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Comparative Study of Traffic Accident Reconstruction in Winter

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1. INTRODUCTION

Traffic accident reconstruction is the application of the principles and techniques of mathematics, physics and other sciences to estimate unknown events in the traffic accident. The accident reconstruction method which is adopted here includes impact model[1], tire model[2] and driving simulation model[3]. The method requires fairy troublesome task for estimating unknown parameters. On the other hand, there is another traditional speed equation[4] which is very simple and easy to estimate the unknown parameters. The speed equation can be determined by knowing the length of lock braking distance and the dynamic coefficient friction for the roadway surface. In this equation, the difference in the kinetic energy of the vehicle at the onset and offset of braking, is equal to the work performed by the braking force applied to the vehicle through the braking distance. The determination of the suitable restitution and friction coefficients is very important aspect of the traffic accident reconstruction. We estimated the restitution coefficient at impact phase and friction coefficient at pre-impact and post-impact phases by using the reconstruction method and traditional method. This paper aims to compare the coefficients estimated by the traditional method with the ones estimated by traffic accident reconstruction method. For this purpose, the data obtained from 18 rear-end traffic accidents in winter were analyzed using the methods described above.

2. ESTIMATION of PARAMETERS

We estimated the restitution coefficient at impact phase and friction coefficient at pre-impact and post-impact phases by using the reconstruction method and traditional method.

2.1. Traditional Method(TA)[4]

The traditional equation which is used to determine the speed of the vehicle at the onset of braking is shown in the following;

$$v_0^2 - v_d^2 = 2.g.\mu.l \qquad (1)$$

where:

v_0 : speed of the vehicle at the onset of braking,

v_d : speed of the vehicle at the offset of braking,

g : acceleration of the gravity,

μ : friction coefficient,

l : braking distance of the vehicle.

Knowing the pre-impact velocity, we calculated friction coefficient in the pre-impact phase by using traditional equation (1). Then , we calculated post-impact velocity of the vehicles that skid to the stop positions assuming the same friction coefficient of pre-impact phase . knowing the pre-impact and post-impact velocities, we calculated restitution coefficient of impact phase using the following general equation (2);

$$e = \frac{v_2' - v_1'}{v_1 - v_2} \qquad (2)$$

where:

e : restitution coefficient,

v_1 : speed of the striking vehicle at pre-impact phase,

v_2 : speed of the struck vehicle at pre-impact phase,

v_1' : speed of the striking vehicle at post-impact phase,

v_2' : speed of the struck vehicle at post-impact phase.

The traditional speed equation is based on the first law of thermodynamics. It says that energy can not be created or destroyed. Based on the first law theory, the energy of the system is equal to the energy entering the system plus the performed work minus the energy leaving the system. In other words, the kinetic energy of the vehicle at the onset of braking is equal to performed work by the braking force plus the existing kinetic energy.

There are some problems with practical using of traditional speed equation in traffic accident reconstruction. The first problem becomes apparent when it is assumed that there is not any energy loss in the time of skidding. However , some energy is dissipated in removing rubber from the surface of the tire and also heat is generated when the braking pad is contacting with the braking drum or disc. The second one is that the equation is based on an instantaneous lockup of all tires. But, the speed of the vehicle at the onset of braking is not equal to the speed of the vehicle at the point in time that the first deposited skid mark is visible on the road surface. The third problem appears when attempting to determine the friction coefficient of the road surface.

2.2. Traffic Accident Reconstruction Method(TARM)

A two-dimensional car-to-car impact model combined with a tire model and driving simulation model was applied for reconstructing traffic accidents. We estimated restitution and friction coefficients using Box complex algorithm in this method. These models are explained briefly in the following.

1) Impact model[1)]

There are three degrees of freedom for each vehicle; two translations and one rotation. In order to apply the impact model, six equations are necessary: Four equations can be obtained from the law of conservation of linear and angular momentum. The last two equations are obtained from the constraint conditions at the impact center, in which the normal and the tangential restitution coefficients are defined.

2) Tire model[2)]

An analytical tire model was proposed by Gim and Nikravesh. In the model, not only slip angle and slip ratio but also camber angle, which represents the rotation around z-axis, was considered as shown in Fig. 1.

However, the bending and torsion produced by side force were not considered. In this model the resultant friction coefficient is assumed to be function of the sliding velocity by order of two, a friction parameter at zero velocity, and two suitable reduction factors, which are obtained experimentally. A Schematic drawing of interaction friction forces between a tire and road surface is shown in Fig. 1. There are three main forces; the force acting in the lateral direction of the tire as the side force (S_F) , the force acting in the longitudinal direction of the tire as the braking force or traction force (D_F), and the moment acting in the opposite direction of wheel yawing (M_Z). The slip angle and the camber angle of the tire are denoted by β and γ. It is necessary to establish a function that relates the forces to slip angle, slip ratio and friction coefficient. This function is called tire model.

