the wealthier places of the world. This is a result of the much better road environments in these places (World Health Organization, 2015).

Road signs, for example, have a critical role in reducing the number of traffic accidents. When significant intersections and crossing points are appropriately marked, there is a decrease in traffic-related problems. The same applies to manufacturing settings, where an unsigned crossing point in a factory increases the risk of safety problems (Jamson, Tate, & Jamson, 2005). When approaching a busy crossing, it is critical that the signage at the crossing is accurate and that the crossing can be easily viewed. Additionally, when talking about the layout of a road, there must be enough room for both vehicles and people to move. It directly contributes to safety difficulties when a vehicle does not have enough room to pass over its driving lane or a pedestrian's walking path is too narrow (Millot, 2008) (Marshall & Garrick, 2011).

Lack of information about the traffic issues

Another reason why traffic problems exist is a need for more information. When one has sufficient knowledge about traffic, traffic accidents can frequently be prevented (Callcut, Agliozzo, Varga, & McMillan, 2021). For example, when there is enough information about a traffic situation, drivers can plan when they know the traffic conditions they will encounter in a few blocks. When a piece of slick road approaches, vehicles can easily slip over it, which might result in accidents. This can be avoided with the correct knowledge. This also holds for the flow of traffic within a manufacturing hall. A potential accident may be avoided if a particular traffic road user detects a vehicle approaching from his right or left (Makino, Tamada, Sakai, & Kamijo, 2018).

Additionally, having sufficient knowledge about a particular traffic point can prevent an accident long before it occurs, as opposed to knowledge functioning on the spot as it did in the previous example. When data indicates that a crossing location is the site of several near-accident events, the crossing point may have to be adjusted. However, without knowing that near-accidents often happen at that point, it is more unlikely that anybody would realize that hazardous circumstances are occurring there (Rodgers & Endsley, 2016).

Human Behaviour

Human factors are cited as the leading cause of most accidents (Treat, Tumbas, McDonald, Shinar, & Hume, 1979) (Harantova, Kubikova, & Rumanovsky, 2019). According to Hung and Huyen (2011), there is, for example, a higher likelihood of accidents when a driver rides aggressively. People frequently drive or walk aggressively/distracted and pay too little attention to the road. Just like in actual traffic, this might happen in a manufacturing environment. After a busy morning on the assembly line, workers may be less focused while navigating through a packed workplace. At such a point, there is a greater risk to one's safety (Guerin, 1994) (Petridou & Moustaki, 2000). Safety in a factory increases significantly as soon as the employees can use the vehicles in the factory in a controlled manner.

The way that an employee views risk also has a significant impact on traffic safety. Traffic safety quickly rises if he is well aware of the risks involved in driving (Lobanova & Evtiukov, 2020). Therefore, it is no surprise that the education of those involved in traffic is another factor that is brought up and is very important in determining the number of accidents in traffic. According to a study, children who receive enough instruction about traffic laws will experience a significant reduction in the number of accidents they cause during their lifetime (Hong, 2021). This state of affairs is similar to that found in factories. Employees will be far less likely to have safety incidents in the workplace if they receive proper training on the traffic laws that apply to their facility.

The last significant human factor contributing to traffic issues is the speed at which certain vehicles travel. Exceeding speed limits raises the risk of safety problems in the workplace (Khan & Haq, 2016). When drivers accelerate beyond safety, they lose awareness and control over the road and their vehicle. A road accident is more likely as a result (Ditcharoen, Chhour, & Ammarapala, 2018) (McCarthy, 2001). Vehicles traveling at an inappropriate pace are considered a primary cause of traffic accidents. Both the driver and the victim cannot react in time in the event of a potentially harmful circumstance when drivers drive too quickly (Aljanahi, Rhodes, & Metcalfe, 1999).

Conclusion

This section makes it clear that excessive movements at particular traffic places significantly contribute to issues with traffic safety in manufacturing environments. As a result, the likelihood of road accidents rises. The same holds for poorly designed roadways. Furthermore, the leading causes of traffic safety concerns are human behaviour and a lack of knowledge about traffic issues.

3.2 Possible Solutions to Solve Traffic Issues

In this section, we look at possible solutions to the traffic issues mentioned in Section 3.1. These solutions are tested further in this research to try to solve the traffic issues that are present at Scania Zwolle at the moment. We first discuss solutions to reduce the number of movements per area. Then, we will look at how to change the road layout efficiently, and finally, we will look at how to introduce new SOPs to increase traffic safety in the factory.

Reduce the number of movements per area

A significant cause of factory traffic problems is the high number of movements co-occurring in the same place. According to Archer and Kircher (2015), the primary strategy for reducing traffic issues is to lower traffic density because it reduces the interaction between road users. However, in a factory, this is more easily said than done. Because it can be challenging to change the traffic flow in factories. Since production areas often follow quite a tight schedule in terms of production, the traffic flows have to be very punctual as well. Otherwise, there will be delays in the production process (when materials are, for example, arriving too late to the production line). Therefore, when making changes in the traffic flows, it is essential to consider that the production process is not disturbed.

The first strategy we consider to go against a factory's busyness is changing the shift system. One potential way is to experiment with varying employee shift changes from one to several times. So, employees could not change shifts only at one time but multiple times in a time range of a couple of hours. This reduces the traffic intensity in a factory during peak hours since employees are not moving all at once but rather in a flow throughout various periods (Kabak, Ulengin, Aktas, Onsel, & Topcu, 2008).

Establishing new traffic routes across the organization can adjust the amount of traffic in specific plant areas. Changing the traffic pathways can make certain busy points in the factory less crowded. This could decrease the number of unsafe situations in the factory. However, how can we alter these paths while maintaining the same degree of organizational productivity? The route must be changed in such a way that we prevent an excessive rise in the routes' distance (Alkhatib, Maria, AlZu'bi, & Maria, 2022). Routing models are often used to change the routing of the traffic flows in manufacturing environments. Methods such as the Shortest Path Method are a way to solve this problem.

The Shortest Path Method tries to find the shortest route between two vertices (Magzhan & Mat Jani, 2013). When talking about traffic safety, this should be done so that the combined traffic intensity at all the points visited is minimized. The Shortest Path Method can be used for all kinds of routing problems, including routing problems in manufacturing environments. It is the first routing method that we may use to change routes in a manufacturing environment.

We also investigated additional routing algorithms to modify traffic flow pathways and timing effectively. It is evident from the study by Merschformann, Xie, and Erdmann (2018) that there are several interesting multi-agent path-finding algorithms. The WHCA (Windowed Hierarchical Clustering Analysis) algorithm is the first one we will examine. Volatile and Non-Volatile WHCA algorithms are the two different kinds of WHCA algorithms. Volatile WHCA uses three factors to rank the agents: the robot's priority, whether or not the robot is carrying a pod, and the distance to the final destination.

This algorithm has an issue while examining a traffic system in production environments because each robot's current path may need to be updated many times. This has the potential to cause chaos to manufacturing environments' traffic systems. Manufacturing environments are frequently busy with road users. As a result, drivers must pay close attention to the traffic surrounding them. If frequent changes occur, road users may need to focus more on monitoring their route changes. As a result, the factory's traffic receives less attention, which increases the risk of accidents. Consequently, the Non-Volatile WHCA algorithm provides a safer solution for traffic issues in manufacturing environments. Like the Volatile algorithm, the Non-Volatile WHCA algorithm ranks the agents based on for example the robot's priority and distance to the end destination. However, the non-volatile WHCA does not change anything to a robot's path once it has been determined. One benefit is that the driver can fully concentrate on the traffic around him because they know which route it will follow. However, if we utilize the Non-Volatile WHCA, one drawback is that the current pathways cannot be modified to accommodate the pathways of new road users entering the traffic system.

The BCP (Biased Cost Pathfinding) algorithm is another algorithm we consider. The BCP algorithm uses a reservation table to record continuous periods for each robot and does a binary search to look for collisions. BCP looks for paths without collisions until the runtime limit is achieved or all paths are discovered to be collision-free. A robot must wait for a predetermined time if no collision-free way can be found. Therefore, a robot may wait for quite a long time. Excessive waiting times for road users may disadvantage manufacturing facilities with tide production schedules. Consequently, drivers may be unable to wait to avoid a collision with another driver on the road every time since this would take too much time. However, when we wish to adjust the timing of routes, the BCP algorithm's underlying principle, which cleverly uses road user waiting times to reduce the number of interactions in traffic, is an interesting one to consider.

CBS (Conflict Based Search) is the final algorithm from the Mershformann, Xie, and Erdmann paper. CBS operates in this manner. First, each robot has a path found when CBS first starts. Collisions are not considered in this. Subsequently, if collisions arise, the algorithm will examine each robot individually to determine the most effective way to improve the robots' routes and minimize the overall number of collisions. The algorithm considers the time intervals a driver must travel from point A to point B. It is essential to consider these time constraints when working in a production environment with tight time restrictions. However, this algorithm may not be effective when road users have tight enough time constraints because there is minimal opportunity to enhance the paths.

Using a Bounded Multi-Agent Algorithm (BMAA), a real-world routing system, is an additional method of routing numerous agents. Here is how this approach works. The routing heuristic chooses a route for a road user when it starts to drive. However, the vehicle's route may alter while driving when another route leads to fewer traffic interactions. This decision is based on real-time data. The fact that the heuristic only functions with individual values and does not share heuristic values with other vehicles in the traffic system is a disadvantage of this method (Sigurdson, Bulitko, & Yeoh, 2018). This may result in an enhancement that is advantageous for a single road user rather than for the traffic system as a whole.

The study by He, Guan, and Ma (2013) on Traffic-Condition Route Guiding Strategies (TCRGS) for road networks (TCRGS) is the last algorithm we look at. To prevent accidents, the authors of this research suggest dividing a single traffic flow into several traffic flows. One way to accomplish this would be to use a splitting rate. The splitting rate will determine the amount of traffic that passes each specific route. For instance, the splitting rate may be determined by total costs, travel distance, or waiting time. When talking about traffic intensity, one possible way is to base the splitting rate on the number of interactions. The splitting rate should then be selected to minimize the total number of interactions (He, Guan, & Ma, 2013).

We need to figure out which of the algorithms above is best suited to lowering traffic intensity in manufacturing environments. BMAA places too much emphasis on a single road user's performance, not the system's overall performance. Volatile WHCA causes many route changes, forcing drivers to pay more attention to route modifications and less attention to the traffic around them. The route of a road user is permanently fixed using Non-Volatile WHCA; once the path is established, it cannot be changed. This also leads to less-than-ideal pathways.

Road users' routes are changed using CBS to lower the number of collisions. However, this could not be useful for enhancing road users' routes when tide time schedules are in place. When using BCP, a road user must wait a predetermined period before finding a path free of collisions. This would not be viable in a setting with tide periods as well, but waiting a little until there is more space to travel may be an intelligent way to distribute the traffic intensity more evenly over time. Therefore, in Chapter 5, we shall investigate further the use of waiting times to change the timing of routes.

It might be a good idea to use TCRGS to shift the direction of routes. Here, we attempt to distribute the traffic intensity more evenly by splitting rates. This will not result in optimal routes, like with volatile WHCA. However, the routes does not change often when using TCRGS, which is advantageous for traffic in manufacturing environments. Furthermore, supposed to BMAA, we concentrate on the overall performance of the traffic system with TCRGS rather than just one road user.

Change road layout and design.

Changing a factory's road layout is another recommended tactic to reduce traffic issues (Zein & Navin, 2003). Rearranging a factory's layout may increase the space available for road users of the traffic situation, like trains and pedestrians. The first strategy is physically splitting traffic flows by changing the factory's layout. We want to accomplish this by letting the pedestrians walk over bridges in the factory. In this way, the flow of vehicles and pedestrians is separated. Nevertheless, there should be a close watch on the cost of building the bridges, as the costs can be significant (AlSabah, Bauer, Elahi, & Goldberg, 2013).

Using traffic barriers could be beneficial because they ensure that a pedestrian cannot continue walking. However, it takes time for barriers to rise and fall. Therefore, even after the dangerous situation has passed, road users may still slow down by a few seconds. On the other hand, using barriers would be a good idea if they significantly increase factory safety (Fard, Samuels, Burgess, & Komostioglou, 2013). Additionally, safety signs might be applied in the factory's busiest areas (Bassan, 2016). Safety signs are frequently already in place in manufacturing facilities, although the number of signs various companies use varies. While some businesses use lights to warn of potentially dangerous circumstances, others also use stopping signs to clarify that further walking is forbidden. What must be considered is that we do not place too much traffic barriers/signs in the factory, as this lowers the importance of other safety signs (Pulugurtha & Nambisan, 2014).

