**P39 HVTT16; ACCESSIBILITY PERFORMANCE (SPEED AND SPACE CLAIMS IN INTERSECTIONS) AND NORDIC LEGISLATION COMPARISON FOR HEAVY**


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| **Lena Larsson**<br>**Volvo GTT, Sweden**<br>M.Sc. in Mechanical Engineering at Chalmers University of Technology and MBA at Gothenburg University<br>Currently Project manager, High Capacity Transport. | **Emil Pettersson**<br>**AFRY, Sweden**<br>M.Sc. in Mechanical Engineering at Chalmers Uni of Tech. Currently Design Engineer; High Capacity Transport Vehicle combinations at Volvo GTT. | **Krishna Kashampur**<br>**AFRY, Sweden**<br>M.Sc. in Automotive Engineering at Chalmers Uni of Tech. Currently Simulation Engineer; High Capacity Transport Vehicle combinations at Volvo GTT. | **Clive Misquith**<br>**AFRY, Sweden**<br>M.Sc. in Automotive Engineering at Chalmers Uni of Tech.<br>Currently Design Engineer; High Capacity Transport Vehicle combinations at Volvo GTT. |


**TRUCK COMBINATIONS**

## 1. Abstract


Performance-based demands have been used to test High-Capacity Transport (HCT) vehicle combinations safely on road networks. However, one of the major bottlenecks in the implementation of large road network HCT is infrastructure, accessibility, road and bridge bearing capacity. For safety rollover stability and dynamic stability is important.

In this paper presents accessibility performance and static rollover for 12 basic type vehicle combinations ranging between 16.5 m and 34.5 m in length. To hold good speed in intersections and keep a good traffic flow, a good road infrastructure is necessary. The vehicle combinations were simulated to maneuver different turning outer radii and turning angles. The low speed swept path along with outboard off tracking were studied. The results are compared with the current legislation in Finland, Sweden and Norway.

Vehicle combinations with similar configurations pass both between Swedish 180° turn and Finnish 120° turn demands. This paper aims to guide the authorities and road owners through the different legislations for HCT combinations they drive in their country.

**Keywords: High-Capacity Transport, Legislations, Accessibility, Performance Based Standards**

## 2. Introduction

High-Capacity Transports (HCT) evolved as a solution to increase transport efficiency and limit environmental impact from road transport. HCT involves vehicle combinations with multiple units which are modular. HCT vehicles are also identified as vehicles under European Modular System (EMS). The first regulation on the limit of length of vehicle combination in Sweden was passed in 1972. The vehicle combination length limit was 24 m. This was increased to 25.25 m in 1997. The ambition is to increase the length limit to 34.5 m as done by Finland in 2019.

To implement such vehicle combinations there needs to be requirements on performance, infrastructure, and road network. The acceptance of such vehicle combinations by society and logistics & transport companies is equally important. It is comparatively easy to build a HCT vehicle combination, but it requires efforts to match the necessary road and bridge infrastructure. In Sweden, HCT vehicles upto 25.25 m are allowed on BK4 road network only. The introduction of new vehicles has been tough due to the limitations on road infrastructure. The work in this paper tries to address issues regarding accessibility and speed in roundabouts for longer HCT vehicles.

In the report [6], the authors present proposals for performance-based standards and their thresholds that could be used in Sweden. As of now, the HCT vehicles in Sweden are run on exemption or dispensations from the road authorities. One of the important proposed PBS threshold is the low speed swept path. The vehicle performs a 90°, 120°, and 360° turn depending on the country's legislation at low speed. In Sweden, one of the performance based demand that an EMS vehicle combination over 24 m needs to comply with is a 180° turn having outer radius of 12.5 m while traversing a swept width less than 10.5 m.

This paper is a continuation of the previous work [7] presented at HVTT15. Previously, stability and manuverability were studies using 2-D models. The aim of the paper [7] is to compare HCT vehicle combinations based on stability and manueverability with a two track 3-D models, highlighting the importance of detailed models. The same models are used in this paper. The work in this paper focusses on understanding how the vehicle performs in intersections. The speed that a vehicle can hold in roundabouts and intersections helps determine the traffic flow and congestion. This in turn provides suggestions to the road and transport authority on the infrastructure needed to implement such vehicle combinations. The next section deals with literature review and legislation around HCT in different Nordic countries. In the following sections, a brief introduction to the models used and the results from simulations will be discussed. Lastly, the paper considers seven intersections around the city of Gothenburg and discusses the speed that can be held in the intersections with the limit being rolling over. The simulations provide the theoretical max speeds that the vehicle can maneuver at these intersections.

