Title: Development of a snow plow truck simulator that contributes to efficient and early skills acquisition for snow plow truck operators

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0 ABSTRACT

Central Nippon Expressway Company Limited has signed a joint development agreement with Central Nippon Highway Maintenance Nagoya Limited and FORUM8 to develop a snow plow operation training simulator for the purpose of early training of snow plow operators engaged in snow and ice operations on expressways. The following sections introduce the functions, features, etc. related to this simulator development.

1 INTRODUCTION

In order to prepare for the aging of snow plow truck operators, who are indispensable for snow and ice operations on expressways, and for the shortage of workers due to the decrease in the working population, it is necessary to train new operators as soon as possible. Until now, snow plow truck operators have been trained over a long period of time (5 to 10 years) by having them ride along with snow plows and passing on their skills from the skilled to the inexperienced. However, with the conventional training method, there are many training opportunities and time constraints to acquire the skills, such as the fact that the opportunity to operate the actual snow plow truck is limited only during the snowfall season, and the number of dispatches for snow removal work is small in areas with light snowfall.

For snow removal work on expressways, two or three snow plow trucks form a formation and operate the snow plow mounted on the front of the snow plow truck to remove snow from the roadway at once. The snow and ice operation requires advanced driving skills and

vehicle coordination to keep as much snow as possible on the expressway at a working speed of about 40km/h.
In response to this situation, while developing technology to automate the operation of snow plow mounting equipment to save operator labor and reduce the number of passengers, Central Nippon Expressway Company Limited, Central Nippon Highway Maintenance Nagoya Company Limited and FORUM8 Company Limited have signed a joint development agreement to jointly develop a simulator that enables driving training under conditions similar to those of an actual snow plow truck.

2 SIMULATOR DEVELOPMENT

2-1 Requirements for development
The following (1) to (2) were positioned as prerequisites for the development of the simulator.
(1) Development of a simulator that faithfully reproduces the operation lever and operation button of the mounting device in the cabin of a snow plow truck
(2) Development of a simulator that enables three people to simultaneously train in the operation of a snow plow truck by linking up to three simulators that simulate actual mainline snow removal.
As mentioned earlier, snow and ice removal work requires the operation of mounted equipment at a working speed of about 40 km/h, and the operation techniques must be mastered, so we decided to faithfully reproduce the operation lever and buttons on the operation panel for the mounted equipment. In addition, since the speed and positional relationship of the snow plow trucks are important for safe and reliable snow removal work, a system for training in cooperation with three snow plow trucks was required.

2-2 Overall structure for development
The overall configuration of the simulator is shown in Table 1.
The simulator consists of three elements: hardware, software, and VR contents. This simulator will enable simulated driving under conditions similar to actual snow removal operations, assuming an expressway.

Table 1 - Overall configuration of the simulator

Components	Placement
Hardware	Simulate driving using parts that are equivalent to those of an actual car.
Software	Reproduce driving by hardware in VR space. Feedback of events that occur in the VR space to the hardware.
VR Contents	3DCG data that models roads, buildings, snow, etc. to represent the real world in VR space.

2-2-1 Hardware

(1) Snow plow trucks for simulated driving

Figure 1 and Figure 2 show the snow plow trucks to be simulated in this development. It consists of a heavy truck equipped with a snow plow and a truck grader, and two types of snow plow trucks: a truck with one-way snow plow and a truck with folding snow plow.

A snow plow is mounted on a heavy truck to remove fresh snow from expressways and freeways, while a truck grader is mounted on a heavy truck to remove pressurized snow and prepare the road surface for snow removal.

Among snow plows, one-way plows are often used in areas with heavy snowfall.

Figure 1 - Truck with one-way snow plow

Figure 2 - Truck with folding snow plow

(2) Hardware configuration

Table 2 shows the hardware configuration for this development. order to meet the requirements of the development shown in the previous section 2-1, the simulator has a total of three driver's seats that simulate actual snow plow trucks. The snow plow trucks to be simulated are shown in Figure 1 or Figure 2. The devices used in each simulator are different in order to simulate the operation of an actual snow plow truck.