Introduce SOPs

Providing Safety Operating Procedures (SOPs), such as instructions on how employees should safely move around the factory, can increase traffic safety (Dien, 1998). When implementing SOPs, it is crucial to look into which SOPs improve traffic safety in factory settings the most. For example, modifying the speed restriction is a way to address potential safety issues. Road users have more time to anticipate a potentially risky traffic situation when they reduce their speed (Lee, Hellinga, & Saccomanno, 2006). Additionally, the following SOPs were found to have the most significant beneficial impact on traffic safety in manufacturing environments after research, next to decreasing the speed limit:

- Make it mandatory for all road users at crossing points in the factory to pause for a minimum of three seconds. This ensures that each vehicle in the traffic has enough time to

see whether other vehicles are approaching the factory crossing point. As demonstrated in Section 3.1, another significant contributing factor to road accidents is not giving enough thought to the traffic situation (Batishcheva & Ganichev, 2018).
- Give every crossing point in the factory a mandatory speed limit lower than the usual speed limit. This ensures that the pace at the crossing locations is sufficiently slow to respond to any unexpected events that may happen there (Bella & Silvestri, 2015).

3.3 Chapter Summary

This section summarizes the leading causes of traffic-related problems in manufacturing settings as reported in the literature and provides a summary of the solutions suggested by the literature for these issues. The high traffic volume at particular locations is an underlying cause of traffic-related problems in manufacturing facilities. The chance of safety problems increases as the number of road users in a given location increases. One of the primary causes of traffic issues both within and outside factories is poor road design. Furthermore, human behaviour, such as exceeding the speed limit, significantly contributes to traffic issues in manufacturing facilities. Drivers who drive too fast are more likely to have accidents, as they do not have enough time to react to a potentially dangerous scenario.

After the primary causes of traffic accidents were identified, we looked for potential solutions to these issues. Table 4 illustrates the connection between the leading causes and their potential solutions:

Table 4: Summary Chapter 3

Reason Traffic Accident	**Way to solve the problem**	**How?**
High intensity of road users	Switch traffic flows	1 Change shift system, 2 Dynamic Routing
Poor design of roads	Change road design	3 Bridges 4 Traffic barriers 5 Road signings
Human behaviour	Introduce new SOPs to make employees more responsible	6 New speed rules 7 Stop at crossing points 8 Reduce speed at crossing points

In Chapter 5, we describe in more detail how we intend to solve the main traffic problems in Scania. For example, we discuss where bridges are placed, where exactly traffic barriers are placed in the factory, and which new speed limits we wish to implement. However, before discussing these possible solutions further, we create a model that allows us to replicate the traffic situation mentioned in Chapter 2.

4 Model Description

The main research question for phase 3 is: *How should the conceptual model be made considering the traffic situation in a manufacturing environment we want to replicate?* In this chapter, we try to answer this question. We first define the kind of model we will construct before discussing the assumptions, inputs, and logic used in the generic model. Finally, we elaborate on which KPIs should be in the model's output.

4.1 The Type of Model

We currently know the solutions that the literature suggests to improve traffic safety in manufacturing environments. As a result, we must figure out how to test these solutions. We first look at the possibilities available for replicating a traffic system. Then, we choose the best method to use.

Making a dynamic programming model (DP model) to simulate a traffic system is the first approach we consider. A DP model is often used to find solutions to optimization problems (Murray, Cox, Lendaris, & Saeks, 2002). In this instance, the main objective of the DP model would be to reduce the amount of traffic interactions inside the traffic system. The factory's production efficiency can be considered using the DP model's constraints. For instance, we can ensure that the eventual solution lives up to the requirement that the total distance traveled by all road users does not exceed a specific value. One of the main disadvantages of a DP model is that when you have to deal with a significant amount of input variables, the DP model can get too complex (Denardo, 1982).

Another approach to test solutions is to put them into practice in real life and see their effects on the current situation by doing an observational study (Rosenbaum, 2005). A primary disadvantage of observational studies is that it can be challenging to keep track of the results of the implemented changes in a reliable way. It can, for example, be difficult to oversee the consequences of the solutions if the effects they have on the KPIs are minor or if the system we look at is complex.

Finally, one method frequently proposed by the literature to simulate a traffic system in a manufacturing environment is the creation of a discrete event simulation. Discrete event simulation is a modeling technique that depicts a system subject to change over time due to events within the system. Discrete event simulations can be applied in various contexts, such as simulating logistics or industrial processes (Goti, 2010).

We use a discrete event simulation, primarily due to the factory's extensive traffic system. For this reason, creating a discrete event simulation is ideal. The size of the Scania factory's traffic system makes it impossible to recreate it as a DP model because doing so would make the model extremely complex. Additionally, because it will be impossible to oversee the entire factory to determine the effects of the solutions on the KPIs, we will not use an observational study.

Our academic contribution is the development of a discrete event simulation that will eventually be used to study the factory's traffic safety. Current discrete event simulations of industrial traffic systems primarily concentrate on total costs and production efficiency. However, our simulation will ultimately provide a clear picture of the factory's existing level of traffic safety and how it will change if we put our intended solutions into practice.

To build a discrete event simulation, we need to understand the model's underlying assumptions, inputs, logic, and outputs to construct a discrete event simulation. In Section 4.2, we first examine the model assumptions.

4.2 Model Assumptions

The goal of the model should be to replicate the real-world traffic situation of a manufacturing environment as closely as possible. However, in certain circumstances, it might not be possible to replicate the traffic situation precisely due to time or complexity constraints. To construct the most accurate model in a finite timeframe, we make assumptions explained in this section. We apply the following assumptions.

- The model starts at t=0. Additionally, if the factory is open 12 hours daily, the model simulates a 12-hour workday.
- The factory's road structure is the same as in the real world. Therefore, it is important to make the path lengths and directions of roads the same as in the real world.
- The number of depots, roadways, crossings, destinations, and road users in the model is limited.
- The road users have an arrival distribution as they enter the factory. If precise arrival times are unknown, a distribution that allows for the computation of global arrival times should be implemented.
- We measure a limited set of KPIs. The number of interactions at straight lines, the number of interactions at crossings, the total travel distance of road users, and the total waiting time of road users should be among the KPIs we measure. In Section 4.4, we describe why we should measure these KPIs.
- The following events can be simulated by the model: a road user entering the system, a road user leaving the system, an interaction at a crossing, and an interaction at a straight line.
- Before entering the system, each road user knows where it wants to go. Every road user always goes to a predetermined end destination.
- The road user can reach every possible end destination by going over the roads in the model.
- Road users travel through the factory at the speed stated in the road users' characteristics.
- The model should be able to apply stopping rules for road users.

<u>Conclusion</u>

This section mentions the assumptions regarding our conceptual model. We can now look at the inputs required to build the model.

4.3 Inputs of the Model

In this section, we describe which parameters our model uses as input. In order to acquire the desired results for the KPIs of the model, we should be able to simulate every event using the input parameters we implement in the model. As a result, the following input parameters are used:

<u>Depots h's</u>

Depots are the road users ' starting points within the system. Each depot is an entry for one or more types of road users. The depots have the following characteristics:

- Each depot can produce multiple types of road users.
- The depot is located at the same place where it also is in a real-life situation.
- The depot can generate road users l according to arrival rates λ.

<u>Roads i's</u>

This is the set of roads required to connect each depot and destination within the factory. Roads should have the following characteristics:

- Road users use the set of roads i to get from their starting depot h to their end destination k. Therefore, the set of roads connects every depot with every final destination.

- Each road can have an entrance/exit strategy implemented to implement logic into the model. For instance, this is required to determine how many interactions are happening at the crossing points (see Section 4.4).
- The model can change the color of roads to provide a clear image of the factory's road layout.

Crossing Points j's

The set of crossing points can connect the roads. Crossing points j should have the following characteristics:

- In the model, every road i that connects to a crossing point j in a real-life situation also connects to the same crossing point.
- If necessary, each road user l can go over crossing point j.
- Each crossing point j can indicate if it is empty (whether or not a road user l is on the crossing point).
- The locations of the crossing points correspond to the actual locations in real life.

Destinations k's

These are every potential destination in the system that road users can visit. The destinations should have the following characteristics:

- Each destination can receive multiple types of road users
- Each destination is located in a location comparable to its location in real life.
- Each destination can have an entrance strategy. This is necessary to calculate the total distance traveled by road users (see Section 4.4).

Road users l's

This set of road users can represent every user of the system. Each road user has the following characteristics:

- Every road user type l may move at a different speed.
- Every road user can have a unique destination.
- In the model, each road user type may be represented by a different image, which gives a clear overview of the traffic situation.
- By implementing logic for each road user, it is possible to determine how much time the road user spends waiting in the system. Moreover, to count the number of interactions at straight lines, each road user l should be able to measure the distance to another road user to determine the distance between vehicles. This is required to calculate the total waiting time and number of interactions at straight lines (see Section 4.4).

Running Times t's

The model has a running time t. The model's situation may change at each moment. Running time t should have the following characteristics in order to make the model run as the actual situation:

- Running time t is the duration from t=0 to the model's specified end time. This end time can be any length, depending on how long we want to measure the system's performance.

Arrival Times λ's

The arrival times λ of road users l are also required as input into the model. The model must know each road user's arrival time before it runs. The characteristics of arrival times λ regarding road user arrivals should include the following:

- Arrival times λ may differ depending on the road user and depot.

Conclusion

The inputs of the model are, for example, all the depots, destinations, roads, and road users that are applicable to the system. Now that we know the inputs of the model, we can look at the logic behind the model.

4.4 Logic Behind the Model

With the inputs mentioned in the previous section, we have all we need to run the model. The logic underlying the model is all that is additionally required. We elaborate on this logic in this section. We first look at the logic behind the entire model and then at the logic behind each event. In Figure 6, the model's logic flowchart depicts the logic behind the entire model.

Logic Flowchart

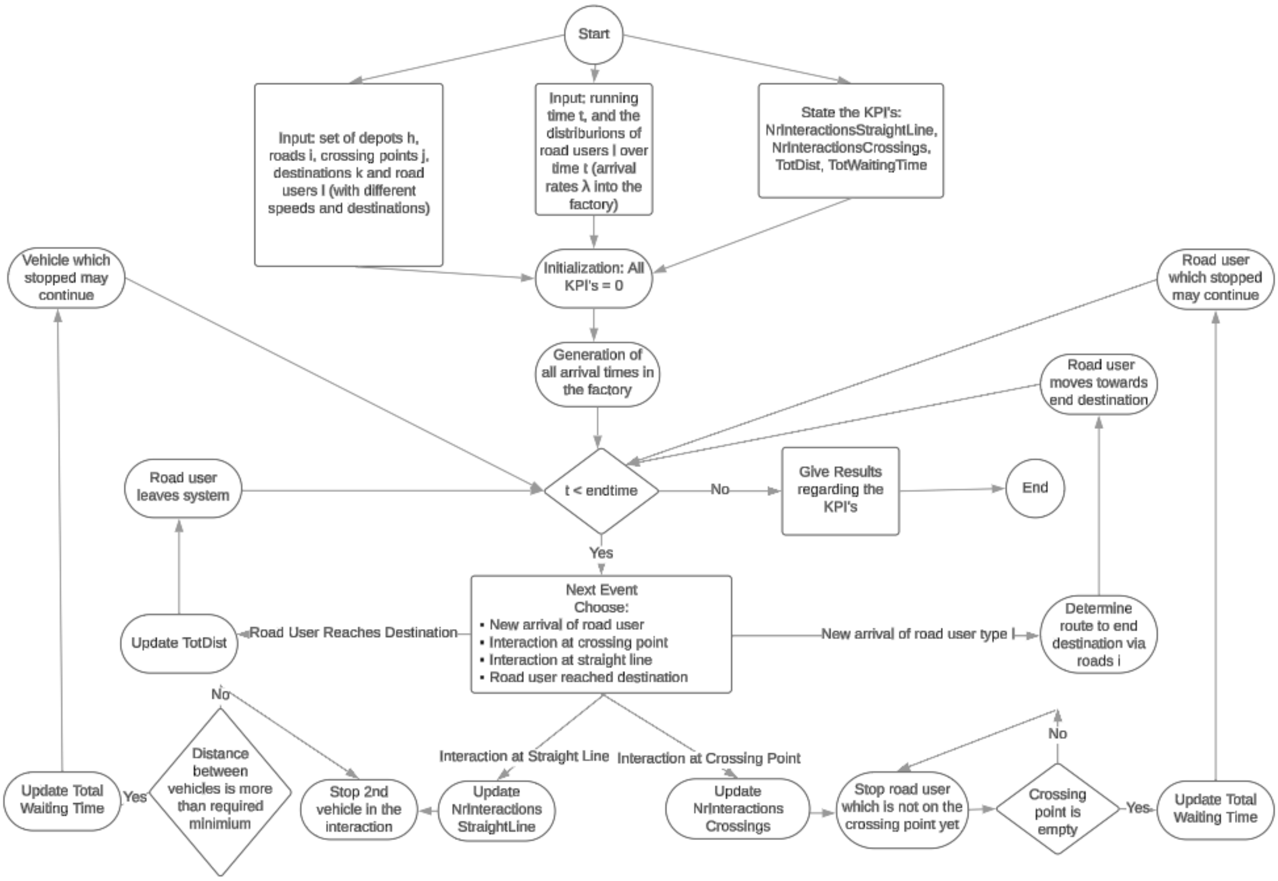

Figure 6: Model Flowchart

All of the model's input parameters are added to the model before any events have happened. These inputs are all described in Section 4.2. The KPIs that the model computes are also implemented at the initialization. We explain the calculation process for the results of these KPIs later in this Section. For further explanation regarding the logic of our model, we now go over the most significant events that are taking place in the model.