## 3. Literature Review

In the European Union, every country has its standards for vehicle combinations. The Directive 96/53/EC [1] allows the vehicle length to be higher than 18.75 m under the European Modular System. Under EMS, using loading units of length 7.82 m and 13.6 m leads to a vehicle combination with a length up to 25.25 m. These vehicle combinations are commonly used in Nordic countries under EMS. HCT vehicle combinations were observed to have immense benefits in Australia and Canada [3, 4]. Vehicle combinations or road trains developed from the EMS concept also exhibited similar benfits. During the test period of HCT in Nordic countries, the focus will be to test vehicle combinations on road network through excemption, regulation and dispensation in respective countries. Over the last couple of years, the need to have cross-border regulations has taken priority. Figure1, shows the European Union with different countries having different length restrictions

To allow HCT vehicles across borders there needs to be unified demands. Since this paper is on accessibility, the main focus is on low-speed demands. According to Australian PBS [3], the low-speed category includes a 90° turning maneuver measuring the low speed swept path, frontal swing, and tail swing. In the report [6], one of the proposed PBS for Sweden is a 90° turning maneuver with 12.5 m outer radius and 2 m inner radius, measuring low speed swept width. The Finnish standards consider an outer radius of 12.5 m, and 120° turn accessing similar swept path and outer swing.

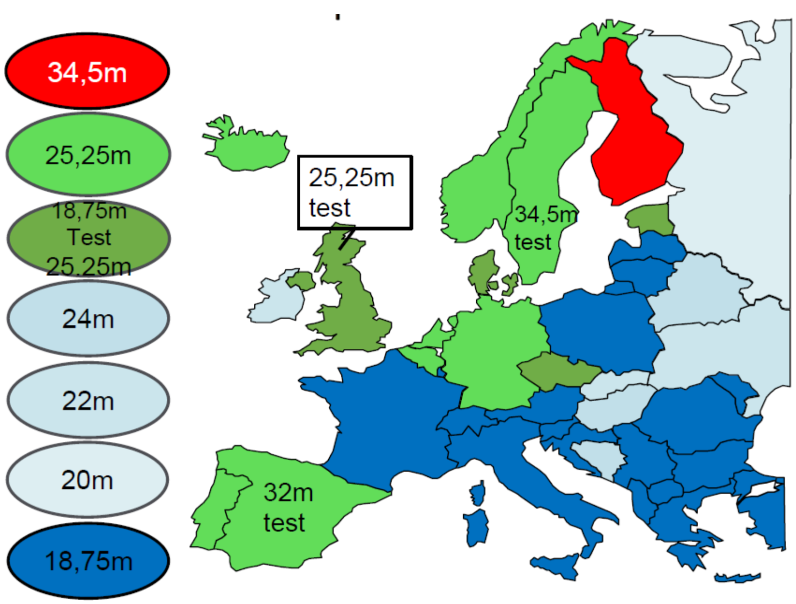



Figure 1: Length restriction in European Union

## 3.1 Legislations

According to Directive 97/27/EC [2] section 7.6 and 96/53/EC [1], any motor vehicle and semitrailer should be able to maneuver a complete trajectory of 360° turn with an outer radius of 12.5 m and inner radius being 5.3 m without any of the vehicle's outermost points projecting outside the circumference of the two circles. This is valid for all the Nordic countries. In Table 1, a comparison between the different legislation in different countries and combination types can be seen.

Table 1 An overview of some of the legislations regarding 25.25 m combinations

| Country | Max length(m) | Type/Comment | Turn | Outer Radius(m) | Inner Radius(m) | Outer swing(m) | Swept width(m) |
|---|---|---|---|---|---|---|---|
| Finland | 34.5 | | 120 | **12.5** | **4** | 0.8 | ***8.5*** |
| Finland | 34.5 | | 120 | **12.5** | **3.7** | 0.5 | ***8.8*** |
| Sweden | 25.25 | | 180 | **12.5** | **2** | | ***10.5*** |
| Sweden | 24m | No Demand | ND | ND | ND | | ND |
| Norway | 25.25 | MVT1.2+24m | 180 | **12.5** | **2** | | ***10.5*** |
| Norway | 25.25 | MVT3 | 180 | **13** | **2** | | ***11*** |
| Norway Timber roads "TVT" | 25.25 | MVT1.2+24m | 360 | **12.5** | **2** | | ***10.5*** |
| 96/53 EC | EMS 16.5/18.75 | | 360 | **12.5** | **5.3** | | ***7.2*** |
| Iceland | 25.25 | | 360 | **12.5** | **5.3** | | ***7.2*** |
| Denmark | 25.25 | Test- no demand set | | | | | |