Drawings of the hardware we created are shown in Figure 3 and Figure 4. The driver's seat is made to resemble that of an actual snow plow truck, and the seat, steering wheel, shift lever, control panel, and other parts are equivalent to those used in an actual snow plow truck. The position of the steering wheel, control panel, etc. was determined based on the measurements of the actual snow plow truck.

Two types of operation panels will be manufactured: one for snow plow operation only, and another for snow plow and track grader operation.

In addition to the driver's seat, each simulator is equipped with three monitors, one of which

displays VR space images using VR goggles.

Table 2 - Hardware configuration

Simulator No.	Snow plow	Truck grader	Motion sheet	VR goggles
1	folding snow plow	nil	equipped	nil
2	folding snow plow	nil	nil	equipped
3	one-way snow plow	equipped	nil	nil

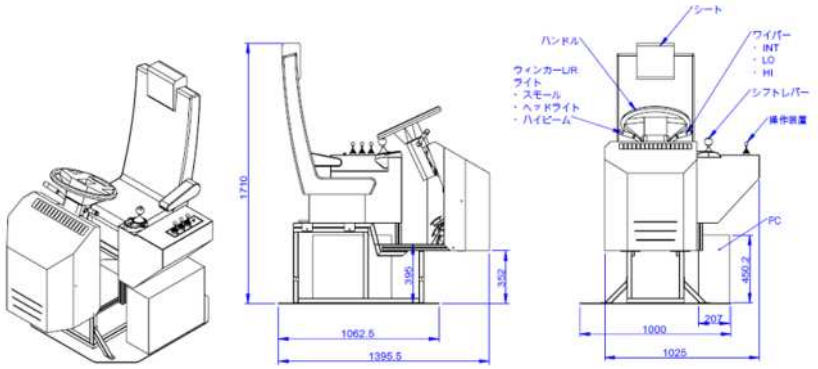

Figure 3 - Driver's seat drawing (without motion seat)

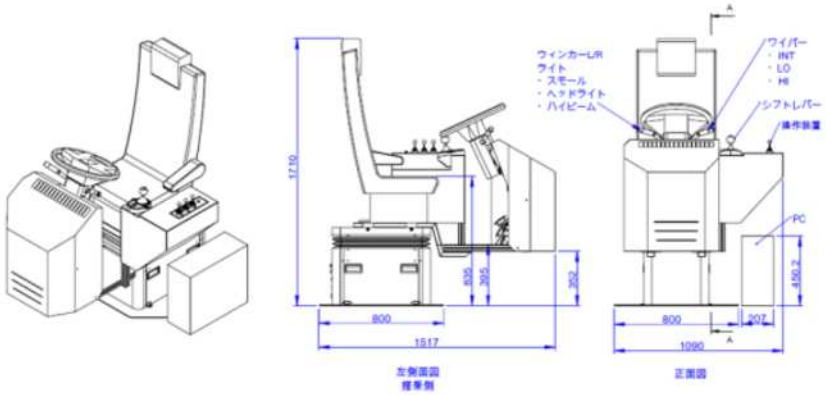

Figure 4 - Driver's seat drawing (with motion seat)

2-2-2 Software

(1) Basic functions of the software

The software shall be UC-win/Road Ver.14.1, which is a 3D real-time virtual reality software developed by FORUM8, and UC-win/Road has the following basic functions.

(a) Create a large-scale 3D terrain based on actual measured topographical data, and generate roads on the terrain. In addition, it functions as a platform for VR space that can import BIM/CIM design result data into VR space and create VR contents.

(b) Functions that can be linked to a variety of devices and hardware through multiple communication methods