Event 1: Initialisation of the Model

We initialize the model once all of the input parameters are added. At this stage, all the KPI values and the running time are set to t=0. In addition, we know when each road user is expected to arrive in the system at this point.

Event 2: Arrival of New Road User + Routing Logic

The end destination k is determined when a road user enters the system. As a result, the road user knows which way to go when it enters. The road user begins traveling in the direction of its destination, as can be seen in Figure 7. The road user waits until it has a free range of 10 meters to travel in if it does not already have it. The road user then takes the route that takes him from depot h to end destination k with the shortest distance.

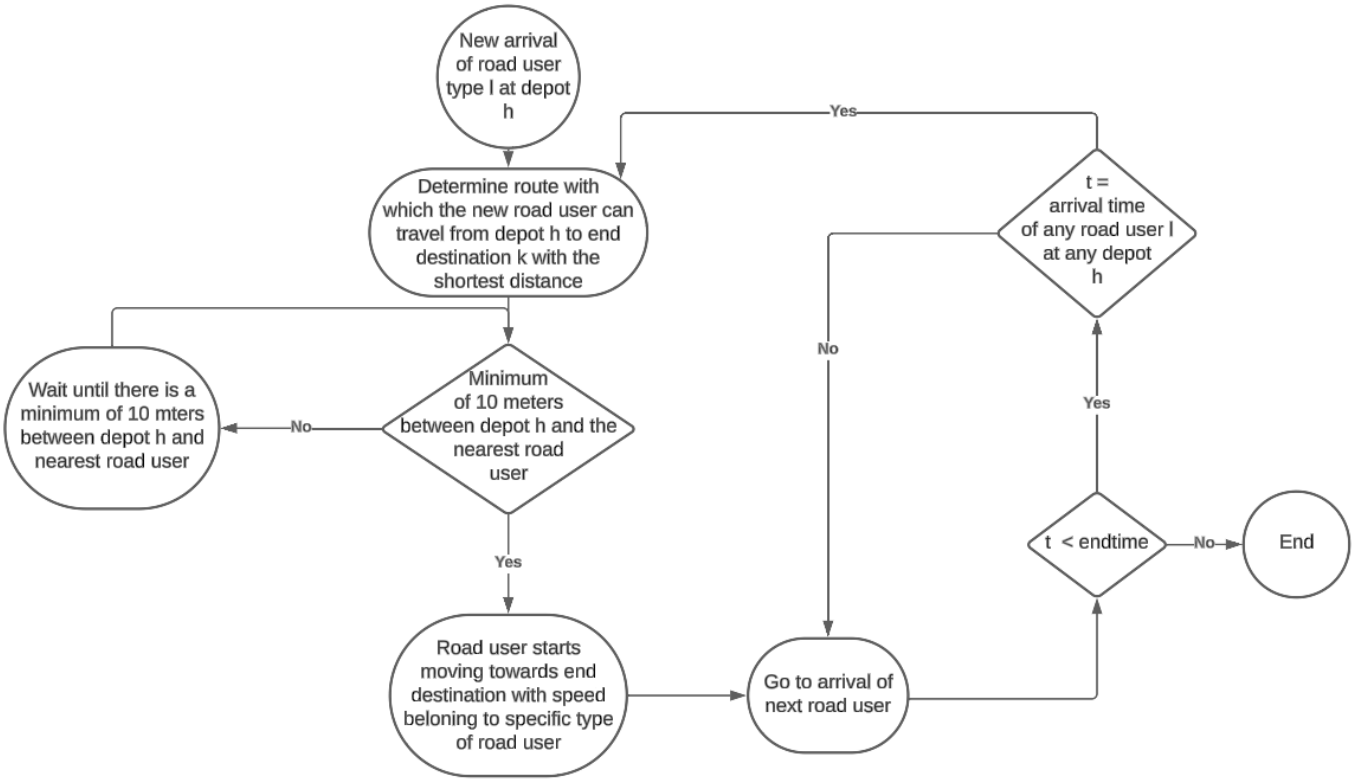

Figure 7: Arrival of New Road User

Event 3: Interaction at Crossing Point

The road user may meet other road users while traveling. If road user A wants to go over a crossing point while road user B is already on it, road user A must wait for road user B to leave the crossing point. The crossing point is then considered as 'not empty.' The number of interactions at crossings is updated at that point. The TotalWaitingTime (TWT) has also been updated: it adds the time road user A must wait to enter the crossing point.

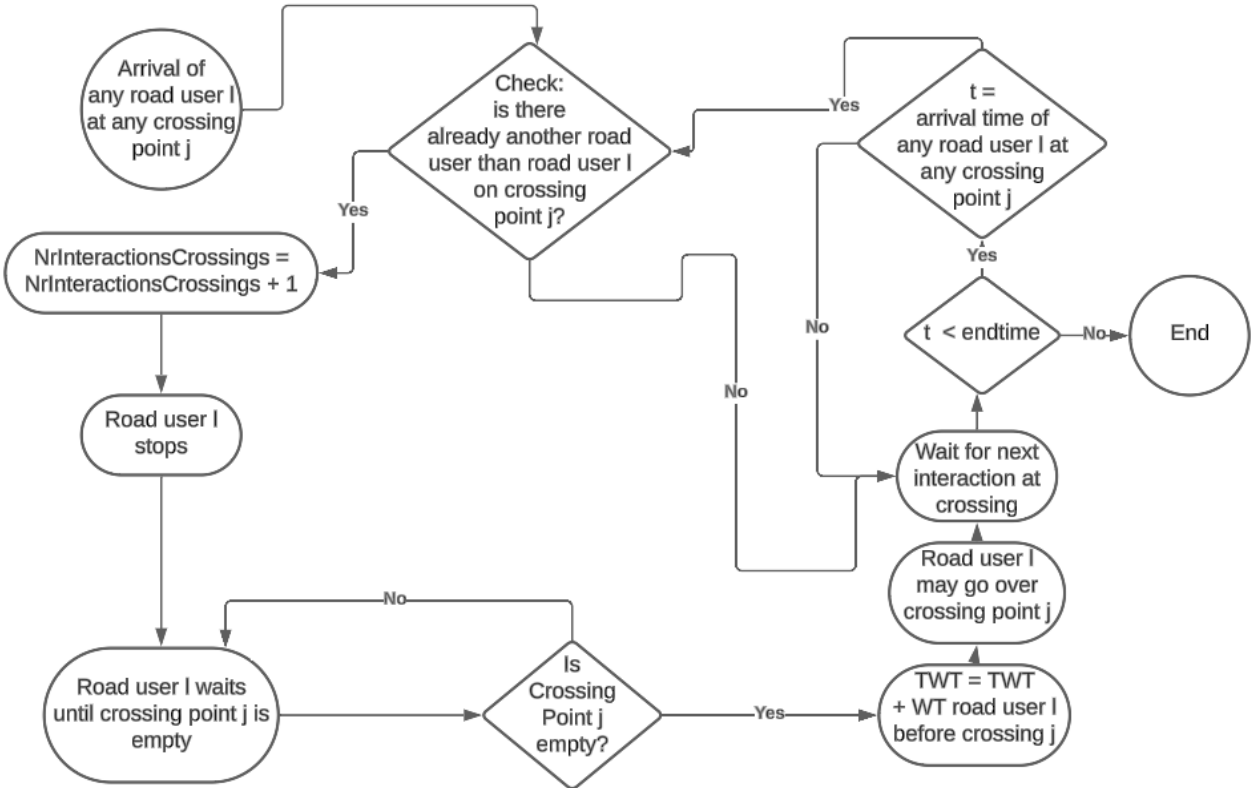

Figure 8: Interaction at Crossing Point

Event 4: Interaction at Straight Line

Furthermore, it is possible for a road user to meet with other road users at the straight lines. Once a road user approaches another road user from behind on a straight line, the number of interactions at the straight lines is updated. During this interaction, two people are driving in the same direction, and road user A is driving in front. When this is the case, road user B should stop until road user A and B are sufficiently far from each other. The total waiting time is increased by the time road user B must wait. Once there is sufficient space between the two road users, road user B can continue its journey to its destination.

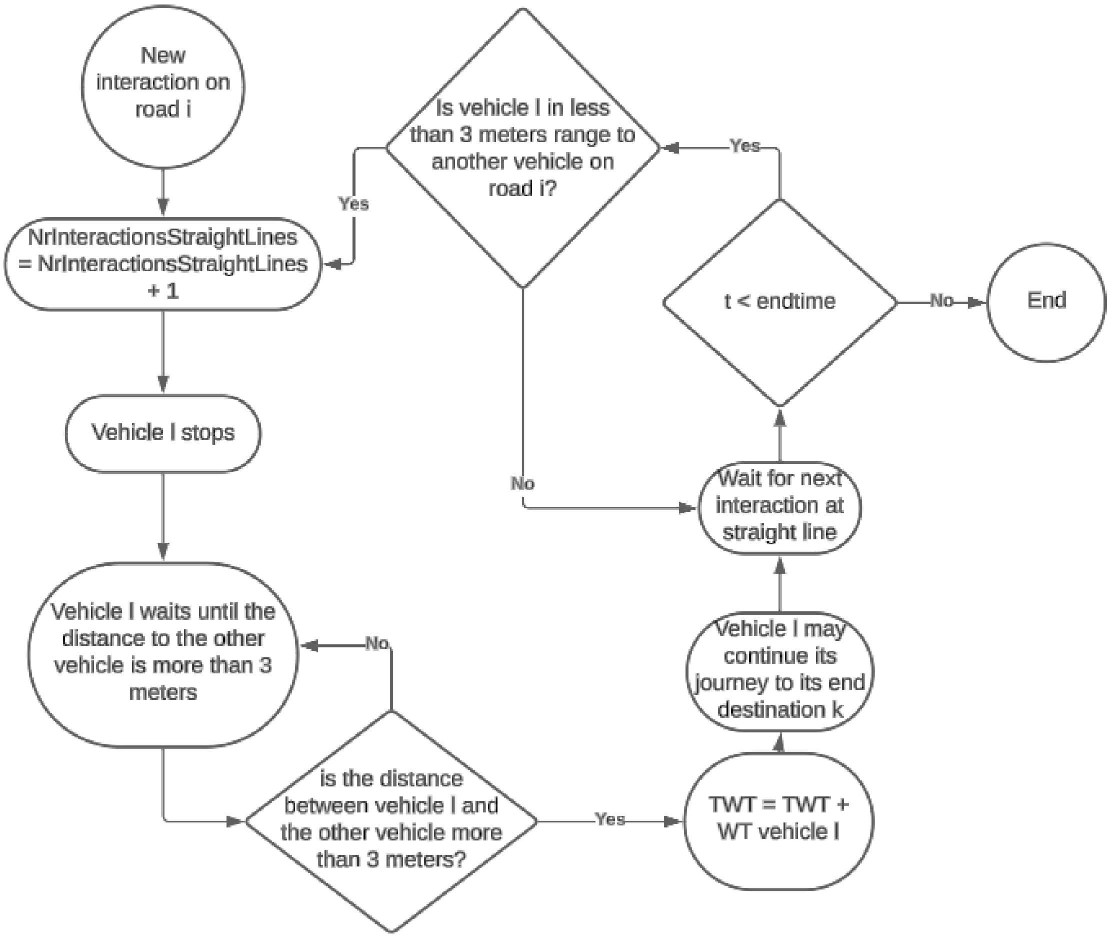

Figure 9: Interaction at Straight Line

Event 5: Road User Reached Destination

The road user exits the system if it has arrived at its final destination. The road user's total travel distance from depot h to destination k is added to the total travel distance before the road user exits the system.

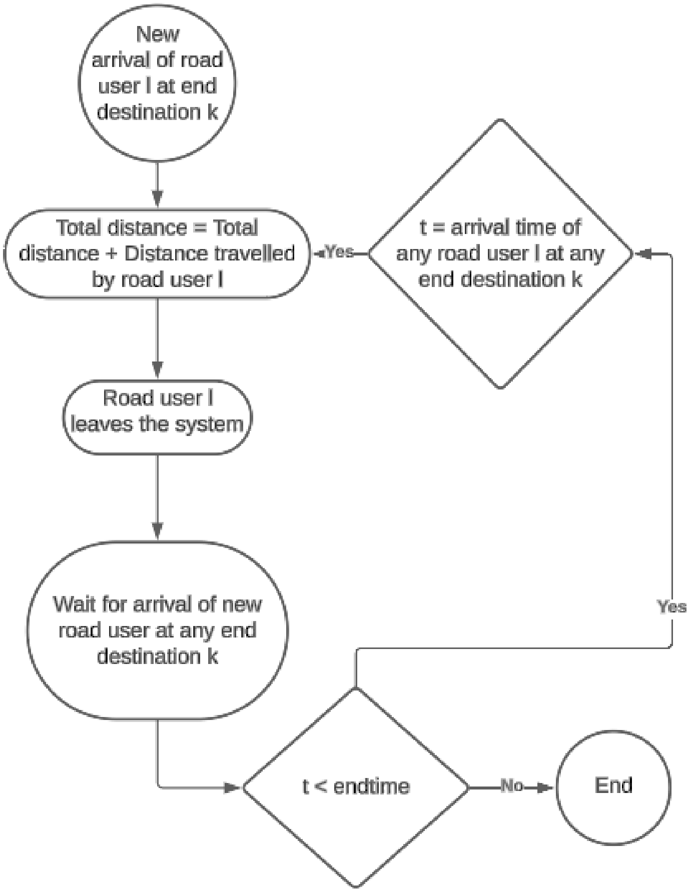

Figure 10: Road User Reached End Destination

Event 6: Running time has ended

When the model's running time reaches its limit, the model gives the final values for the KPIs, and the model stops running.