As seen from the above table, the legislations within the Nordic countires are different. A vehicle combination allowed in one country need not necessarily fulfill the legislation of another country. So, the transportation of goods in such a vehicle combination across Europe becomes challenging. For example, a vehicle combination originating from Germany fitted with a special type of dolly with steered axles will not be allowed to enter the Netherlands, because this vehicle combination does not comply with different set of rules present in the Netherlands. It is preferable to have performance based demands and not technical solution based demands where it is possible.

# 4. Simulation models

The vehicle models used to simulate turning maneuvers are models developed by Volvo Trucks. The models are implemented on MATLAB, Simulink, and Simscape software. VTM models are semi-detailed average fidelity models that are 2-track model used for various simulations and controller development. The models are 3 dimensional with each subsystem modeled with a good correlation with physical testing. The model also has a speed controller and driver model to be able to mimic the driver.

The input to simulate low speed swept path is vehicle velocity, distance and curvature defining the path, loading height, and payload along with vehicle parameters. The vehicles were chosen to represent the distribution of vehicle combinations used across the European Union. The vehicles chosen can be divided into 3 categories.

**Table 2: Category I – vehicle combinations length > 25.25 m and upto 34.5 m**

| | | |
|---|---|---|
| ✚ | AB-double (2 x 20 ft, 1 x 40 ft container) |  |
| ▼ | AB-double (2 x 7.82 m, 1x13.6 m box) |  |
| ✖ | A-double (2 x 13.6 m box) |  |
| ★ | B-double (2 x 40 ft containers) |  |
| ◆ | C-double (3 x 7.82 m box) |  |

**Table 3: Category II – vehicle combinations length > 18.35 m and upto 25.25 m**

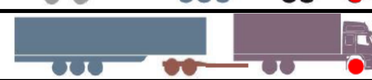
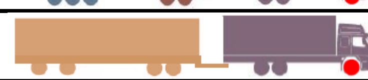
| | | |
|---|---|---|
| ✚ | B-double (2 x 20 ft, 1 x 40 ft containers) |  |
| ▼ | C-double (3 x 20 ft containers) |  |
| ✖ | Truck with semitrailer and center-axle trailer |  |
| ★ | Truck with dolly and semitrailer |  |
| ◆ | Truck with full trailer |  |

**Table 4: Category III – vehicle combinations length between 18.35 m and 16.5 m**

| | | |
|---|---|---|
| ✚ | Truck and full trailer |  |
| ▼ | Tractor semitrailer |  |

In the above vehicle combinations, only red wheels indicate steered axle. The vehicle combinations mentioned above were simulated for different low speed maneuvers. The outer radius of turning was varied from 12.5 m, 15 m, 20 m, 30 m, 50 m, and 100 m. While the vehicle performs 3 different maneuvers namely, 90° turn, 120° turn, and 180° turn with the various radii. The next section discusses the results obtained from these simulations.

## 5. Results

The following sub-sections explains the results obtained from the simulations performed. It also provides brief understanding of the road infrastructure around the city of Gothenburg, represented through various intersections. The results can be broadly classified into speed in intersections and the infrastructure or geometry of intersections. The aim is to clarify the need for generous infrastructure for implementation of longer combinations. As seen in Figure 2, a maximum speed of 30 km/h and 70 km/h can be achieved at outer turn radii of 20 m and 110 m respectively. These values are upper limit of the vehicle speed. The value in each box is the speed at which the round-about or turn can be performed. Beyond these speeds for turn radius, the lateral acceleration value crosses the allowed threshold of 3.5 m/s$^2$ and vehicle is regarded as unsafe. This threshold is as specified for vehicle combinations over 64 tons by Swedish road authorities.

