Design and Simulation of Safe Truck-Cargo Matching System for Rollover Prevention

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Abstract— Commercial vehicles have a higher center of gravity than passenger vehicles, so the rollover rate is higher. In particular, overloading has the effect of further raising the center of gravity, causing rollover even at small lateral acceleration. In this study, we propose a system that identifies and recommends trucks that can safely drive on curved roads by finding factors that cause vehicle rollover through cargo information and driving conditions. It is expected that drivers will be able to transport more safely by preventing overloading, and users will be able to reduce transportation costs by reducing the occurrence of errors in vehicle selection.

Keywords— Overload, Center of gravity, Rollover, Truck recommendation.

I. INTRODUCTION

ACCORDING to traffic accident statistics, [1], in 2021, the total number of truck accidents is 22.8% compared to the total number of passenger car accidents, and the number of deaths in truck accidents is 51% of the passenger car accidents. The number of overturning accidents of cargo trucks was 37.4% compared to the passengers car accident, which was 14.6%p higher than the total accident rate, and the death rate of cargo truck overturning was 121.4% of passenger car overturning accidents. As one of the causes of the accident, commercial vehicles have a higher center of gravity than passenger cars, so the accident rate of overturning is very high. In particular, when luggage is loaded, the vehicle mass increases and excessive lateral acceleration occurs during driving, making the vehicle easily overturned. Therefore, it is crucial to load cargo suitable for the performance of each vehicle. As an example of these efforts, the Ministry of Land, Infrastructure, and Transport, [2], posted “Traffic Safety Republic of Korea! Let's start, the model truck system” shows that the number of fatal traffic accidents due to cargo overload, which had a very high index, decreased after the 2020 intensive crackdown.

There are many considerations when deciding on a vehicle to dispatch, but in some cases, it is determined only by weight or size. At this time, there is no problem if the condition is sufficiently relaxed, but in a situation where the performance limit of the vehicle is required, the probability of an accident occurring even with small external factors increases. In some sites, overloading is intentionally forced due to cost problems, but vehicles are incorrectly selected due to poor calculation by practitioners. Therefore, there is a need to consider a method of reducing transportation costs while determining a vehicle capable of stable driving.

This study proposes a system to recommend a vehicle that can drive stably and reduce transportation costs by entering the size and weight of the cargo to be loaded and evaluating the possibility of overturning through the center of gravity of the loaded situation. The lateral force acting when driving on a curved road was calculated by referring to the driving conditions of the actual road, and it was possible to determine whether it was possible to drive through the rollover index.

The rest of this paper consists of the following. Section 2 will present various methods for generating cargo loading models and evaluating the possibility of overturning. Section 3 describes the structure and operating sequence of the proposed system. The element description, calculation formula, and simulation results for vehicle identification will be discussed in Section 4. Finally, Section 5 summarizes the areas to be improved.

II. RELATED WORK

A. Load Methodology

Shin Jung-ho, [3], tried to minimize the number of containers used by obtaining the loading position of boxes that can be loaded in a minimum container and suggested a method of generating multiple container loading patterns using a complex genetic algorithm. Loading multiple containers reduces the number of containers used in the terminal. Previously, container loading according to the number of boxes was done manually, but if the loading algorithm is supplemented, it will be possible to determine the loading position of the boxes more efficiently.

Kwon Yo-han, [4], conducted a study on the loading algorithm of lightweight and small cargoes of various sizes. Overall, the latest packaging automation system process was presented and analyzed amid the development of logistics automation equipment, and based on this, research was conducted on how to load cargoes of various sizes to be loaded in packaging boxes. Cargo loading efficiency in the packaging box can be increased by generating a loading pattern considering the diversity of cargo types handled at the logistics site, the diversity of cargo sizes, and the diversity of cargo types

Ryu Min-Ji, [5], conducted a study on a packing algorithm for packaging combined orders containing various cargoes. In particular, combined orders contain many problems that increase the complexity of the logistics center, and the packaging problem of combined orders can be seen as one. Among the modified tower construction method and the modified block combination method presented in the study, the superiority of the modified block combination method was confirmed, and the possibility of use in the actual logistics site was confirmed.