Conclusion

This part explains the logic behind our conceptual model. We also demonstrated the connections between each input and event. Figure 6 shows an overview of these connections. Now that we understand the logic behind the model, we can discuss its outputs in more detail. This is what we do in the following section.

4.5 Outputs: The KPIs

In this section, we discuss the reasoning behind the model's outputs. Since the model's main goal is to determine the right values for the KPIs, it is crucial that this section provides an answer to this question.

Understanding which KPIs to consider when looking at the final solution is crucial for solving a problem. Safety is our project's main KPI since we aim to improve the safety of the manufacturing environment. There are several ways to measure safety risk. We choose to focus on the number of interactions between the road users of the traffic situation. The number of accidents is closely related to the number of interactions between road users in traffic. The greater the number of interactions, the bigger the chance of accidents (Mohamed A. & Radwan, 2000). We distinguish two essential types of interactions based on the place in the manufacturing environment where the interaction is happening:

- Interactions at crossings (NrInteractionsCrossings): An interaction at a crossing occurs when one road user must stop for another road user who is at the crossing point.
- Interactions at straight lines (NrInteractionsStraightLine): When two road users are below a minimum range towards one another on a straight line (so not on a crossing), an interaction at a straight line occurs.

So, the number of interactions is used to measure traffic safety. However, we want to look at additional KPIs that significantly impact the production efficiency of the manufacturing environment. Therefore, we also look at the following KPIs:

- TotalDistanceTravelled (TotDist): This is the total combined distance each road user has traveled. A company may decide not to apply the solution when the Number of Interactions decreases by factor 0.95 while the Total Distance increases by factor 2. A greater Total Distance can namely imply that the efficiency of the factory decreases. Therefore, it is essential to measure this KPI.
- TotalWaitingTime (TotWaitingTime): The total waiting time is determined by adding the waiting time for each road user during the model's run. Calculating TotWaitingTime is crucial since it has a big impact on the manufacturing environment's productivity.

Conclusion

This section indicated the KPIs for our conceptual model and the reasoning behind our selection of them. At this point, all of the conceptual model's components are discussed. The chapter is summarised in the following section.

4.6 Chapter Summary

Chapter 4 is summarised in this section. First, it was found that the most effective way to simulate the traffic system inside the Scania facility and test potential solutions to our problem is to create a discrete event simulation. After that, the model assumptions we use were mentioned. Next, the model's inputs were given. We then provided the logic behind our model. After that, we discussed the KPIs given in the model outputs. Our top priority should be the "safety" KPI. Analyzing the number of interactions leads to determining this safety factor.

After providing the conceptual model in this chapter, we can now look at the implementation of the solutions in Chapter 3. We do this in Chapter 5. In Chapter 6, we examine how well the solutions from Chapter 5 work in our situation.

5 Solution Design

This chapter indicates our strategy for implementing the solutions found in Chapter 3. We start by discussing ways to lessen the intensity of road users. We then discuss solutions that aim to enhance the road's design. Lastly, we outline solutions that aim to improve traffic users' behavior.

5.1 Reducing Intensity of Road Users

This section describes how the solutions we implement to reduce the intensity of road users are implemented in our model. To reduce the intensity, we want to change the shift system and we want to use dynamic routing.

Shift System Change

The first possible solution is to change the shift system. Currently, Scania employees work two shifts, switching shifts at 2:00 p.m. This time of day is the busiest for traffic density, according to the interviews done in Section 2.4. Additionally, there are often conflicts between vehicles and pedestrians because of the high pedestrian intensity at pedestrian entrances. Thus, changing this shift system is one solution method that needs to be considered. According to information provided by Scania, the shift changes must occur between 1 and 3 p.m. Furthermore, it would be tough to have the process still function well from a planning perspective if there were more than four shift changes. As a result, we would like to attempt implementing the following substitutes for the current shift system:

- Two shift changes: at 1 p.m. and 3 p.m. (Scenario 1)
- Three shift changes: at 1 p.m., 2 p.m. and 3 p.m. (Scenario 2)
- four shift changes: at 1 p.m., 1:30 p.m., 2 p.m. and 2:30 p.m. (Scenario 3)

We changed the intensity of the pedestrian flows to implement the solution technique into the model. When one shift occurs, the initial intensity is 100%; when two shifts occur, it is 50%; and when four shifts occur, it is 25%. Therefore, we can reduce the pedestrian intensity when there are several shift changes rather than raising it to a maximum when the shift shifts at two o'clock in the afternoon. However, how can the intensity in the simulation model be indicated for each timeframe? We make a difference between the level of pedestrian activity during shift changes and the "normal" scenario. While the intensity of the scenario during shift changes is significantly higher than that of the normal situation, the intensity of the normal situation remains constant. To create the pedestrian intensity during shift changes, we developed a different source that produces the pedestrians entering the process at the shift change. From this source, we may modify the pedestrian intensity and the time window for pedestrians to enter the factory. Appendix C1 displays the frame in which we can modify this data. This frame contains data related to the current situation's shift change. Twelve workers arrive at the Portiersloge every minute between 7:45:00 and 8:00:00. We can view the shift change data when we switch to two shift changes rather than one in the table included in Appendix C1. For instance, six workers check in at the PortiersLoge every minute between 7:30:00 and 8:00:00 in the case of two shift changes.

Dynamic Routing

TCGRS

We aim to split up some existing traffic flows to lessen the traffic volume at the factory's busiest crossings. We realize this by using splitting rates, which depend on the number of interactions that occur at crossings in the current situation. Table 5 provides this number of interactions.

As Table 5 illustrates, four crossings stand out in terms of the number of interactions. These are the crossings at the Aorta, the PortiersLoge, the EagleOvergang, and the Blue Building. Consequently, we wish to divide the traffic flows so that there is less traffic at these points.

Table 5: Number of Interactions at Crossings

Crossing	**Number of Interactions/Hour**
CrossingPortiersLoge	12
CrossingAorta	22
CrossingEagleOvergang	14
CrossingBlueBuilding	20
CrossingPollux	2
CrossingCastor	4
CrossingSouthEast	6
CrossingSouthEntry	2
CrossingEndPollux	2
CrossingHalfway	4

It is impossible for most vehicles to choose alternate routes when they cross the busiest crossings. This is because getting to their destination requires the vehicles to pass the busiest crossings. Since all of the traffic streams that pass this crossing are vehicle streams, we do not separate streams at the CrossingBlueBuilding. Consequently, we consider the pedestrian streams at the CrossingEagleOvergang, the CrossingPortiersLoge, and the CrossingAorta for the purpose of dividing traffic streams.

We now give an example of how we divide the traffic streams. As an example, we consider the pedestrian stream that passes the crossing at the Aorta. First, we point out the pedestrian streams that pass by the intersection. Next, we identify three paths per old stream under "New Streams." We then use splitting rates based on the numbers from Table 5. Per route, the crossing on that route with the most interactions determines the route's traffic intensity. To calculate the splitting rates, we take the following steps.

Step 1: Determine the Intensity Weight of Each Route
In this step, we calculate each route's weight. The base weight, which has a value of 1, is the weight of the original route. We calculate the weights of the alternative routes based on the number of interactions at the crossings. Then, the weights are calculated as follows.

Table 6: Calculation of Weights

Route	Busiest Crossing	Calculation of Weight	Weight
1	The CrossingAorta	Base Weight	1
2	The CrossingHalfway	NrIntBusiestCrosR1 (22) / NrIntBusiestCrosR2 (4)	5,5
3	The CrossingEndPollux	NrIntBusiestCrosR1 (22) / NrIntBusiestCrosR3 (2)	11

Step 2: Determine the Combined Intensity Weight of the three Routes
Combined Weight = Weight1 + Weight2 + Weight3
Combined Weight = 1 + 5,5 + 11 = **17,5**

Step 3: Determine the Splitting Rates
Splitting Rate Route i = (100%/Combined Weight) * Weight Route i
Splitting Rate Route 1 = (100/17,5) * 1 = **5,7%**
Splitting Rate Route 2 = (100/17,5) * 5,5 = **31,4%**
Splitting Rate Route 3 = (100/17,5) * 11 = **62,9%**

Thus, by using the splitting rates, we divided the original NWEntry-PLExit stream into the following new streams:

Table 7: Example Splitting Rates

Old Stream	New Streams	Splitting Rate
NWEntry-Aorta- PLExit	1 NWEntry-Aorta-PLExit	5,7%
	2 NWEntry-CrossingHalfway-PLExit	31,4%
	3 NWEntry-CrossingEndPollux-PLExit	62,9%

We took these steps for all the traffic streams that pass the three busiest points mentioned. The results are in Appendix C2.

Now that we are aware of the routes and splitting rates, we can implement splitting the routes into our model. The routes are set at the depots. Appendix C2 shows an example of how this is done. The original code to determine the pedestrian path from Main Entrance to LogisticExit is shown in Figure 7, and the splitting rates' implementation is shown in Figure 8.

Waiting Times

In addition to splitting rates to the current routes that go past the busiest locations, we would like to add waiting periods before road users access the traffic system. This will more effectively separate the traffic intensity over time.

The following is how we implement waiting times at the depot. A road user must wait until he/she is more than 10 meters away from other road users before proceeding into the factory. Subsequently, there is always enough room for road users to join the system, reducing the amount of traffic interactions on each user's particular path. We include this into the model by having each depot run the code provided in Figure 9 of Appendix C2.

Eventual Solution Implementation

By splitting the streams and adding waiting times for road users at depots, we will have two dynamic routing solutions we want to implement in the model. These are the following solutions:

- Wait at Depot (Waiting Times) + Split streams at Aorta (TCGRS)
- Wait at Depot (Waiting Times) + Split streams at EagleOvergang/PortiersLoge (TCGRS)

Conclusion

This section outlines the implementation strategy for the dynamic routing solutions. We split the routes that pass the busiest intersections to change the routes for road users. These streams were divided according to splitting rates. At depots, we require road users to wait until ten meters surrounding the depot are clear from other road users. Finally, we changed the two-shift shift system to two, three, and four shifts.

5.2 Improving the Road Design

This section explains how bridges and traffic barriers are implemented in the model. Chapter 3 clearly outlines the solution approaches we want to implement to improve the factory's road design.

Bridges

As mentioned in Section 3.2, splitting the several traffic flows up with bridges is one way to improve the traffic situation at the Scania factory. We can remove the pedestrian flow from the factory to add the bridges to the simulation because people will be walking above the rest of the production process. After this flow of traffic is removed, we may evaluate whether the factory's traffic situation has become safer.

We would like to test several scenarios where we use bridges.

- Construct bridges throughout the factory. This will remove the factory's entire pedestrian flow.
- Construct bridges around the three busiest pedestrian/vehicle points mentioned in Chapter 2: the Aorta, the EagleOvergang, and the PortiersLoge.
- Only bridges should be constructed around the busiest pedestrian/vehicle point in the factory, which is the Aorta (see Chapter 5.1).

Since it is expensive, we should only install bridges throughout the factory if necessary. As a result, we consider building bridges at specific locations in the factory as well. We look at the busiest locations because they will have the biggest positive impact on traffic safety in the factory. We use connections at bridge locations rather than constructing the yellow paths, as can be seen in Appendix C3.

Traffic Barriers

Installing traffic barriers for pedestrians is an additional solution to our problem. When installing traffic barriers, there should be barriers placed for pedestrians on both sides of the intersection. The following is how we would like to try to put traffic barriers in place:

- Install traffic barriers at all the factory's crossing locations.
- Only place traffic barriers at the factory's three busiest pedestrian/vehicle points (the PortiersLoge, the EagleOvergang, and the Aorta).
- Install traffic barriers only at the busiest pedestrian/vehicle crossing point (the Aorta).

Thus, we aim to test whether installing traffic barriers at one crossing point or several crossing points significantly impacts traffic. If this is not a significant factor, we choose fewer traffic barriers because more barriers increase expenses and cause road users to move more slowly.

We can prevent interactions between pedestrians and vehicles in the areas where traffic barriers are built by prohibiting pedestrians from going over the crossing point when the barriers are down. Traffic barriers can be added to the model by altering the code at the end of the track prior to the crossing. An example of a code at a pedestrian track can be seen in Appendix C4. It can be seen that the pedestrian must wait an additional five seconds before going over the crossing point. This is the time that the traffic barrier is rising. The interaction between pedestrians and vehicles at the crossing is avoided in this way.