(c) Functions that can reproduce real-world physical phenomena in VR space, such as correspondence to specific seasons and dates, representation of weather, and 4D

simulations that take into account changes in time.
(d) A function that allows multi-users to simulate driving in the same VR space by using various vehicles and roads.
In addition, functions that allow simulation in the fields of disaster prevention and mitigation and construction planning.
(e) After the simulation, the user can evaluate the driving speed and validity of the driving trajectory, and check the past driving by replaying. The driving diagnosis functions include: whether the snow plow truck is positioned appropriately according to the line, whether the snow plow is operated appropriately in plowed and non-plowed areas, whether the speed limit is observed, and whether there is no sudden acceleration, sudden deceleration, or sudden steering.
(2) Extension to snow plow truck operation
Based on the basic functions described in the previous section, the following customizations will be made to UC-win/Road in order to reproduce the simulated operating environment of a snow plow truck required in this development.
(i) Hardware coordination
This is an extension of the functions related to the previous section (b), and in this development, the various hardware described in 2-2-1 above are linked. Specifically, the following enhancements will be made.
① Reflects each operation by the driver's seat and control panel to the vehicle behavior running in the VR space.
② The three axes of the motion seat (Roll, Pitch, and Heave) move according to the simulated driving in the VR space, allowing the user to experience the acceleration and deceleration of driving.
(ii) Snow accumulation and snow removal expression
This is an extension of the function described in the previous section (c); although there is a function to create snowfall in the entire VR space, the following extensions will be made to the representation of snow accumulation and snow removal on the road surface.
① Expression of snow accumulation
The expression of snow cover is shown in Table 3. The snow cover is classified into three categories: 2 cm, 5 cm, and 15 cm. The snow accumulation of 15 cm is assumed to be the case when snow cannot be removed due to road closures, etc. In addition, the color of each type of snow accumulation will be changed, and there will be two types: fresh snow and pressurized snow. Snow accumulation is indicated in a lumped manner for the entire road and is represented by a mesh model.

Table 3 - Snow cover conditions

Parameter name	Meaning
Amount of snowfall	2cm / 5cm / 15cm
Color (fresh snow condition)	Color of fresh snow condition

Color (pressurized snow condition)	Color of pressurized snow condition
Color (snow removal condition)	Color of plowed snow
Color (snow condition)	Color of the moved snow

② Snow removal expression

In this development, the mesh model of snow accumulation shall be changed depending on the speed of the snow plow truck and the snow plow position and angle.

The method used to represent snow removal is shown in Figure 5. The cutting edge of the snow plow (the point of contact with the snow) is defined as a line segment with a certain length at a certain position and angle relative to the vehicle.

The area of contact between the plow and the snowpack is identified by calculating the distance between the line segment, which is subdivided by dividing the line segment by the interference determination interval, and the mesh vertex position.

In addition, the amount of snow to be removed is calculated by comparing the height from the road surface of the vertices in the area of contact with the height from the road surface of the plow.

Snow removal is expressed by moving the snow-covered area calculated from the above forward from the area where it is in contact.

The snow removal expression by the track grader is the same as above, and a snow-free road surface texture is drawn on the road surface where snow removal has been completed.