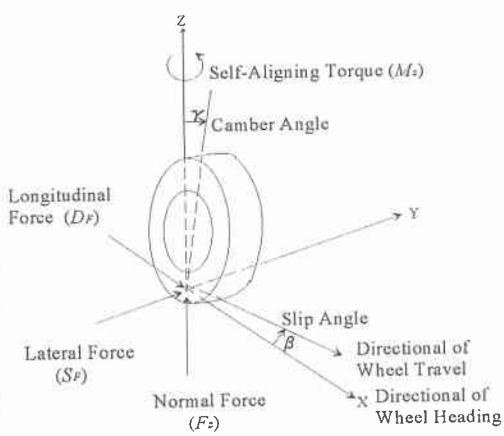

Fig 1 Forces and moment applied to a tire

3) Driving simulation model[3)]

The two-wheel equivalence model was applied for calculating the resultant forces at the gravity center of each vehicle. In this model, It is assumed that the rolling and pitching movements are negligible. Consequently, the vehicle acceleration in both x and y directions and the angular acceleration can be obtained from the resulting forces of the gravity center of vehicle.

We estimated the restitution coefficient at impact phase and friction coefficient at pre-impact and post-impact phases by using the reconstruction method and traditional method.

4) Estimation method[5)]

A lot of parameters are used in the above-mentioned models, such as restitution coefficients, friction coefficient, slip ratio, and steering angle. We assumed that the movements in pre-impact phase were also known in advance, based on the data collected from the accident site, driver's witness and damage profiles. In other words, we assumed that only the parameters with respect to the dynamics characteristics of tire and vehicle were unknown in both impact and post-impact phases. We estimated the restitution coefficient at impact phase and friction coefficient at post-impact phase. Evidently, slip ratio and steering angle vary with time. For simplicity, we assumed that they were constant in the pre-impact and post impact phases. Moreover, the friction coefficient is dependent on the slip ratio. we defined a function that related the friction to the slip ratio. We estimated the unknown parameters using Box's algorithm. In this method, we estimated the parameters so as to minimize the difference between the calculated rest positions of the vehicles and the observed ones.

3. NUMERICAL EXPERIMENTS

3.1. Traffic Accidents Data

Data obtained from 18 rear-end traffic accidents in Sapporo in December, 1995, are shown in Table 1. These data were analyzed using traffic accident reconstruction method and traditional method.

Table 1 Data of 18 rear-end traffic accidents in winter.

No.	road surface cond.	type	speed(km/h)	braking distance(m)	post-impact distance(m)	type	speed(km/h)	post-impact distance(m)
		striking car				struck car		
1	icy	sedan	30	16.2	0.5	sedan	0	0.8
2	icy	wagon	30	35.4	0	sedan	0	5.5
3	icy	sedan	30	26.3	0.4	wagon	0	0.8
4	snowy	sedan	30	15.2	0.4	van	0	0.7
5	icy	sedan	40	19	1	sedan	0	1
6	icy	wagon	40	23.8	1.1	wagon	0	2
7	snowy	wagon	40	19.5	0	sedan	0	0.4
8	icy	sedan	30	9.6	6.9	sedan	0	7.27
9	icy	sedan	40	40.2	0.4	sedan	0	1.5
10	icy	sedan	40	39.9	0.5	van	0	1.2
11	icy	sedan	40	20.4	1	sedan	0	1
12	icy	sedan	30	15	0.8	sedan	0	0.8
13	icy	sedan	20	6	3.1	sedan	0	3.1
14	icy	sedan	20	10.3	0.8	sedan	0	0.8
15	icy	sedan	30	11.1	0.7	sedan	0	1.5
16	icy	sedan	20	9.6	0.5	sedan	0	0.7
17	snowy	wagon	30	9.7	0.6	sedan	0	0.6
18	snowy	sedan	50	35.8	2.1	wagon	0	5.1

3.2. Unknown Parameters

We estimated the restitution coefficient at impact phase and friction coefficient at pre-impact and post-impact phases.

1) Friction coefficient

The determined friction coefficients of striking vehicle at pre-impact phase using traffic accident reconstruction method(TARM)and Traditional method(TM) are shown in Fig(2). The estimated friction coefficients of striking vehicle and struck vehicle at post-impact phase using mentioned above methods are shown in Fig (3) and Fig(4), respectively.