B. Rollover Prevention

The main factors affecting vehicle rollover were the center of gravity height, the horizontal distance from the center of gravity, and the vertical drag of tires, and the National highway traffic safety administration accepted GM's opinion and established safety evaluation criteria using a static safety factor (SSF) model, [6].

$$SSF = \frac{T}{2h} \tag{1}$$

T: Wheel distance
h: Center of gravity height

Jimmy, [7], shows in the simulation that the SSF does not accurately or conservatively predict the take-off threshold and that the rollover can be achieved with a lateral acceleration lower than that of the SSF. It is also shown that suspension dynamics do not play a significant role in rollover propensity after takeoff.

J. Park, [8], divided and examined the risk section of subversion through the change in lateral acceleration for each factor. The entry speed and lateral acceleration were linearly proportional, and the size of the dangerous section was a curved radius of 50m

In this case, there was no significant difference from the road design speed of 40km/h, but there were relatively many differences in the curved radius of 75m and 100m.

Ali Abdi Kordani, [9], studied the effect of shoulder width, shoulder tilt, and shoulder surface material on improving safety according to driver behavior and road shape through vehicle dynamics simulation. The results showed that the shoulder type (width, material, and transverse slope) affects safety in consideration of the roll angle of the vehicle. Some other relevant studies can be found in [10], [11] and [12].

III. Safe Truck-Cargo Matching System

A. System Structure

Some working-level officials have difficulty selecting vehicles. Accurate dispatch is further required because transportation costs should be reduced while selecting a means to transport goods safely. In the case of Junior, there is a greater possibility of misallocation due to lack of experience, so quantitative calculation based on data is more effective.

This study proposes the Safe Truck-Cargo Matching System with the aim of creating a safe driving environment for vehicles and distributing them reasonably.

Fig. 1 [1] is a schematic representation of the following.

Fig. 1: Truck-cargo matching system

Pack in units of palettes or loading spots based on information such as size and weight of each cargo and generate a loading model according to the size of the loading box of each vehicle. At this time, under the current Domestic Road Traffic Act, the loading weight of a truck is limited to 110% of the loading weight according to its structure and performance, and a loading model is created for the vehicle's loading box standard. Therefore, based on the total weight and size of the loading model at this stage, only the possibility of loading is determined except for the driving stability.

Based on the generated loading model, the center of gravity of the loaded vehicle is calculated to evaluate safety and determine whether it is possible to operate. Various indices can be used to evaluate driving stability, and in this study, it is determined using Index R, which approximates the lateral load transfer ratio (LTR) of the vehicle.

Among the evaluated vehicles, a recommended vehicle with high stability and a vehicle that can be loaded but needs attention to transportation are output together. When dispatching a vehicle, a person in charge may make a reasonable decision by comprehensively considering the output results, transportation time, and cost.

B. Operation procedure

Fig. 2 schematically illustrates the process of selecting a transportable vehicle.

[1] Image by macrovector on Freepik

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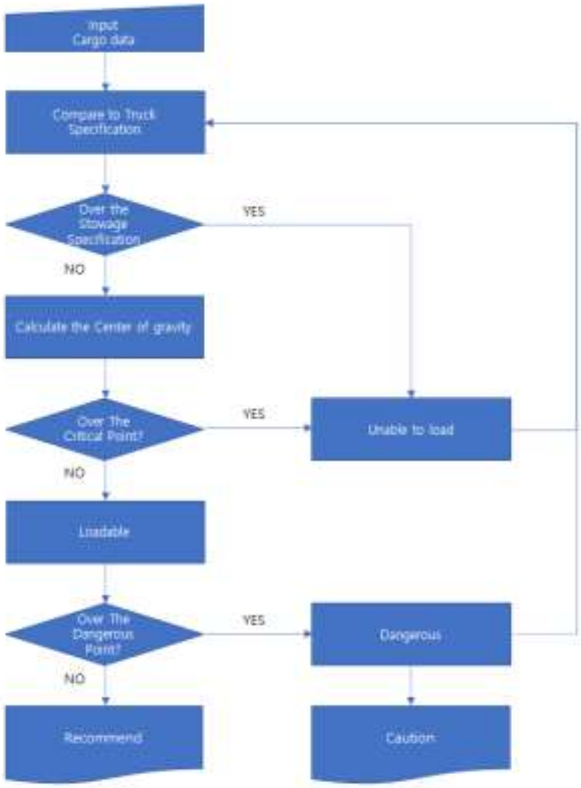