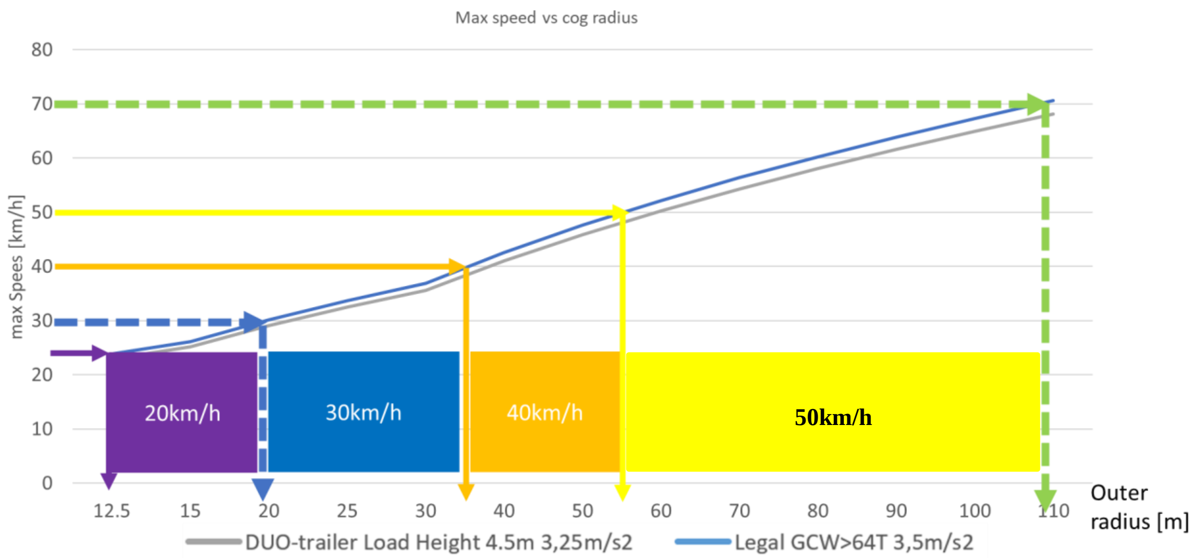



Figure 2: Maximum Speed in curves at a lateral acceleration limit of 3.5 m/s$^2$

## 5.1 Simulation of 90° turn

All 12 vehicle combinations were simulated using the VTM model with even loading. The outer radius of turning was varied from 12.5 m, 15 m, 20 m, 30 m, 50 m, and 100 m. The minimum inner radius while turning and the outboard off tracking of every unit was considered critical. The results obtained for different radii and vehicle combinations are shown in Figure 3. The minimum inner radius achieved among all the vehicle combinations was 3.9 m for a 12.5 m outer radius turn and 96.6 m for a 100 m outer radius turn.

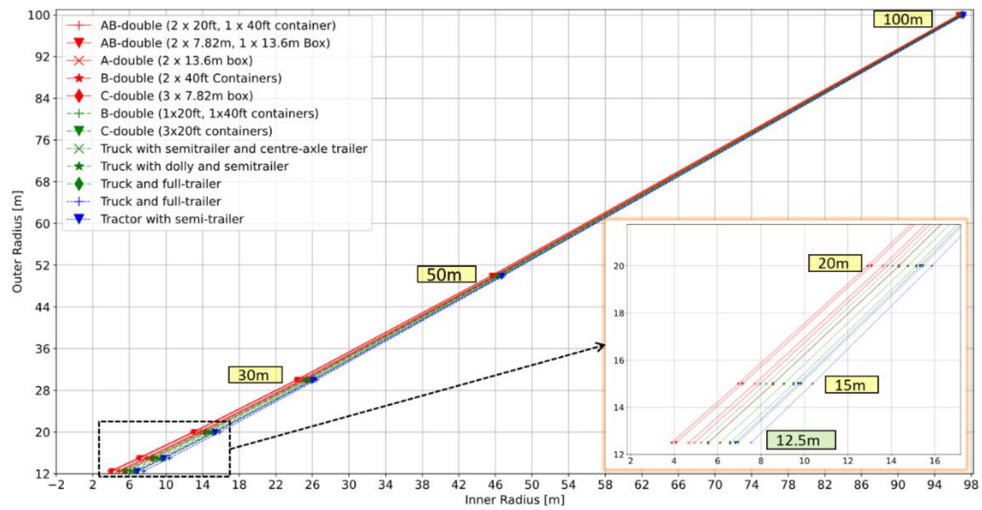



Figure 3 Simulation results for low speed swept width (90° turn)

Another way to visualize these results is as swept width. In Figure 4, the outer radius is plotted on the Y-axis and the corresponding maximum swept width is plotted along the X-axis. All the truck combinations can make the 90° turn within 3.5 m swept width for an outer radius of 100 m. For a 12.5 m outer radius turn however, swept width required goes up to 8.6 m.