Conclusion

In this section, we describe how the bridges and traffic barriers are implemented into the model. We want to apply both solution methods to the entire factory, the three busiest pedestrian/vehicle crossings, and the Aorta.

5.3 Changing Human Behaviour

This section explains the solutions to changing Scania employees' behavior. As we can see from Chapter 3, we try to realize this change in behavior by lowering the speed limits at crossings and implementing new speed limits in general.

New Speed Limits

We want to investigate changing the current speed restrictions as a potential solution. Vehicles are still frequently driving 8 km/h inside the factory. We wish to change the speed limits of the traffic road users in the following manner to see if this speed limit is contributing to the traffic problems:

- speed limit of 7,5 km/h
- speed limit of 7 km/h
- speed limit of 6,5 km/h

Reducing the speed affects the likelihood of an accident. This is because, during the contact, road users have more time to prepare for the circumstances. As a result, the chance factor is lowered while the speed restriction is brought down (Aarts & van Schagen, 2006). Therefore, we should remember that lowering the speed limit can somewhat improve traffic safety even when it does not affect the number of interactions. However, given the limitations on productivity, the speed limit should not be lowered too much.

In the simulation model, changing the speed limit can be accomplished by changing the features of the road users involved in the traffic situation. In the transporters’ attributes method, one can adapt the speed at which the transporter is going. In Figure 11 of Appendix C5, the speed is changed to 7 km/h for example.

Reduce Speed Limits at Crossing Points

Our final solution is to lower the speed limits at crossings. This approach functions more or less in the same manner as the previously mentioned solution. By reducing the speed limits at crossing places, we give road users more time to get a clear overview of the traffic situation at the crossings. We want to reduce the speed limit from 8 km/h to 4 km/h around the crossing point. We wish to investigate the impact of changing the speed limits at almost the same crossing points that are mentioned at 'Traffic Barriers' (see Section 5.2). We change the speed restrictions at all the crossing points, the four busiest intersections, and the Aorta.

To implement our idea, we alter the exit strategies of some tracks surrounding the crossing places. To lower the speed of the road user, we first modify the exit strategy of the second-last track before the crossing site to slow down the road user. After the road user crosses the crossing point, the first track's exit strategy is modified to realize acceleration.

The following code has been incorporated into the exit strategy of the second-last track before the crossing point: "@.speed: 1.1". After the crossing, the exit strategy of the first track contains "@.speed: 2.2" to return the vehicle to its initial speed.

Conclusion

In this section, we looked at the model implementation for the different speed restrictions and maximum speed at crossings. We wish to lower the speed limit to 7.5, 7, and 6.5 km/h and change the speed limit to 4 km/h at all of the factory's crossings, at the four busiest locations, and at the Aorta.

Note: About the Road Signings and Stopping at Crossings

Adding new road signs is another action that we can take, as suggested by the literature in Section 3.2. Nevertheless, we are not evaluating road signs as a possibility. This is because the factory already has many road signs in place. Additionally, several interviewees in Section 2.4's interviews claimed that adding extra road signs would not help the factory's traffic problem. Furthermore, it is recommended to stop at crossing sites in Section 3.2. However, there will be chaos in the factory if every road user needs to stop for three seconds at a crossing point. When a vehicle must stop at every intersection, other vehicles behind him are also forced to stop, leading to traffic jams.

Furthermore, how do the employees consider the three seconds exactly? Do they have to count them? Thus, we decided not to investigate this alternative further due to the chaos it would cause.

5.4 Chapter Summary

In this chapter, we researched how to adapt and quantify the solutions that emerged from the research in Chapter 3. We looked at multiple solutions to the cause of traffic unsafety. The main conclusions of this chapter are given in this Section.

We want to investigate changing the shift system to go against the high intensity of road users in traffic. We wish to examine the consequences of switching the shift change from one time at 2 pm to several times between 1 pm and 3 pm. In addition, we wish to split the pedestrian streams that go past the busiest locations in the factory. In order to improve the road design, we first examine the impact of including bridges in the model. Additionally, we want to add traffic barriers to the model. This is done in order to divide the various traffic flows physically. Finally, to change traffic road users' behavior, we also want to investigate what happens to traffic safety if we modify the traffic laws in the factory. We lower the speed limit first. Additionally, we want to slow down road users at crossing points.

6 Testing the Solutions

First, we describe the experimental setup of our tests, including the warmup period and the number of replications. Then, we present the findings from our research. We initially examine each solution individually. Afterward, we combine the best individual solutions into hybrid solutions to determine whether implementing them improves the results.

6.1 Settings and Experimental Setup

This section explains the experimental settings used in this thesis. First, we explain how we calculate the KPIs. Then, we determine the number of replications and the warmup period. Finally, we explain the sensitivity analysis we intend to conduct.

Calculating the KPIs

We want to determine which solution has improved the factory's traffic situation the most. We must calculate our four KPIs to decide this:

- Number of Interactions at Straight Lines: The "InteractionCounterStraightLines" in the model represents the number of times movements happen less than three meters from a vehicle. Each vehicle's "Distance Control" has a code to track this number.
- Number of Interactions at Crossings: This is the number of times that vehicles and pedestrians must stop for one another at crossing points. The number of interactions at each crossing point is the first thing we count. The code to calculate this is implemented in the exit methods of the tracks leading to the crossings. After adding all of these interactions, the total number of interactions at crossings, "InteractionCounterCrossings," is determined.
- Total Distance: The total distance is the distance each road user travelled from their starting point to their final destination. Each drain has an entry code that adds the total distance travelled by each road user to the total distance travelled. This is how the Total Distance is determined.

TotalWaitingTime: The total waiting time is the total amount of time that each road user must wait to either wait for another road user to drive in front of them (when the distance between them is less than three meters) or to wait before a crossing point when another road user is on the crossing point. Furthermore, the total waiting time is increased by the waiting time at depots (see to Section 5.1, Dynamic Routing). The code of the tracks prior to the crossings (waiting time crossings), of the exit strategies of the depots (waiting time depots), or of the road users themselves (waiting time straight lines) determines these waiting times relatively.

Number of Replications + Warmup Length

We must know the result of the main KPI for multiple timeframes to calculate the model's warmup period and number of replications. As indicated in Chapter 2, the Number of Interactions at Crossings is the most crucial KPI because it significantly impacts factory traffic safety. Therefore, based on this KPI, we tested the number of replications and warmup period.

Number of Replications

Because almost all of the parameters in the model are deterministic, the number of interactions at crossings was almost the same for each replication. Still, there was some variation in the number of interactions at crossings per replication. After 100 replications, we saw that the average number of interactions at crossings remained relatively constant, with the highest number 1118 and the lowest 1034. The data's relative error is low since the highest and lowest numbers lie close. As a result, we choose to make at least one replication.

Warm up Length

We looked at the number of interactions on crossings per hour in order to calculate the warmup period. We did this for six days. We use a warmup length if there would be a significant difference in the number of interactions depending on the time of day. It can be the case that fewer road users are interacting at crossings early in the day when the movements begin to run. Therefore, we looked at this. After six days of simulation running, the following graph was produced:

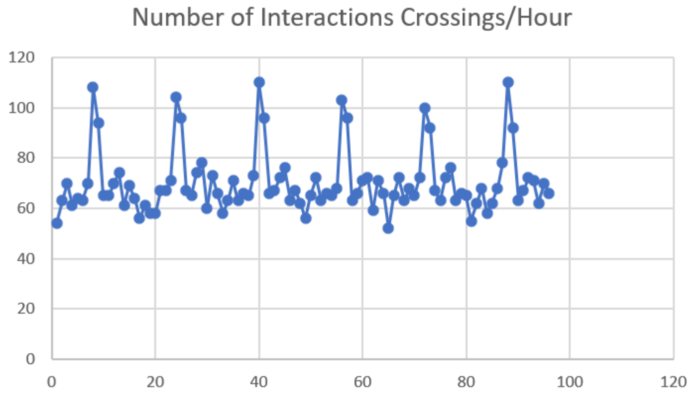

Figure 1: Determining the Warmup Length

The graph shows that the model does not have an actual warmup period. Therefore, the warmup length in our case is 0. The graph also shows that we are working with steady-state cycles that are terminating. The hourly values are clearly cyclical, and since the cycles' performances are independent, we are dealing with a terminating system.

Sensitivity Analysis

To increase the reliability of our findings, we performed a sensitivity analysis. We aim to investigate the impact of varying entry intensities on our KPIs through this sensitivity analysis. When we talk about entrance intensities, we are talking about the intensities at which road users enter the traffic system (see Chapter 2). For instance, we measured that a road user enters the factory at the PortiersLoge on average once every minute. Therefore, one road user per minute is the entry intensity at the PortiersLoge. Each vehicle entrance and pedestrian entrance has an individual entry intensity. We got the intensities from doing observations in the factory. This has led to the intensities given in the 'base' scenario. The pedestrian entry intensities are, for example, shown in the table below:

Pedestrian Distribution

Table 8: Pedestrian Entry Intensities

Entrance	Base Scenario
Northwest Entrance	One pedestrian/ 2:30 min
Logistic Entrance	One pedestrian/ 2:00 min
PortiersLoge	One pedestrian/ 1 min
Main Entrance	1 pedestrian/1:00 min

South East Entrance	1 pedestrian/5 min
South West Entrance	One pedestrian/2.5 min
Pollux Entrance	1 pedestrian/1:30 min
Castor Entrance	1 pedestrian/1:30 min

We considered five different scenarios for every situation. Fewer road users in the factory would be positive for Scania regarding traffic intensity. Therefore, we refer to the scenario where entry intensities are at their lowest as the “Very Positive Scenario." The “Very Negative Scenario" is when entry intensities are at their maximum. We looked at this because the intensity of traffic inside the factory can change over time. Traffic will increase if Scania produces more trucks since more materials must be supplied to the assembly lines.

First, we looked at the base scenario, in which the entry distributions retrieved from direct observations are the basis for the various traffic flows' intensities. From there, we examined several scenarios to evaluate how the solutions affect a potentially busier or calmer factory. Table 9 lists the multiplication factors for each scenario's entry intensities.

Table 9: Multiplication Factors

Scenario	Factor of Multiplication
Very Negative	1,2
Negative	1,1
Base	1
Positive	0,9
Very Positive	0,8

Conclusion

This section indicates the experiment settings. We determined the calculation process for the KPIs, the number of replications, the warmup period we used for our experiments, and the sensitivity analysis we wanted to conduct. We can now carry out the experiments.

6.2 Results

We now examine the outcomes that each solution produced in this section. We examined eighteen different solutions in total, in addition to the current situation. Appendix D1 indicates every solution we implemented. We examined each option while focusing on our four main KPIs. We now discuss the test outcomes per KPI.

KPI 1: NrInteractionsCrossings

We start by examining the data provided by the most important KPI, the number of interactions at crossings. As discussed in Chapter 2, this is the most significant KPI because it has the greatest impact on traffic safety in the factory. It becomes clear that, while considering this KPI, the top five solutions are as follows:

1 Bridges S1
2 Bridges S2

3 Traffic Barriers S1
4 Traffic Barriers S2
5 Dynamic Routing S2

The tests also clearly show that changing the shift system has almost no positive effect on reducing the number of interactions at crossings. The same is true for decreasing the speed at crossing points. Furthermore, when decreasing the speed limit, it is recommended to reduce it to 7.0 km/h.

Additionally, the sensitivity analysis shows that, at some solutions, the number of interactions at crossings does not decrease when entry intensities do. As an illustration, we consider Figure 12. These interactions occur in the scenario when we lower the speed restriction to 7.5 km/h. The number of interactions at crossings does not necessarily decrease when the entrance intensities decrease. This is shown in Figure 12 since you do not see a linear relation between the different scenarios.

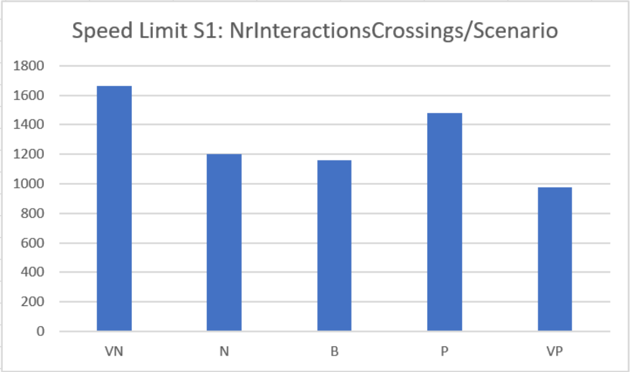

Figure 2: NrInteractionsCrossings/Scenario

<u>KPI 2: NrInteractionsStraightLines</u>

Understanding the experiment outcomes of the NrInteractionsStraightLines and the NrInteractionsCrossings is crucial. The factory's overall level of traffic safety may not rise if the NrInteractionsCrossings lowers, but the NrInteractionsStraightLines grows significantly.