Fig. 2: Operating flowchart

When the information of the cargo is input, it is compared with the information of the vehicle stored in the database. If it is impossible to load due to the size of the loading box or overweight, it is determined that the loading is impossible, and if loading is possible, the changed center of gravity is calculated in the loading situation. In this step, the possibility of overturning the vehicle is evaluated based on the predetermined driving environment. If the evaluation index exceeds the critical point where the rollover occurs, it is judged as a dangerous environment and the vehicle is declared non-loadable. If it does not exceed the critical point, compare it with Dangerous Point and determine if driving is possible. If it exceeds the Dangerous Point, it outputs transportable with caution, and calculations are performed for the upper model. If it does not exceed the dangerous point, it is judged as a safe vehicle, and the recommendation is output, and the calculation is completed.

IV. Simulation Experiments

A. Equations

Fig. 3 is a diagram that expresses the change in the center of gravity when the cargo is loaded.

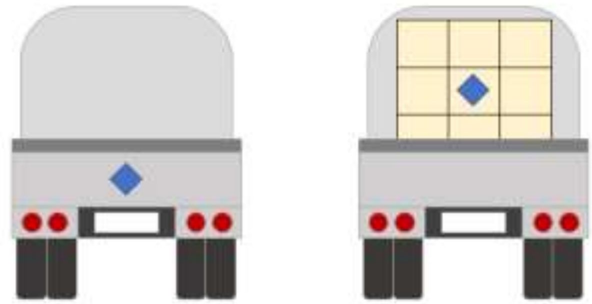

Fig. 3: Center of gravity shift

The position of the center of gravity indicated by the blue dot is higher than the unladen state when the cargo is loaded, and the changed center of gravity coordinate G in the loaded state can be obtained as (2).

$$G\left(\frac{m_t y_t + m_c y_c}{m_t + m_c}, \frac{m_t z_t + m_c z_c}{m_t + m_c}\right) \tag{2}$$

m_t: Vehicle mass
y_t : y-coordinate of the center of gravity of the vehicle
z_t : z-coordinates of the center of gravity of the vehicle
m_c: Cargo mass
y_c : y-coordinate of the center of gravity of the cargo
z_c : z-coordinates of the center of gravity of the cargo

Fig. 4 expresses the variables for evaluating the possibility of overturning and the torque generated in the vehicle body.

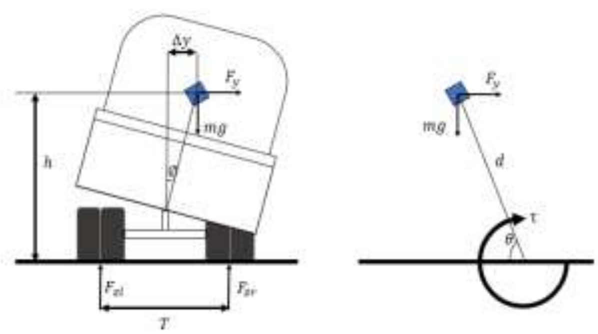

Fig. 4: Schematic diagram of roll motion and torque generated

The overturning of the vehicle occurs when the rotational force is changed around the rotational axis by the force applied in the transverse direction. When the vehicle is turning, the axis of rotation is the outer wheel in the direction of turning. The lateral force F_y applied to the vehicle is determined by the vehicle's mass m and lateral acceleration a_y, and the lateral acceleration is determined by the vehicle's driving speed v and the turning radius r.

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$$F_y = ma_y = \frac{mv^2}{r} \tag{3}$$

When the vehicle is upright ($F_y = 0$), the vertical reaction force is equal to the vehicle's load, and when the center of gravity is located in the left and right centers, the vertical reaction force of each tire is equal to each other. As the rotational force increases and decreases, the moment the vertical reaction force of either side becomes zero, the wheel lift occurs.

$$F_z = mg \tag{4}$$

$$F_{zl} = F_{zr} = \frac{1}{2}mg \tag{5}$$

Torque τ is the physical quantity multiplied by the force acting on the distance d from the axis to the center of gravity.

$$\tau = d(ma_y sin\theta - mgcos\theta) = ma_y h - mg(\frac{T}{2} - \Delta y) \tag{6}$$

At this time, the LTR can be obtained through the ratio of the force of the + sign and the force of the - sign in (6).

$$LTR = \frac{\tau_+}{\tau_-} = \frac{2(ma_y h + mg\,\Delta y)}{mgT} \tag{7}$$

$$\Delta y = h * \sin\phi \tag{8}$$

At small angles of ϕ, the measurement of ϕ can be neglected. It can be assumed that $sin\phi$ is approximately equal to zero. Therefore, equation (7) for a small roll angle can be rewritten as (9), [9].

$$R = \frac{2a_y h}{gT} \tag{9}$$

B. Simulation condition

The specifications of each vehicle by tone class were referenced in the catalog of automobile manufacturers, and in the simulation, the specifications of the vehicle were applied as shown in Table 1.