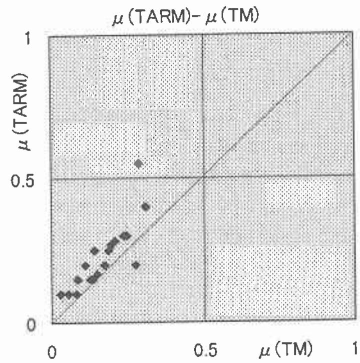

Fig. 2 Determined friction coefficient of striking vehicle at pre-impact phase.

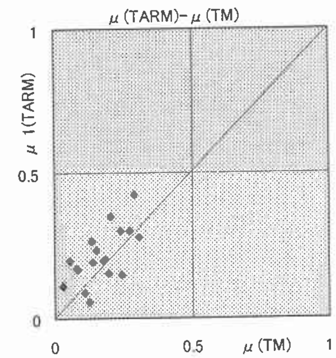

Fig. 3 Estimated friction coefficient of striking vehicle at post-impact phase.

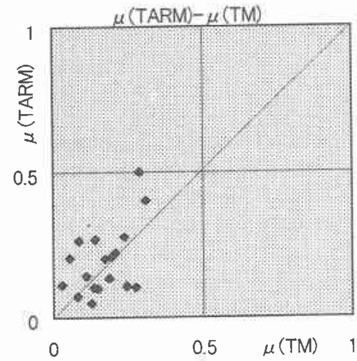

Fig. 4 Estimated friction coefficient of struck vehicle at post-impact phase.

We can see that there is not so large difference between the friction coefficients estimated by TARM and ones estimated by TM. But on the average, the friction coefficients of striking and struck vehicles estimated by TARM are a little larger than ones estimated by TM.

2) Restitution coefficient

The estimated restitution coefficients by TARM and TM are shown in Fig.5. There is large difference between their estimated values. We can see that all of the restitution coefficient values estimated by TM are positive which are a little unreasonable. However, in the case of rear-end collisions, the restitution coefficients can be negative.

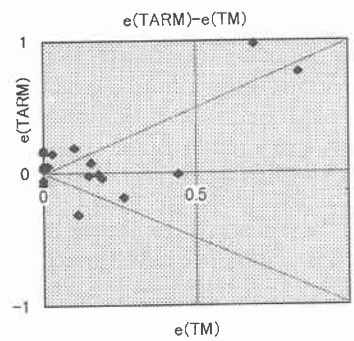

Fig. 5 Estimated restitution coefficient by TARM and TM.

3) Sensitivity of friction coefficient

The appreciate friction coefficient value has an important effect in traffic accident reconstruction. We performed the simulation of pre-impact phase of observed traffic accidents shown in Table 1 by TARM. We predicted the friction coefficient values at which the accidents would not be occurred. Then, we compared those values with estimated ones by TARM which are shown in Fig6. We can result that it is very effective for restraining from traffic accidents in winter, if we can make high the friction coefficient value even 0.5~0.1.

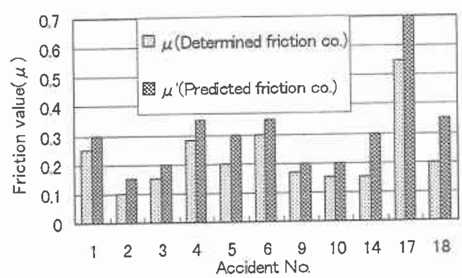

Fig. 6 Comparison of friction coefficient values determined by TARM

4. CONCLUSIONS

From this study the following conclusions can be dawn:

1) The restitution and friction coefficients estimated by TARM varied from those estimated by TM.
2) The restitution coefficients by TARM were more reasonable than ones estimated by TA.
3) The improvement of the friction coefficients was very effective for restraining from the rear-end accidents in winter.

REFERENCES

1) Hirotoshi. Ishikawa,"Impact model for accident reconstruction normal and tangential restitution coefficients", SAE paper No. 930654, 1993.

2) Gwanghun Gim and Parviz E. Nikravesh, " An analytical model of pneumatic tires for vehicles dynamics simulations.", Int. J. of vehicle design, 12-1, (1991).

3) Abe Masato, Dynamics and control of vehicles, Kyoritsu press, 1979.

4) 上山 勝,"交通事故の実証的再現手法",技術書院,1992

5) J. Kuster & J. Mize,"Box(Complex Algorithm)", Optimization Techniques with FORTRAN 368-386, 1973.