Our experiments show that the number of interactions at straight lines stays relatively constant for most solutions, except for the solutions where the factory lowers the speed limit. This lowers explicitly the number of interactions at straight lines by 20%, 27%, and 39% when we lower the speed limit to 7,5, 7, and 6,5 km/h. Also, letting road users wait at their depot before there is space to move (Dynamic Routing S1 and S2) reduces the number of interactions by 11%. Therefore, the only way to significantly reduce the number of interactions on straight lines is to lower the speed limit or introduce waiting times at depots. This is because when someone is waiting for a crossing or another vehicle, road users approach one another more slowly and behind when reducing the speed. Additionally, when waiting times are introduced at depots, road users start further away from each other when they start to move at depots, resulting in more space between road users throughout the process.

Given that there is no evidence of a linear relation between the outcomes of the scenarios, it can be concluded from the sensitivity analysis that the entry intensities have no meaningful impact on the Number of Interactions at Straight Lines. Figure 13, which shows the scenario in which we construct bridges around the Aorta, illustrates this.

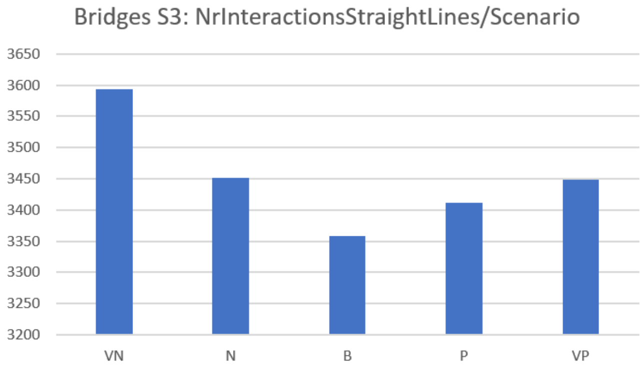

Figure 3: NrInteractionsStraightLines/Scenario

KPI 3: Total Distance Travelled

We now examine the total distance travelled. The total distance travelled tells us more about the factory's production efficiency than it does about the safety of the factory's traffic. Scania may decide to refuse a solution even in cases where fewer interactions occur. This can be when road user travel distance increases significantly, as this could lead to a decrease in production efficiency.

The tests show that no solution significantly changes the total distance travelled. All total lengths are nearly the same. The sensitivity analysis also concludes that, in contradiction to the number of interactions, a decrease in the factory's entrance intensity does result in a decrease in the total distance travelled. Examining the three shift change systems, the various scenarios result in the following distances. This graph shows a clear linear relation between the scenarios.

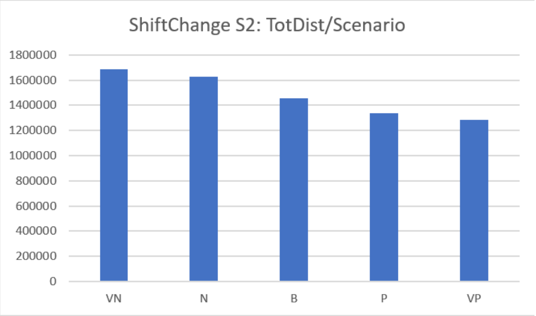

Figure 4: TotalDistance/Scenario

KPI 4: Total Waiting Time

The total waiting time is the last KPI we examine. Similar to the total distance travelled, the vehicles' waiting times provide insight into production efficiency. Production efficiency typically decreases when vehicles wait a lot because materials may arrive at their destination later.

The total waiting time is rather constant in the majority of cases. The factory's maximum total waiting time was reached when we reduced the speed limit at all crossings to 4km/h. In this case, the total waiting time increased by 11% compared to the current situation. This can be explained by the fact that vehicles attend crossings for longer. Therefore, road users have to wait longer for vehicles that are on the crossing points when there is a reduced speed limit.

When we lower the speed limit to 6.5 km/h, the total waiting time is at its lowest—36%. Fewer interactions occur at straight lines (see "KPI2: NrOfInteractionsStraightLines"), so there is less waiting time for vehicles in straight lines. However, because they travel slower, the vehicles will probably reach their destination later. Therefore, reducing the speed restriction does not necessarily improve the efficiency of production.

Another effective technique to bring down the total waiting time is to let road users wait at the depots until there is enough room for them to move. Especially in the case of Dynamic Routing S2, where we also split the pedestrian streams at the Portiersloge, the total waiting time is reduced by 19%. When implementing Dynamic Routing S2, the total waiting time is reduced because the interactions at crossings and straight lines are decreasing.

Regarding the sensitivity analysis, it can be stated that entering intensity and total waiting time do not directly correlate. This can, for example, be seen when we examine the solution to implement traffic barriers at the three busiest locations in the factory. The absence of a linear relation in the graph is demonstrated by the figure.

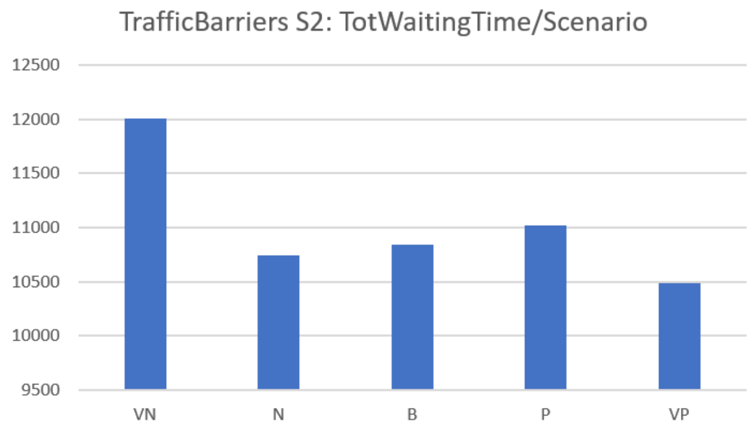

Figure 5: TotWaitingTime/Scenario

In short, six solutions come to mind when considering solutions that have the most significant positive effects on traffic safety without negatively affecting production efficiency. Table 10 also shows this. The three solutions that reduce the number of interactions at straight lines the most are presented in this table, together with those that reduce the number of interactions at crossings the most. They are as follows:

- Building bridges at the three busiest pedestrian/vehicle points (decreases the Number of Interactions at Crossings)
- Implementing traffic barriers at the three busiest pedestrian/vehicle points (decreases the Number of Interactions at Crossings)
- Dynamic Routing, where we introduce waiting times at depots and split the pedestrian streams at the Portiersloge (decreases the Number of Interactions at Crossings and the Number of Interactions at Straight lines)
- The speed limit of 6,5 km/h, 7 km/h, or 7,5 km/h (decreases Number of Interactions at Straight Lines)

Furthermore, Table 10 shows that the six suggested solutions generally improve production efficiency (total distance and total waiting time) as well. Consequently, the optimal "hybrid" solution is found by combining these six options.

Table 10: Trade-off KPIs (Reductions in Percentage)

Solution	NrInteractionsCr	NrInteractionsSL	TotalDistance	TotalWaitingTime
Three Bridges	52%	2%	11%	9%
Six Traffic Barriers	40%	2%	8%	3%
Dynamic Routing S2	25%	11%	8%	19%
Speed Limit 7,5km/h	-8%	20%	-1%	20%
Speed Limit 7,0km/h	10%	27%	0%	29%
Speed Limit 6,5km/h	1%	39%	0%	36%

Testing Hybrid Solutions

We combine the best solutions to test if they function better together. We combine the three best solutions to lower the Number of Interactions at Crossings with the three best solutions to lower the Number of Interactions at Straight Lines. The following three solutions brought down the total number of interactions from these nine hybrid solutions the most.

Solution	NrInteractionsCr	NrInteractionsSL	Total Distance	Total Waiting Time
Three Bridges + Speed Limit 6,5 km/h	56%	35%	9%	38%
Six Traffic Barriers + Speed Limit 6,5 km/h	48%	34%	7%	24%
Dynamic Routing S2 + Speed Limit 6,5 km/h	13%	41%	7%	43%

The number of interactions at crossings decreases the most when bridges are built at the three busiest pedestrian/vehicle places, and the speed limit is decreased to 6.5 km/h. The number of interactions at crossings, namely, then decreases by 56%. This is better than just lowering the speed limit or implementing bridges at the busiest points.

Regarding interactions at straight lines, combining Dynamic Routing S2 with reducing the speed limit to 6,5 km/h is best. However, every hybrid solution works well once we reduce the speed limit to 6,5 km/h. In particular, every solution results in several interactions at straight lines of around 38%.

In terms of production efficiency, the hybrid solutions can be considered near one another when considering the total distance travelled. The reduction in total distance travelled lies between 7% and 9%, which is more or less the same as when using the individual solutions. When comparing the total waiting time, the implementation of traffic barriers has a slightly higher total waiting time than the other two methods.

Conclusion

The best solution for Scania would be installing bridges at the factory's three busiest pedestrian/vehicle points and lowering the speed restriction to 6.5 km/h. This is the best solution since it would decrease the number of interactions at crossings the most. Furthermore, the number of interactions at straight lines would be significantly reduced, the total travel distance would be reduced the most, and the total waiting time of the road users in the traffic system would significantly positively be impacted.

6.3 Chapter Summary

We put the solutions from Chapter 5 into the model in this chapter to test if the solutions improved the current traffic situation. With these tests, we mainly examined the impact of the solutions on the four main KPIs. The main results were the following:

- Building bridges at the factory's busiest pedestrian/vehicle points, implementing traffic barriers at the busiest pedestrian/vehicle points, and applying Dynamic Routing S2 (waiting at depots, split pedestrian streams at Portiersloge) reduces the number of interactions at crossings the most.
- Decreasing the speed limit reduces the number of interactions at straight lines the most.
- The total travelled distance and total waiting time are most of the time not negatively affected by the proposed solutions.

The best (hybrid) solution is to lower the factory's speed limit to 6.5 km/h and construct bridges at the busiest pedestrian/vehicle points. This solution has the greatest impact on reducing the number of interactions at crossings, and it also has a beneficial effect on the other KPIs. We can now make our conclusions because we know which solution is best for increasing traffic safety in Scania's factory. We do this in the following chapter.

7 Conclusion and Recommendations

This chapter provides the most critical findings gathered in this research. We then explain how these findings should be considered. Furthermore, we look at where the research could have been improved by highlighting its limitations. Finally, we give recommendations for future research regarding this topic.

7.1 Most Important Findings and Recommendations

In this section, we discuss the most important findings of this research. Scania Zwolle had a problem within the factory. Too many unsafe situations were happening between vehicles and pedestrians/other vehicles in the facility. To address this problem, we formulated the following main research goal: *Provide a strategy for Scania Zwolle to improve worker safety and the safety of all those utilizing the factory, all while taking into account the impact on production efficiency.* To provide this strategy, we started by describing the current situation at Scania's factory. From this research, it, for example, turned out that there are four points in the factory that are the busiest. These are the 'PortiersLoge', the 'Aorta', the 'Crossing at the Blue Building', and the 'EagleOvergang.' The solution should address the safety issues at these points.

Then, we performed a literature review, in which we first looked at the main reasons for unsafe occurrences in traffic situations in manufacturing environments. From this research, it came out that too many movements, poor road design, and human behaviour are the main reasons for unsafe situations in traffic. Solving these problems could, for example, involve changing the shift system of the factory, building bridges, or decreasing the speed limits in the factory.

To see which solution best suits Scania's current situation, we built a discrete event simulation. At first, this simulation depicted a realistic view of Scania's factory. We determined how we wanted to measure the safety measures' performance, which was the number of interactions expected on a daily basis. Then, we quantified the possible solutions and ensured we could implement them in the model.

From these implementations, the following results came forward:

- The best solutions to bring down the number of interactions at crossings are to build bridges at the three busiest pedestrian/vehicle points, to implement traffic barriers at the three busiest pedestrian/vehicle points, or to introduce waiting times at depots and split the pedestrian streams at the Portiersloge (dynamic routing).
- Reducing the factory speed limit, especially to 6.5 km/h, is the best way to decrease the number of interactions at straight lines. When the speed limit is reduced to 6.5 km/h, there are roughly 39% fewer interactions at straight lines.

Furthermore, we combined the solutions that minimized interactions at crossings with those that most effectively decreased the number of interactions at straight lines. The results of these experiments indicated that the best hybrid solution would be to construct bridges over the three busiest pedestrian/vehicle locations and reduce the speed restriction to 6.5 km/h. This solution reduces the number of interactions that occur most at straight lines and crossings. Also, implementing this solution has no negative impact on production efficiency, as indicated by the total waiting time and travel distance.

Thus, we advise Scania to build bridges at the three busiest pedestrian/vehicle points. This is a realistic option with the sidenote that the factory has enough space to build bridges. A point of discussion is that when we mention bridges as the way to go against traffic unsafety, is that we mean that all the pedestrians in the factory also use the bridges. If particular pedestrians are unable or willing to use the bridges, it can lead to very unsafe situations. When bridges are in place, the chauffeurs of the vehicles do not expect pedestrians to walk across the driving paths anymore, so they pay less attention to this possibility. When a pedestrian does not use the bridges and wants to cross on the driving paths, there is a higher chance that it will result in an unsafe situation than now. Furthermore, sufficient funding is needed to build the bridges.

Traffic barriers take up less space and are likely less expensive than bridges. However, the model considers the fact that when traffic barriers are in place, vehicles and pedestrians do not interfere. This may still be the case when pedestrians ignore the traffic barriers or do not wait until they are fully up again. Therefore, it is still essential to keep an eye on the real-life effects of the barriers when implementing traffic barriers.