Table 1. Truck specification

Truck	Unladen weight (kg)	Wheel distance (mm)	Loading width (mm)	Loading length (mm)	Loading ground clearance (mm)	Allowable load weight (kg)
1 ton	1740	1485	1600	2865	800	1100
2.5 ton	3280	1680	1800	4200	1000	2750
3.5 ton	4500	1870	2000	4600	1060	3850
7.5 ton	8070	2080	2350	7300	1200	8250
11 ton	11470	2080	2350	9100	1400	12100
25 ton	13570	2165	2350	10100	1400	27500

In this study, it is assumed that a box-type cargo with uniform density is loaded. One cargo is loaded, and the center of gravity y-coordinates of the loaded vehicle are located in the left and right centers of the vehicle.

The driving conditions were set based on the turning radius and speed of Dongtan JC in the Republic of Korea, shown in Fig. 5. The turning radius r is 55m and the vehicle's driving speed v is 40km/h.

Fig. 5: Dongtan junction

For the index R, 0.4 or more was classified as caution and 0.5 or more as a rollover for safety, considering external factors such as crosswind and road slope.

C. Simulation results

The first simulation considers the situation of loading cargo as shown in Table 2. Table 3 is a result of the output based on the input value of Table 2, and Fig.6 shows the index R of each vehicle as a graph.

Based on the size and weight of the entered cargo, it can be loaded on a 2.5-ton truck, but it was judged to be Caution because Index R exceeded the Dangerous Point at 0.41. On the other hand, in the case of a 3.5-ton truck, Index R was 0.35, which allowed stable driving, and was recommended because it was the next class of a 2.5-ton truck.

Table 2. Input data in condition 1

Cargo	x (mm)	y (mm)	z (mm)	weight (kg)
Input	2000	1500	3000	2700

Table 3. Result in condition 1

Vehicle type	R	Size	Weight	Output
1 ton	0.53	O	X	Unable
2.5 ton	0.41	O	O	Caution
3.5 ton	0.35	O	O	Recommend
7.5 ton	0.29	O	O	Loadable
11 ton	0.30	O	O	Loadable
25 ton	0.27	O	O	Loadable

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Fig. 6: Index R of each truck in condition 1

The second simulation considers the situation of loading cargo as shown in Table 4.

Table 4. Input data in condition 2

Cargo	x (mm)	y (mm)	z (mm)	weight (kg)
Input	7000	2000	2000	12000

Table 5. Result in condition 2

Vehicle type	R	Size	Weight	Output
1 ton	0.52	X	X	Unable
2.5 ton	0.47	X	X	Unable
3.5 ton	0.42	X	X	Unable
7.5 ton	0.36	O	X	Unable
11 ton	0.38	O	O	Recommend
25 ton	0.35	O	O	Loadable

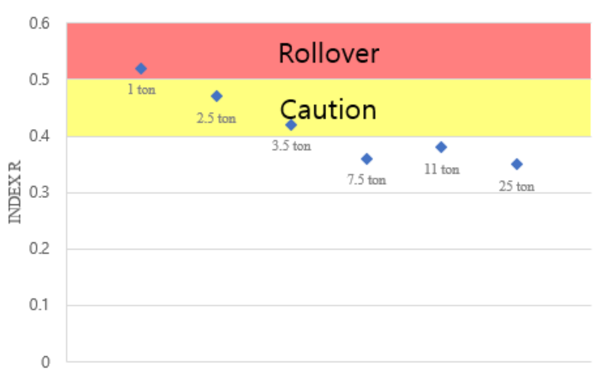

Fig. 7: Index R of each truck in condition 2

According to Table 4 and Table 5, trucks with less than 11 tons were considered unable because they did not meet the size and weight conditions. Figure 7 shows that both 11-ton and 25-ton trucks have an index R of less than 0.4 and can be transported reliably. but you can see that the 11-ton truck, which requires less cost, has been declared Recommended. The user may select an 11-ton truck based on the corresponding result.