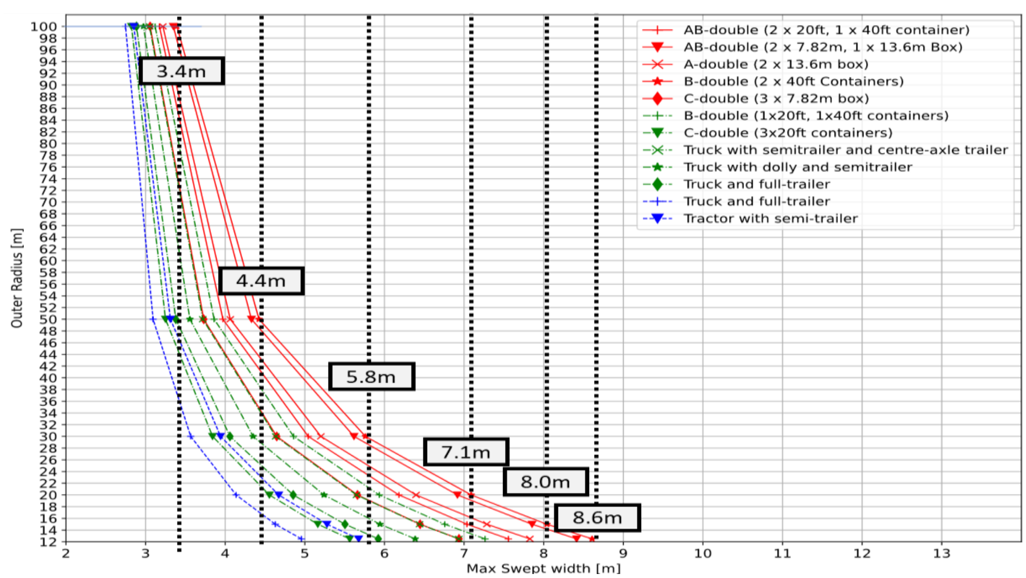



Figure 4 Simulation results for low speed swept width (90° turn)

## 5.2 Simulation of 120° turn

Figure 5, shows the results for a 120° turn in the form of swept width. The current Finnish legislation [5] states that the combination must be able to carry out a 120° turn at an outer radius of 12.5 m while keeping within a swept width of 8.8 m (which is equivalent to observing an inner radius of at least 3.7 m). An outer off-tracking of 0.5 m is allowed in this case. These standards are permitted to be achieved by the lifting and steering of axles while at the same time fulfilling lateral stability requirements at high speeds defined in the same regulation.

As seen in this paper, three of the combinations – A-double (consisting of 2 x 13.6 m boxes), AB-double (consisting of 2 x 7.82 m & 1 x 13.6 m boxes), B-double (consisting of 2 x 40 ft containers) – fail to achieve these criteria. But with the regulations provided in Finland for axle management, all combinations can fulfill these demands.