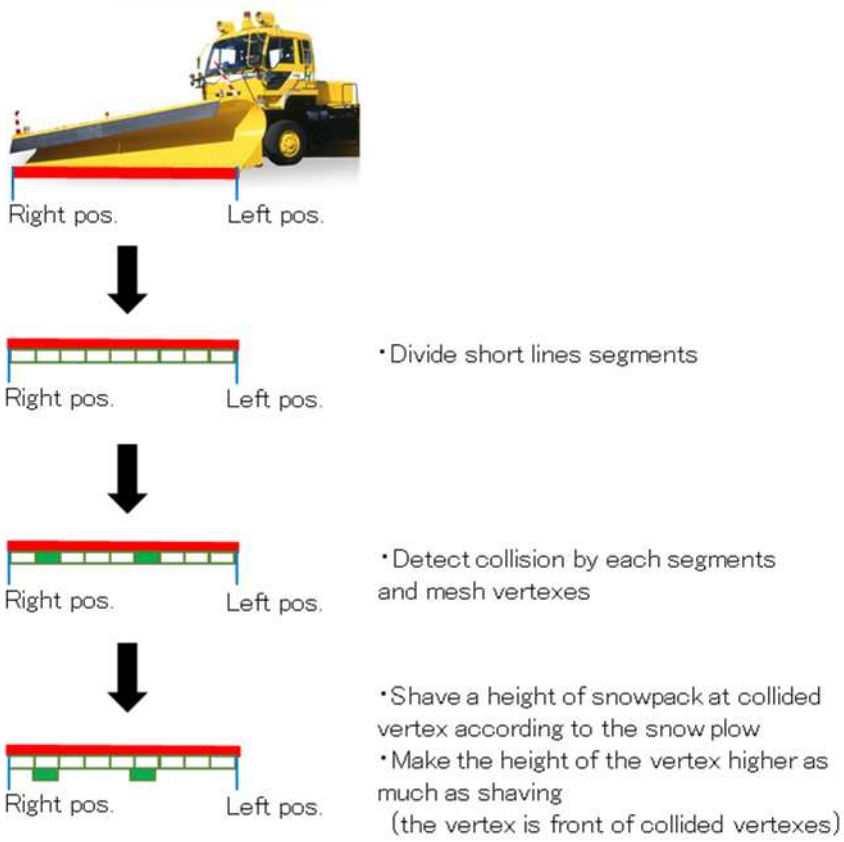

Figure 5 - Method of snow removal expression

(iii) Automatic snow plow convoy

This is an extension of the function related to the previous section (d), and is being developed to reproduce snow removal from ladders in automatic operation.

Snow plow convoy is a method in which two or three snow plow trucks form a group and remove snow from the passing lane, the cruising lane, and the shoulder of the road in that order, as shown in Figure 6, and the positioning of the snow plow trucks is important.

In order to increase training opportunities, the snow removal training for convoy, which is originally conducted by two or three operators, can be conducted by a single operator. The snow plow truck, which is not operated by an operator, is controlled by an automatic operation function that runs along a predetermined model trajectory, as shown in Figure 7.

A snow plow truck traveling with the automatic operation function can automatically adjust its traveling speed to avoid collisions with the preceding or following snow plow truck.

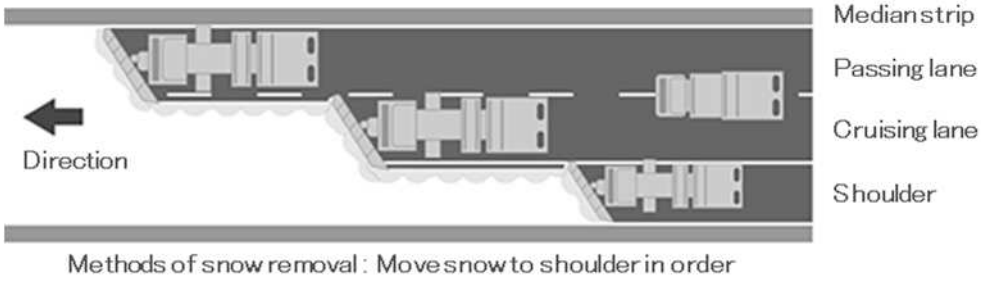

Figure 6 - The snow plow convoy

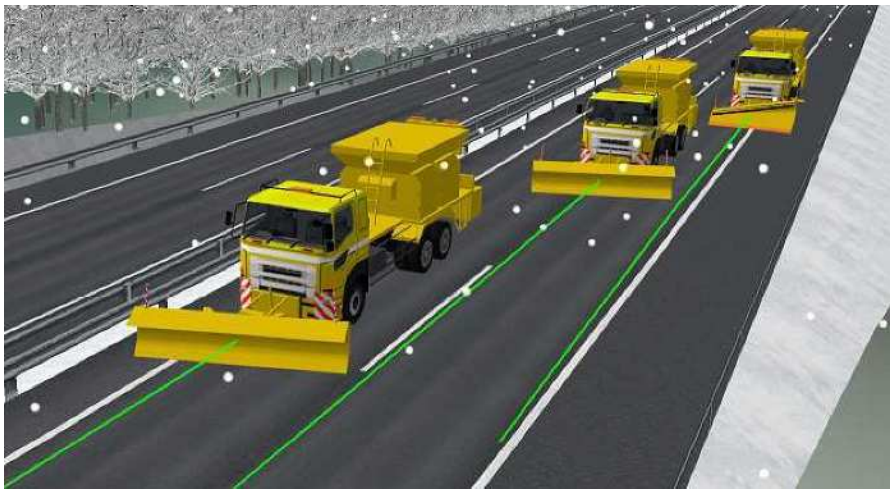

Figure 7 - Model running trajectory

(iv) Simultaneous operation diagnosis and replay of three snow plow trucks

This is an extension of the function related to the previous section (e), which enables us to perform driving diagnosis and replay for three vehicles at the same time, which was previously applied to only one driving vehicle. In order to run the three snow plow trucks in the same VR space, we use the UC-win/Road cluster system, which consists of one PC for management and three PCs for driving simulation.