Dynamic Routing is the third most effective way to reduce the number of interactions at crossings. This is a feasible solution because all that has to be done is adjust the timing and the direction of the current traffic flows. Scania must, however, ensure that drivers do not spend too much time on waiting at their depots since this will seriously affect the efficiency of the production process. Road users will arrive too late at their destination in the factory if they wait too long at their depot. New routes should be brief since this will delay the logistic processes significantly otherwise.

Next to this, we advise Scania to reduce the speed limit in their factory to 6,5 km/h. Nevertheless, Scania should consider the fact that the productivity of the production process may change if all the vehicles have to slow down. Materials may be delivered later to the assembly line, which could delay the production process. This is not because the waiting time is increased when doing this, but because when the speed is lower, vehicles will move slower to their end destination.

7.2 Limitations

In this section, we point out the weaker points of our research. As with every research, this research also had its weaker points. By pointing them out, we acknowledge these weak points and give the reader a more complete picture of the research done.

Firstly, we only examined the results of combining the six best solutions into hybrid solutions. It would have been best to test every single solution with each other and see which combined solution was the best. Nevertheless, due to time constraints, this was not possible in the time frame of this research. Yet, combining some of the other solutions could have resulted in a bigger reduction in the expected number of interactions.

Secondly, a limitation is that when we did the literature review, we included part of the literature that talked about safety measures in real-life traffic situations, not in manufacturing environments. We did this since we assumed that real-life traffic situations were quite comparable to those in Scania's factory.

The final limitation of this research is that it is possible to make a more extensive simulation of the entire Scania factory. In order to get the most reliable results, it would be best if an extensive simulation of the entire factory was made, in which all the distances of roads, the routes of road users, and the number of pedestrians were depicted in the same way as it is in reality. Nevertheless, due to time constraints, this was not possible. Therefore, we chose to make the factory in a more simplified way. In this way, we could deal with the time constraint of this thesis. The simplified model gives a good image of the traffic situation within the Scania factory. However, a more detailed model can help to get even more realistic outcomes regarding this topic.

7.3 Regarding Future Research

In this section, we point out our recommendations for future research. First, we would look more thoroughly into how the suggested solutions, such as lowering the speed limit to 6.5 km/h, affect production efficiency. At this point, it is known quite well what effect the solutions had on the total waiting time and total travelled distance of vehicles. Nevertheless, it could also be valuable to know the solutions' effect on other KPIs that affect production efficiency. In order to investigate this, the simulation model should be extended in such a way that we can also keep track of the number of trucks produced per time unit. Then, we can see how the proposed solutions are influencing this number.

Furthermore, to make the model more in-depth, it may be possible to incorporate human behaviour, which, for example, entails the possibility that employees will make mistakes in traffic at specific locations throughout the factory. Another factor that might be considered is the length of the vehicles participating in traffic. The varying lengths of the vehicles, namely, result in varying accident probabilities. Then, the solutions may be even more realistic as well. In short, extending the simulation model could be a valuable goal of future research.

The second recommendation we want to make regarding future research is to investigate the cost of implementing bridges in Scania. The cost should be investigated around the busiest points. Then, an even more solid decision could be made about whether or not to implement bridges in the factory to increase traffic safety.

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Appendix

Appendix A: Figures of Chapter 1

Appendix A1: Problem Cluster

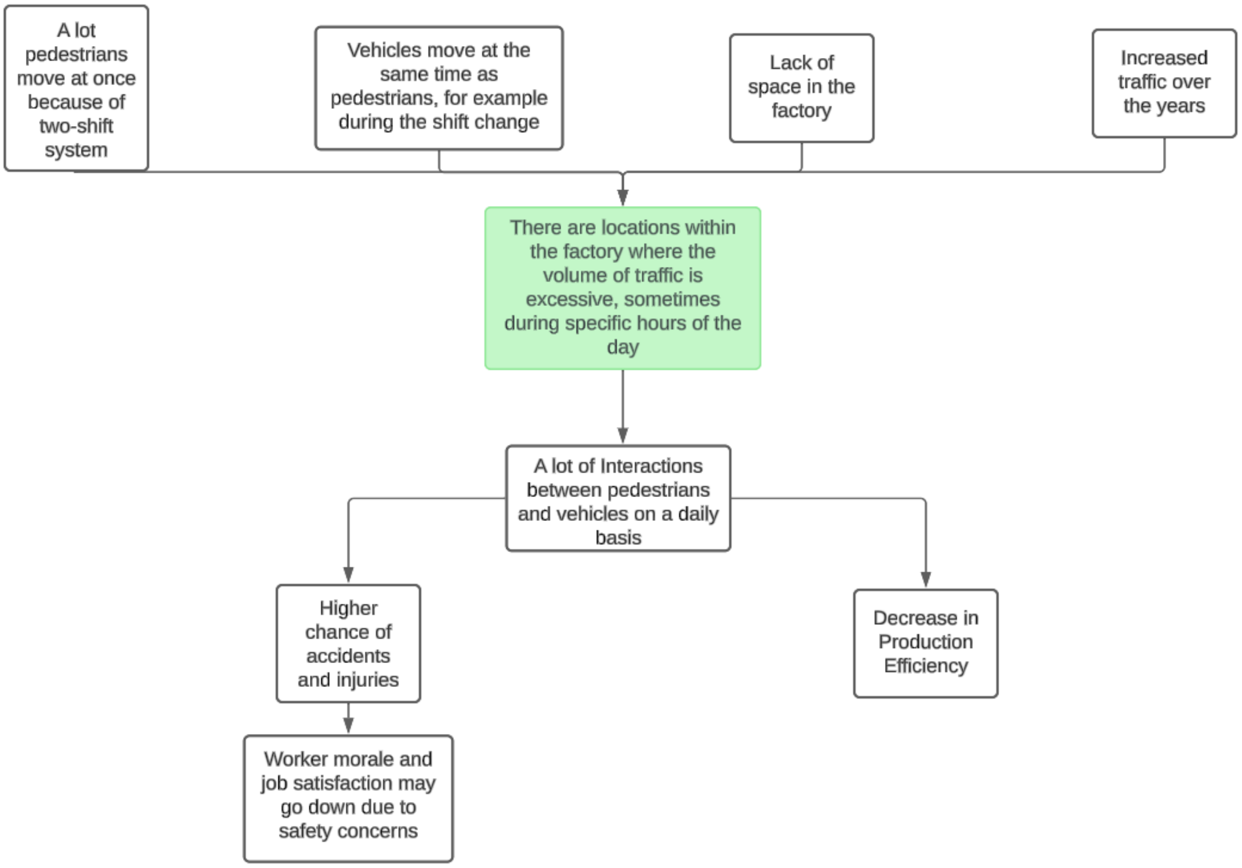


Figure 1: Problem Cluster

Appendix B: Figures of Chapter 2

Appendix B1: Different Types of Transporters

1. Reach truck:

Pallets are transported from the warehouses to the production line using reach trucks.

2. Forklift:

Forklifts are used to move pallets from the warehouses to the production line.

3. Trains:

Trains transport various green and purple buildings to the production line.

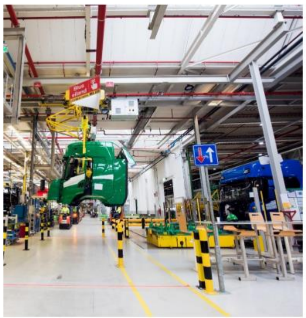
4. Toyota Transporter:

The Toyota Transporter is used at the green flow to move goods from the warehouse to the production line.

5. MAFI Car:

The MAFI car is used as an actuator for small trains. These small trains transport pallets from the blue building to the factory.

6. Hanging Wires



Using hanging wires, the Castor cabins are moved from Awning U7 to the Castor line.

Appendix B2: Yellow Paths

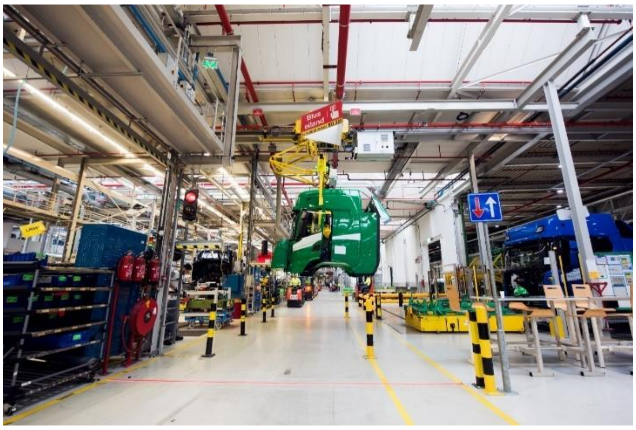


Figure 2: Yellow Paths Inside the Factory of Scania Zwolle

Appendix B3: Project Acceptation Process

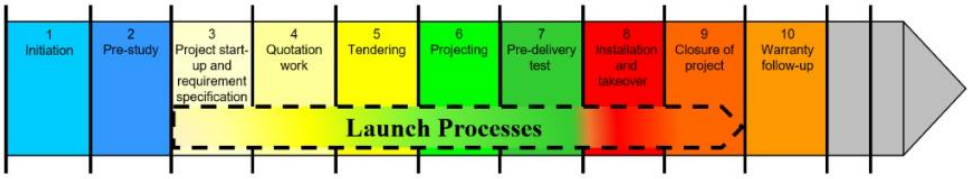
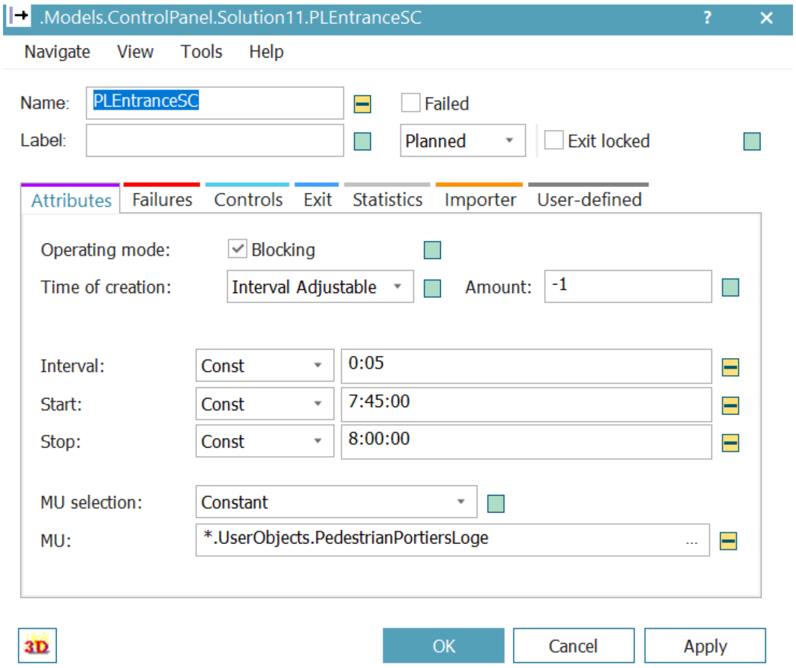


Figure 3: Project Acceptation Process

Appendix C: Figures of Chapter 5

Appendix C1: Changing the Shift System



Name: PLEntranceSC

Label:

☐ Failed

Planned

☐ Exit locked

Operating mode: ☑ Blocking

Time of creation: Interval Adjustable

Amount: -1

Interval: Const 0:05

Start: Const 7:45:00

Stop: Const 8:00:00

MU selection: Constant

MU: *.UserObjects.PedestrianPortiersLoge

Figure 5: Changing the Shift System

<u>Shift Change Addition (7:30-8:30)</u>

Entrance	Intensity	Destinations	Colour
PortiersLoge (7:30-8:00)	5,5 pedestrians/min	40% Pollux, 40% Castor, 10% PL, 10% LE	Red
Main Entrance (7:30-8:00)	6 pedestrians/min	40% Pollux, 40% Castor, 10% PL, 10% LE	Green (light)
South East Entrance (7:30-8:00)	1,5 pedestrians/min	40% Pollux, 40% Castor, 10% PL, 10% LE	Green (dark)
South West Entrance (7:30-8:00)	4,5 pedestrians/min	40% Pollux, 40% Castor, 10% PL, 10% LE	Green (Fluorescent)
Pollux Entrance (7:30-8:30)	5 pedestrians/min	25% SW, 25% PL, 25% ME, 25% SE	Black
Castor Entrance (7:30-8:30)	5 pedestrians/min	25% SW, 25% PL, 25% ME, 25% SE	Black