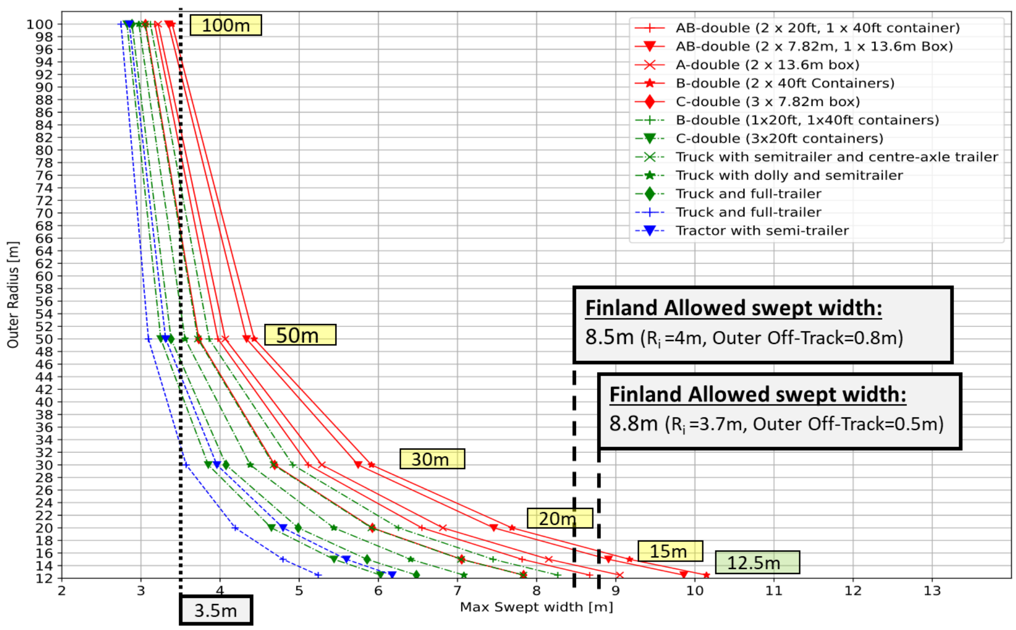



**Figure 5 Simulation results for low speed swept width (120° turn)**

## 5.3 Simulation of 180° turn

Sweden and Norway have similar regulations for vehicle combinations under EMS. Here, the vehicle combination must be able to traverse a 180° turn of outer radius of 12.5 m while observing an inner radius of at least 2 m. The results of the simulations are shown in Figure 6.

The AB-double (consisting of 2 x 20 ft & 1 x 40 ft containers) and the C-double (consisting of 3 x 7.82 m boxes) fit within these regulations as do all the shorter combinations. In Norway, there is also a special road network with 13 m outer radius for B-doubles, needed for box trailers.