2-2-3 VR contents

Using the functions described in the previous section (a), the snow plow truck and the surrounding environment necessary for this development are constructed in the VR space. As shown in Figure 8, the area to be created is a 25 km section of the Meishin Expressway from the Hikone Interchange in Shiga Prefecture to the Sekigahara Interchange in Gifu Prefecture.

The scope of preparation was set to this section because of the following ① to ③.

- To make the training time about 1 hour, the route should be about 50 km round trip.
- The route must be a heavy traffic route and a section where many snow plow trucks are deployed.
- The section must have an IC, JCT, TN, or rest facility where snow plow trucks can be trained to divide and merge at the facility.

The road model will be created based on the creation of the planar alignment based on the IP method and the design of the longitudinal and transverse sections. The data from the Geospatial Information Authority of Japan was used to create the planar alignment, and for the longitudinal and cross-sectional sections, the slope data of the actual expressway was provided by the Central Japan Expressway Company, Ltd. and reflected in the VR contents. In addition to modeling the snow plow trucks, we will also create models of trees, buildings, and snow along the route. The models were created based on the images taken when the vehicles were equipped with cameras and drove along the section (Figure 9).

Snow throwing and snow removal prohibition signs were reproduced on the shoulder of the expressway. The snow throwing/excavation prohibition section is a sign that indicates whether snow throwing/excavation is allowed or not so that snow throwing/excavation is not carried out on the general road that intersects the expressway.

In addition, we have created a scenario that allows us to set up a vehicle stopped on the expressway and train to avoid that vehicle.

In addition, content was created to simulate actual driving, such as weather expressions.

Figure 8 - VR content creation section

Figure 9 - Actual snow plow truck image

3 DEVELOPMENT STATUS

3-1 Hardware

The developed hardware is shown in Figure 10 and Figure 11, and it can be confirmed that all three units are equipped with a driver's seat and a three-screen monitor that mimic those of an actual snow plow truck. In addition, each device is installed as shown in Table 2.

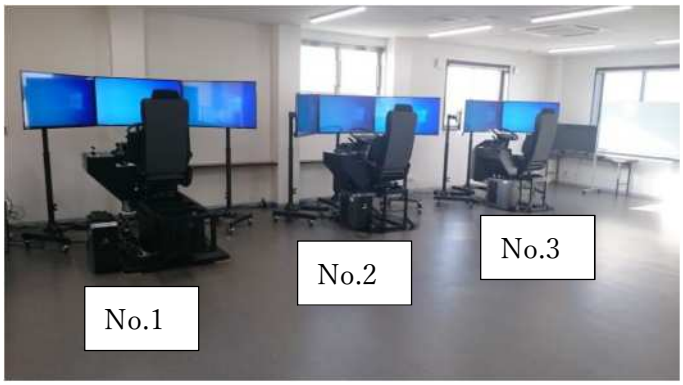

Figure 10 - Three hardware units installed (No. is the number in Table 2)

Figure 11 - Driver's seat

3-2 Software and VR content

The results of creating VR contents in UC-win/Road and simulating driving are shown. First, Figure 12 shows the snow plow truck operated from the driver's seat perspective. Various operations such as gas pedal, brake, steering wheel, snow plow, track grader, etc. were performed from the hardware and reflected as input signals in the behavior of the vehicle model in UC-win/Road. The engine speed and output data by depressing the accelerator pedal were set by referring to the engine speed and output of an actual snow plow truck. In addition, acceleration in response to depressing the accelerator pedal was reproduced using a motion sheet so that the snow plow truck operator could feel the acceleration of the actual snow plow truck.