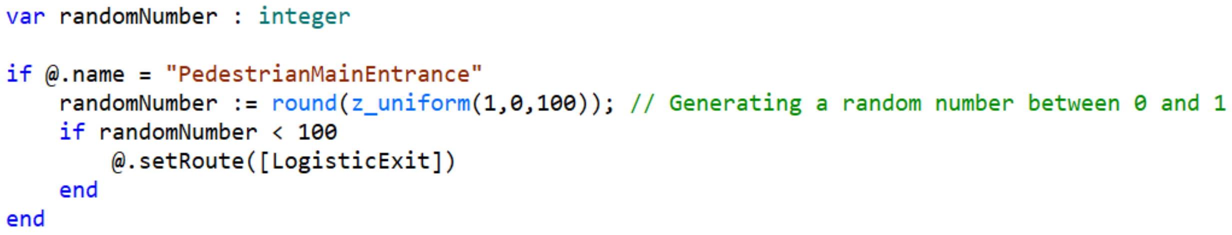
Appendix C2: Dynamic Routing

The Aorta (S1)

Old Stream	New Streams	Splitting Rate
NWEntry-Aorta-MEExit	1 NWEntry – Aorta – MEExit	9,8%
	2 NWEntry – CrossingHalfway – MEExit	36,3%
	3 NWEntry – CrossingSouthEast – MEExit	53,9%
PLEntry-Aorta-NWExit	1 PLEntry – Aorta – NWExit	9,8%
	2 PLEntry – CrossingHalfway – NWExit	36,3%
	3 PLEntry – CrossingSouthEast - NWExit	53,9%
NWEntry-Aorta- PLExit	1 NWEntry-Aorta-PLExit	5,7%
	2 NWEntry-CrossingHalfway-PLExit	31,4%
	3 NWEntry-CrossingEndPollux-PLExit	62,9%

The EagleOvergang + The PortiersLoge (S2)

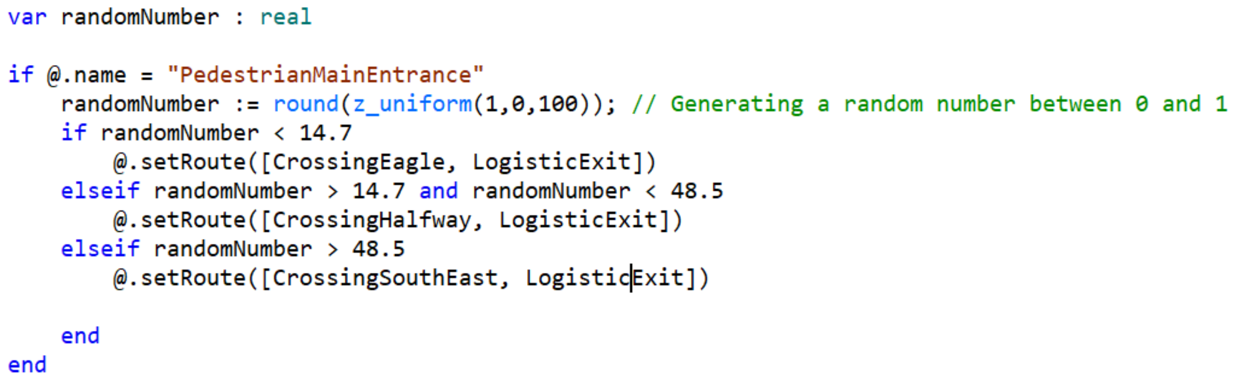
Old Stream	New Streams	Splitting Rate
MEEntry – EagleOvergang - LEExit	1 MEEntry – EagleOvergang – LEExit	14,7%
	2 MEEntry – CrossingHalfway – LEExit	33,8%
	3 MEEntry – CrossingSouthEast – LEExit	51,5%
NWEntry-EagleOvergang-PLExit	1 NWEntry – EagleOvergang – MEExit	8,7%
	2 NWEntry – CrossingHalfway– MEExit	30,4%
	3 NWEntry – CrossingEndPollux – MEExit	60,9%
PLEntry-EagleOvergang-NWExit	1 PLEntry – EagleOvergang – NWExit	14,7%
	2 PLEntry – CrossingHalfway – NWExit	33,8%
	3 PLEntry - CrossingSouthEast - NWExit	51,5%
LEEntry-EagleOvergang-PLExit	1 LEEntry-EagleOvergang-PLExit	14,7%
	2 LEEntry- CrossingHalfway-PLExit	33,8%
	3 LEEntry- CrossingSouthEast – PLExit	51,5%



```
var randomNumber : integer

if @.name = "PedestrianMainEntrance"
    randomNumber := round(z_uniform(1,0,100)); // Generating a random number between 0 and 1
    if randomNumber < 100
        @.setRoute([LogisticExit])
    end
end
```

Figure 7: Routing without Splitting Rates

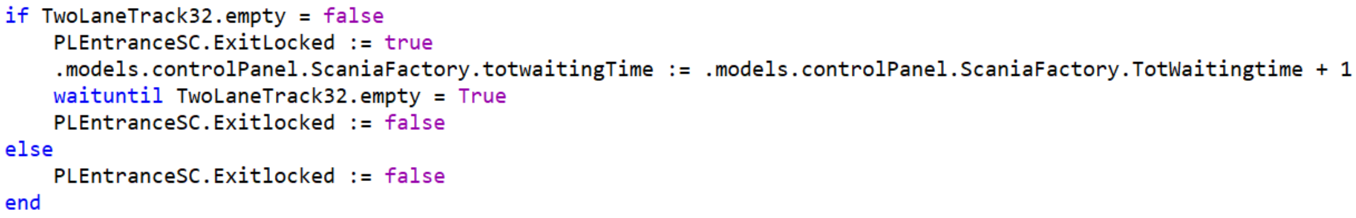


```
var randomNumber : real

if @.name = "PedestrianMainEntrance"
    randomNumber := round(z_uniform(1,0,100)); // Generating a random number between 0 and 1
    if randomNumber < 14.7
        @.setRoute([CrossingEagle, LogisticExit])
    elseif randomNumber > 14.7 and randomNumber < 48.5
        @.setRoute([CrossingHalfway, LogisticExit])
    elseif randomNumber > 48.5
        @.setRoute([CrossingSouthEast, LogisticExit])

    end
end
```

Figure 8: Routing with Splitting Rates



```
if TwoLaneTrack32.empty = false
    PLEntranceSC.ExitLocked := true
    .models.controlPanel.ScaniaFactory.totwaitingTime := .models.controlPanel.ScaniaFactory.TotWaitingtime + 1
    waituntil TwoLaneTrack32.empty = True
    PLEntranceSC.Exitlocked := false
else
    PLEntranceSC.Exitlocked := false
end
```

Figure 9: Exit Strategy for Portiersloge: Waiting Times

Appendix C3: Bridges

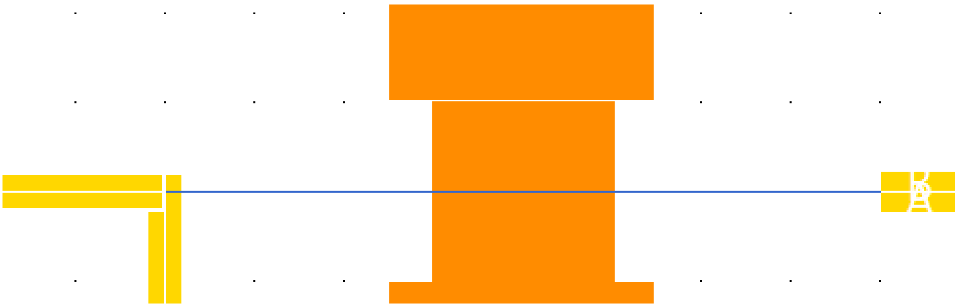
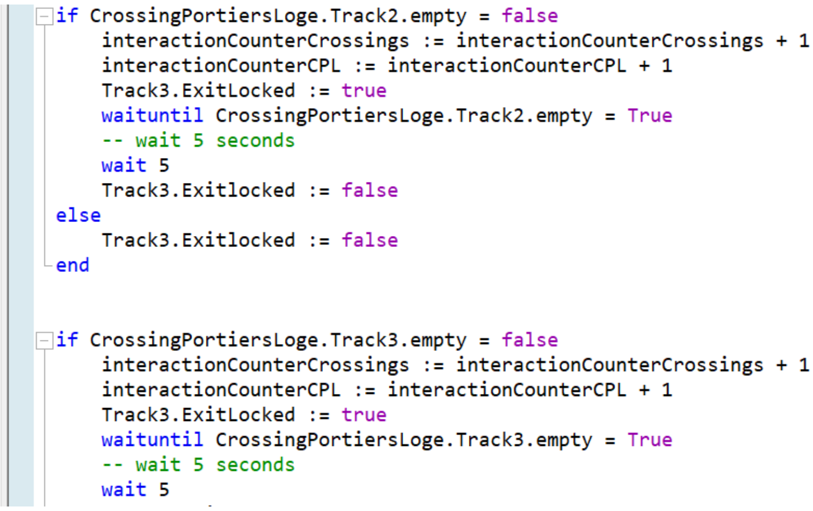


Figure 10: Bridge Above the EagleOvergang

Appendix C4: Traffic Barriers

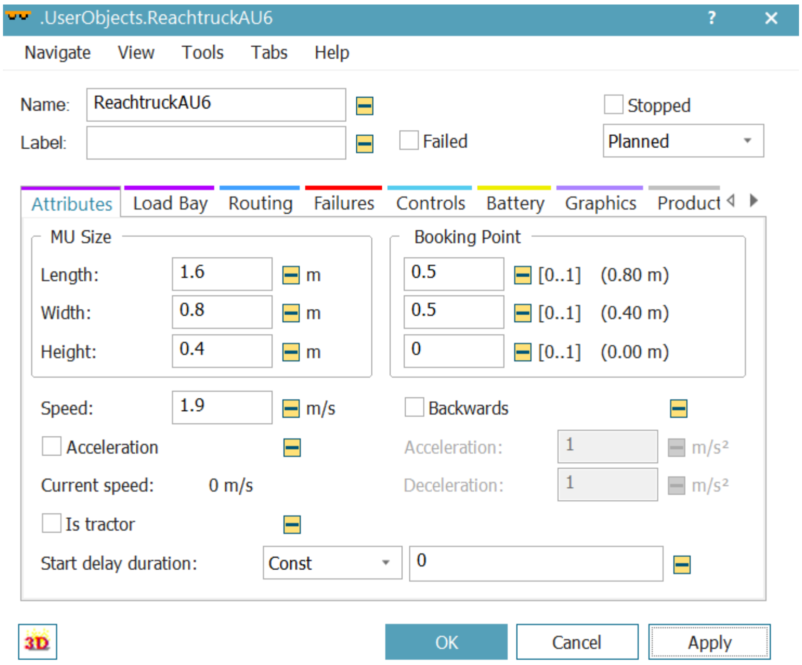


```
if CrossingPortiersLoge.Track2.empty = false
    interactionCounterCrossings := interactionCounterCrossings + 1
    interactionCounterCPL := interactionCounterCPL + 1
    Track3.ExitLocked := true
    waituntil CrossingPortiersLoge.Track2.empty = True
    -- wait 5 seconds
    wait 5
    Track3.Exitlocked := false
else
    Track3.Exitlocked := false
end


if CrossingPortiersLoge.Track3.empty = false
    interactionCounterCrossings := interactionCounterCrossings + 1
    interactionCounterCPL := interactionCounterCPL + 1
    Track3.ExitLocked := true
    waituntil CrossingPortiersLoge.Track3.empty = True
    -- wait 5 seconds
    wait 5
```

Figure 6: Code for Traffic Barriers

Appendix C5: Changing Speed Limits



.UserObjects.ReachtruckAU6

Name: ReachtruckAU6

Label:

☐ Failed

☐ Stopped

Planned

MU Size

Length: 1.6 m

Width: 0.8 m

Height: 0.4 m

Booking Point

0.5 [0..1] (0.80 m)

0.5 [0..1] (0.40 m)

0 [0..1] (0.00 m)

Speed: 1.9 m/s

☐ Backwards

☐ Acceleration

Acceleration: 1 m/s²

Current speed: 0 m/s

Deceleration: 1 m/s²

☐ Is tractor

Start delay duration: Const 0

Figure 11: Changing the Speed Limit to 7 km/h

Appendix D: Figures of Chapter 6

Appendix D1: Type of Solutions

Nr	Name	Solution
1	Current situation	--
2	Shift Change S1	Two shift changes
3	Shift Change S2	Three shift changes
4	Shift Change S3	Four shift changes
5	Dynamic Routing S1	Split streams at the Aorta + Waiting Times at Depots
6	Dynamic Routing S2	Split streams at EagleOvergang/Portiersloge + Waiting Times at Depots
7	Bridges S1	Bridges throughout the entire factory
8	Bridges S2	Bridges at the three busiest pedestrian/vehicle points
9	Bridges S3	Bridge at the Aorta
10	Traffic Barriers S1	Traffic barriers throughout the entire factory
11	Traffic Barriers S2	Traffic barriers at the three busiest pedestrian/vehicle points
12	Traffic Barriers S3	Traffic barriers at the Aorta
13	Speed Limit S1	Speed limit of 7,5 km/h
14	Speed Limit S2	Speed limit of 7 km/h
15	Speed Limit S3	Speed limit of 6,5 km/h
16	Speed Limit Crossings S1	Speed limit of 4 km/h at all crossings
17	Speed Limit Crossings S2	The speed limit of 4 km/h at four busiest points
18	Speed Limit Crossings S3	Speed limit of 4 km/h at Aorta