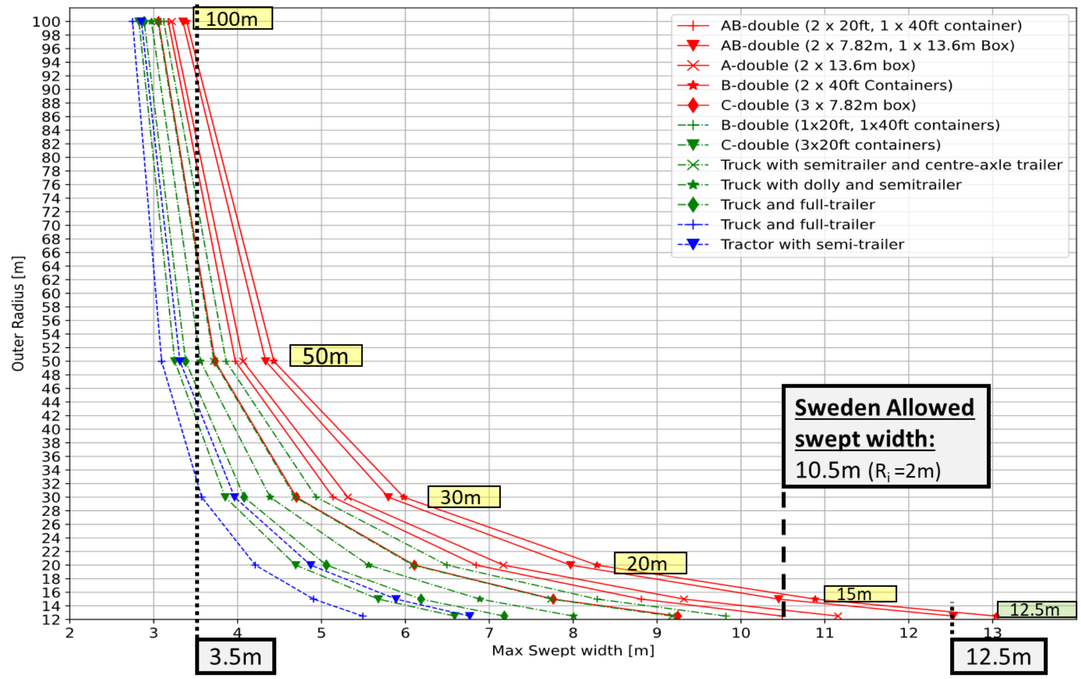



**Figure 6 Simulation results for low speed swept width (180° turn)**

## 5.4 Comparison of current infrastructure in Sweden

**Table 5 Examples of Infrastructure in Sweden and their specifications**

| | Name | Type | Parameters | Outer Radius (m) | Max Speed (km/h)* | Available width (m) |
|---|---|---|---|---|---|---|
| 1 | Intersection between E6 & E45(Älvsborgs bridge) | A: Large Circle | 270° turn left R100 m | 100 | 60-65 | 3.5 |
| 2 | R155 Ytterhamns intersection(Ytterhamnsmotet) | B: Large roundabout | 90° turn left R55 m | 55 | 40-47 | 4 (8 for 2 lanes) |
| | | | 90° turn right R40 m | 40 | 35-42 | 4 (8 for 2 lanes) |
| 3 | Crossing Arendalsvägen - Ytterhamnvägen(Arendal) | C: Medium Roundabout | 90° turn right R30 m | 30 | 35 | 4.3 (7.6 with inner section, 9 for 2 lanes) |
| | | | 90° turn left R26 m | 26 | 30-35 | 4.3 (7.6 with inner section, 9 for 2 lanes) |
| 4 | E45 Bohus intersection(Bohus) | D: Medium Roundabout | 90° turn left R30 m | 30 | 30-35 | 5.2 (max 9.5) |
| | | | 90° turn right R15 m | 15 | 20-25 | 6.4 (max 7.5) |
| 5 | Local road Lerum | E: Small Roundabout | 90° turn left R12.5 m | 12.5 | 20-24 | 6.7 (12.5 with inner section) |
| 6 | E6 Bäckebol intersection | F: Drop-form intersection | 90° turn left R18 m | 18 | 27 | 4.3 (7.0 with inner section, 9 with inner and outer) |
| 7 | Local road Gothenburg | G: Common Swedish roundabout | 90° turn left R18 m | 18 | 25 | 5.5 (10.5 with inner section) |

**Maximum speed within 3.5 $m/s^2$ lateral acceleration*

Table 5, gives an idea of the current types of infrastructure present currently in Sweden (corresponding images shown in Figure 7, Figure 8, and Figure 9). We can also observe some of the associated specifications of these intersections such as their outer radius, available width along with the maximum speed that is possible at each of them.

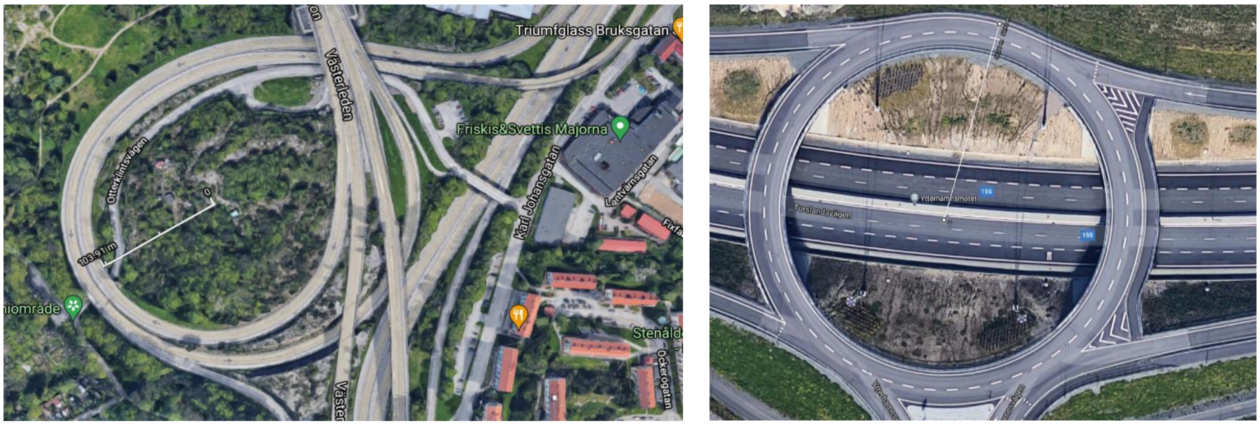



Figure 7 (From Left) Intersection Type A & B as mentioned in table 5


Figure 8 (From left) Intersection Type C & D as mentioned in table 5

Figure 9 (From left) Intersection Type E, F & G, as mentioned in table 5

## 6. Discussion, Recommendation and Conclusions

From the simulations we can see that all but 3 combinations can pass the Swedish and Norwegian legislations without lifted or steered trailer axles. The combinations that do pass are:

- AB-double (consisting of 2 x 20 ft & 1 x 40 ft containers)
- C- double (CAT consisting of 3 x 7.82 m boxes)

The same combinations pass the Finnish legislation of carrying out a 120° turn of 12.5 m outer radius and staying above a 3.7 m inner radius with a maximum outer off-tracking of 0.5 m. Both these regulations could be used together as a base for future cross boarder regulations.