Figure 12 - VR space in the driver's seat

Secondly, the snow removal work in the VR space is shown in Figure 13 and Figure 14. The snow on the road surface is represented, and it can be confirmed that the truck models of the target trucks, i.e., a truck with one-way snow plow and a truck with folding snow plow, are engaged in snow removal work, thus representing snow accumulation and snow removal. The resistance transmitted from the steering wheel during snow removal by the snow plow, etc., was also calculated based on the weight of snow, and adjusted to 1.0 g/cm^3 to make it close to the feeling felt when driving a snow plow truck.

Figure 13 - Snow removal by a truck with one-way snow plow in VR

Figure 14 - Snow removal by a truck with folding snow plow in VR

Thirdly, Figure 15 shows three snow plow convoy removing snow. Snow removal was performed by the operator alone plus automatic operation, and by three vehicles running simultaneously. After the simulation, as shown in Figure 16 and Figure 17, operation diagnosis and replay can be performed for all three vehicles simultaneously.

Figure 15 - Snow plow convoy in VR

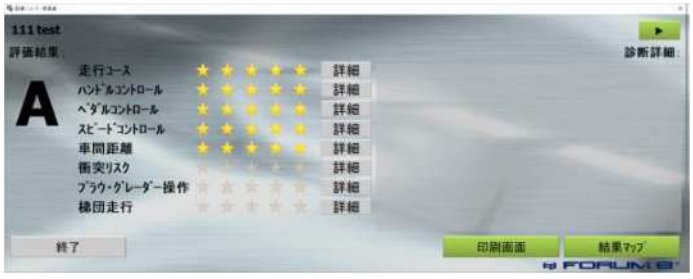

Figure 16 - Driving test results

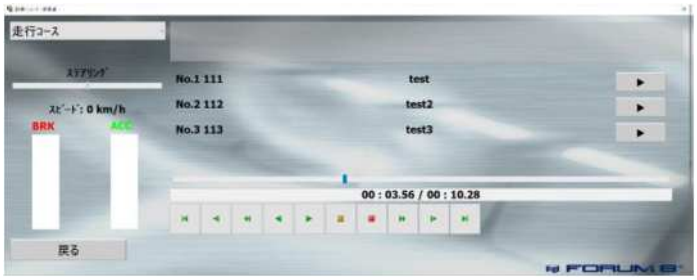

Figure 17 - Replay (Click "▸" in the figure to switch to the driving image of each simulated snow plow truck)

Finally, a partial view of the VR space is shown in Figure 18 and Figure 19. The Hikone IC and Sekigahara IC roads, as well as the mountains, trees, and buildings along the roads are represented. In addition, as shown in Figure 20, tunnels that are equivalent to the ones in the real world are represented according to the topography, and we were able to create VR contents for simulating actual driving.

Figure 18 - VR space near the Hikone IC

Figure 19 - VR space near the Sekigahara IC

Figure 20 - Roads in the Hikone IC - Sekigahara IC section

4 SUMMARY

The main features of the simulator developed in this study are as follows.

(1) Faithfully reproduce in VR the actual expressway road alignment, longitudinal and cross slopes, and road structures such as bridges, tunnels, and toll booths.

(2) Training can be conducted in conjunction with up to three simulators.

(3) Ability to feel the vibration in the driver's seat during snow removal

(4) Even when training alone, it is possible to train in cooperation with two other snow plow trucks using the automatic operation function.

(5) A replay function is provided to store snow plow operation information and travel track

information to reproduce snow removal operations and conditions after training.
(6)The training results were evaluated in 5 levels for each evaluation item.
The effects of the development of this simulator are expected to be early improvement of driving skills through training in coordination of snow plow trucks, skill training in bad weather conditions, training regardless of season or time of day, and visualization of evaluations. In particular, the representation of snow removal and accumulation, and the ability to drive automatically when driving a ladder group are features that are rare in other simulators, and are considered to be unique to this development.
We also had the participants actually train on the developed simulator, and conducted questionnaires on the evaluation of the reproducibility of the driver's seat, the representation of snow plow truck movements in the VR images, the settings of the three snow plow convoy training mode and automatic operation mode, training scenarios and training evaluation items. In the future, we will implement functional improvements based on the opinions obtained from this survey.