V. Conclusion

To identify vehicles that can drive safely and reduce transportation costs, it was determined whether they could be loaded and evaluated the possibility of overturning. The loading model of the cargo was input to decide whether or not it could be loaded based on size and weight, and Index R was calculated to evaluate the possibility of subversion to derive transportation conditions for each vehicle. Simulations were conducted in several limited assumptions, but when vehicle screening was ambiguous, it was possible to determine which vehicles needed attention, and the results of recommending low-cost vehicles were obtained.

In Table 5, the LTR index is expected to grow with an increase of Δy in the actual driving environment, although the index R of the small vehicle does not exceed the Critical Point even though the cargo weights 12 tonnes because the suspension performance is not considered.

This study has several limitations. It plans to improve the model and increase accuracy through further research such as the following. Add and modify factors that cause the overturning, such as vehicle suspension, presence of siding, slope of the road, and setting the exact center of gravity of the unladen condition. Starting with multiple cuboids, the mixed situation of cargo with different densities and appearances shall be considered. The center of gravity will vary more depending on the specifications, materials, and characteristics of the product being loaded. Some other relevant studies with some important applications can be found in [13], [14], [15].

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References

[1] Koroad, Traffic Accident Analysis System, http://taas.koroad.or.kr, 2021.
[2] Ministry of Land, Infrastructure and Transport, “Traffic Safety Republic of Korea! Let's start, model truck system.”, 2022.
[3] Jung-ho Shin, "Hybrid genetic algorithm for the multi container packing problem." M.S. thesis, Pusan National University, 2011.
[4] John Kwon, "A study on the algorithm for loading problem." M.S. thesis, Korea Aerospace University, 2018.
[5] Min-ji Ryu, "A study on the 3D cargo packing algorithm considering cargo size by order." M.S. thesis, Korea Aerospace University, 2020.
[6] Pyeong-An Kim, Sung-Sic Yoo, Heung-Shik Lee, "Predicting the Dynamic Safety of Heavy Vehicle using the Lateral Load Transfer Ratio." Journal of the Korean

Society of Mechanical Technology, vol.24, no.5, pp.936-941, 2022.

[7] Chiu Jimmy, "Rollover prediction using lateral energy models and active rollover prevention." Purdue University, 2013.

[8] J. Park, H. Lee, K. Chang, L. Suh, and S. Yoo, “A Simulation Study of Commercial Vehicle Rollover in Highway Ramp Section According to Vehicle Speed and Curvature.” Journal of Auto-vehicle Safety Association, vol. 7, no. 2, pp. 50–54, 2015.

[9] Ali Abdi Kordani, Sajad Javadi and Afshin Fallah, "The Effect of Shoulder on Safety of Highways in Horizontal Curves: With Focus on Roll Angle." KSCE Journal of Civil Engineering 22, no.8 : 3153-3161, 2018.

[10] Chan-Hyouk Cho, "A Study on the Injury Severity Characteristics of Commercial Truck Accidents." E-Trade Review 18, no.2, 2020.

[11] Byung-seok Lee, Moon-beom Heo, Joon-hwa Lee, “Accident Sensing System Implementation of Hazardous Material Transport Vehicle and JackKnifing & RollOver Accident Detection Algorithm Development.” Journal of Transport Research, 21(3), 35-54. 2014.

[12] Daniel Domović, Tomislav Rolich, Marin Golub, “Evolutionary hyper-heuristic for solving the strip-packing problem.” The Journal of The Textile Institute, 110:8, 1141-1151, 2019.

[13] Young-woo Kim, Jin-hee Jang, “The Effect of Roof Loading on Vehicle Dynamic Characteristics.” Proceedings of the Spring Fall Conference of the Korean Society of Automotive Engineers, 1086-1091, 2006.

[14] Myung-su Lee, Sang-sup Kim, “A Study on the Improvement of Assessment Index on the Characteristics of Vehicle Rollover.” Spring Conference of the Korean Society of Automotive Engineers, 2506-2510, 2011.

[15] H. Imine, A. Benallegue, T. Madani and S. Srairi, "Rollover risk prediction of an instrumented heavy vehicle using high order sliding mode observer," 2009 IEEE International Conference on Robotics and Automation, pp. 64-69, 2009.