The Finnish regulations are harder to pass. However, the Finnish legislation allows lifting to higher axle-weight, so that the axle weight for a triple axle-group could land on 2 axles (up to 12 ton per axle) at speeds up to 30 km/h. Steering of axles up to 40 km/h is allowed in all European countries. Figure10, one can observe that speeds of 30 km/h are suitable up to an outer radius of 35 m and 40 km/h for up to 55 m.

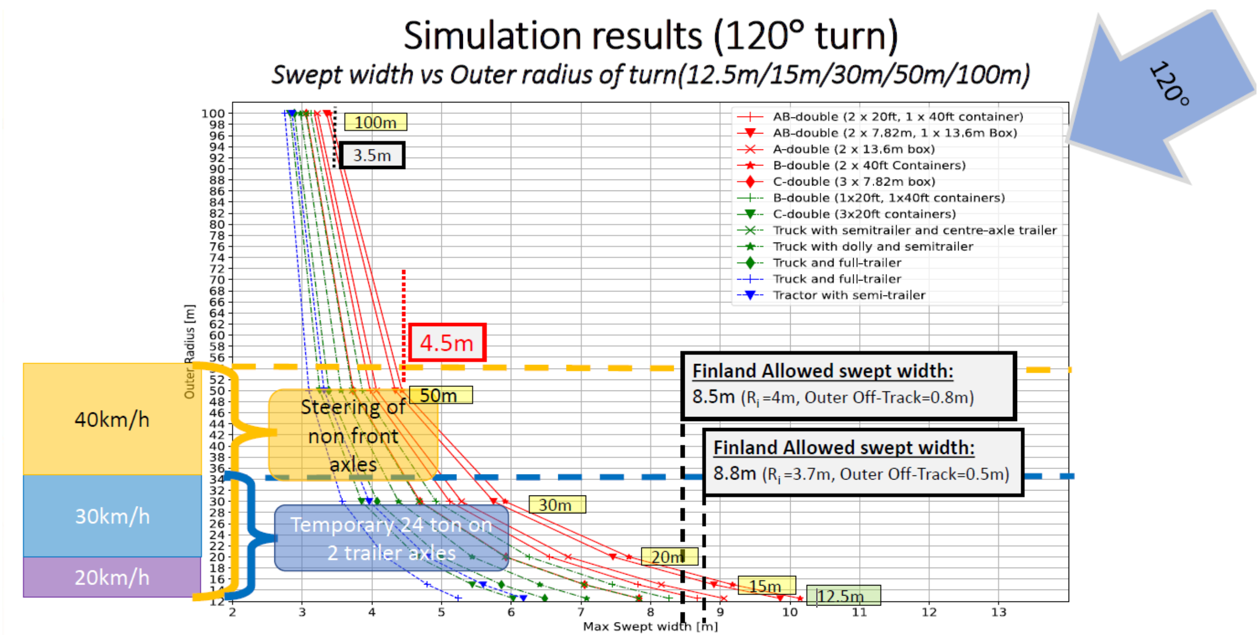



**Figure 10 Simulation results overlapped with speed**

The speeds allowed with lifted and steered axles are incorporated into the swept width diagram, for a 120° turn. Up to 30 km/h, the swept width can be reduced with lifting and steering. Large intersections also provide better traffic flow and hence lower emissions. At an outer radius of 55 meters, the lane width needs to be 4.5 m, this is approximately the same for a 120° and a 180° turn. Bike and pedestrian crossings should be retracted from crossings to make it safer.

The national rules for each country differ making the cross-border transportation challenging for High Capacity Transports vehicle combinations. In the EU, there is a common set of rules for vehicle combinations up to 18.75 m and 44 tons. A fast and firm effort is needed to enable a common view on a framework for future HCT legislation. Finland has already set up a national legislation allowing vehicle combinations up to 34.5 m and 76 tons. The Finnish demands are a good baseline to begin. To set up a standardized set of demands for Nordic countries for vehicle combinations upto 25.25 m will be first step in right direction.

To make more efficient road transports in the future, a deeper understanding of national legislation is needed. Neighboring countries must consider each other's regulations. But this is not enough; worldwide conventions must be set up to make road transport more efficient. Efficient means lower environmental impact, less costly and safer.

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