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The simulation and optimization integration calculation method and application validation for the traffic accident

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ABSTRACT

In the tradition traffic accident simulation method, the main parameters need to be determined by experience. If there is any problem found in the simulation process, we will have to change the model by amending input parameters and re-start the simulation. Therefore, the accident reconstruction result has very big difference with real accident process. This article discusses the coupled calculation method between the traffic accident simulation and simulation optimization. Then it confirms the method's validity through the reliability analysis to simulation result. Finally through the actual traffic accident cases' simulation and optimization analysis, the reconstruction result shows that the deviation of the accident reconstruction result does not exceed 10%. And the reconstruction result is a nice match with the accident scene investigation data. The simulation and optimization integration calculation method provides an effective solution to the problem that lies in traditional traffic accident simulation.

1. Introduction

In traditional numerical simulation of traffic accident, the simulation parameters need be determined by practical experience or subjective judgment. Then through simulation modeling and numerical calculation based these parameters, it can gain the crash process and vehicle termination position. If some problems are found in the simulation result, it has to change the model by amending input parameters to re-start the simulation. The more the process to be repeated, the more problems can be found. Until the satisfactory approximation of simulation result is arrived. This is a repetitive error analysis progress [1].

The management and analysis for the simulation result data will spend very long time. And the various constraints may be contradictory each other. So how to balance these output parameters is extremely difficult. Because of these limitations, usually the numerical simulation only is able to get some satisfactory result, but those results are far from the true process of the accident [2–4]. At the same time, this simulation method cannot consider and evaluate the inevitable uncertainty and variability caused by change in the input parameters [5].

The core of traffic accident reconstruction is to rebuild the crash point location, vehicle speed, pedestrian behavior through the vehicle braking distance and the pedestrian thrown location [6]. The accident reconstruction involves the vehicle speed at crash time, the location of crash point, the pedestrian friction property, the contact property between vehicle and road, the deformation of the vehicle, the pedestrian injury, and so on. Some parameters can be acquired by the traffic accident scene investigation. Based on those data it can deduce the other parameters value and the accident process. But the result, which acquires from the traffic accident scene investigation and simulation calculation, is not accurate to all parameters. Such as the vehicle speed of the crash time only can obtain a rough value by formula based the brake mark. All kinds of friction and contact characteristics can only obtain a value's range through a simple test. So this study integrates the simulation and optimization calculation method to reproduce traffic accident process.

The design of experiment (DOE) is used to analyze the relationship between the simulation result and simulation parameter. And it builds response surface model (RSM). Then based RSM, it analyzes the parameter value and the value's range that meet the optimization goal [7]. Using these parameters as input, it establishes simulation optimization process and selects numerical simulation optimization algorithm to do optimization calculation. It can acquire the best accident simulation result in theory. Then through reliability analysis to the new simulation result, it can describe the reliability of the simulation result. Finally the accident responsibility can be evaluated by comparing the simulation result with the accident investigation report.

2. Simulation and optimization modeling analysis method

The traffic accident simulation is an inverse dynamics problem. Or it can be seen as a continuous feedback optimization problem

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[8]. Generally, according to the accident scene left information and the human body harm to do the preliminary reverse inferred, it can acquire a hypothetical situation at crash time. Then by comparing the simulation result with the accident scene, it can amend the initial assumption and repeat above steps until the simulation result coincides with the accident scene investigation result.

The traffic accident simulation optimization is a repeated analogism process to the accident simulation parameter. Through the coupled calculation between accident simulation and optimization, it can gain the best coincidence result with scene investigation. The traffic accident simulation optimization calculation can realize that: (1) The sensitivity analysis of input parameter namely DOE. It can confirm those parameters play a key role in accident reconstruction and acquire these parameters' value range. And through the response surface model (RSM), it can realize visualization of analysis result. (2) The accident simulation optimization. It can get the best accident reconstruction result through automatically searching in the input parameters' value range. (3) The reliability analysis. Using the probability and statistics algorithm, it can obtain the influence of the input parameters change to the result of accident reconstruction.

2.1. Numerical simulation modeling for traffic accident

First of all, it builds the three-dimensional multi-rigid body model of the road. The road stiffness characteristic is acquired by using the finite element adult head hit program of TNO (the Netherlands Organization for Applied Science Research) [9]. Then the stiffness characteristic of the multi-rigid body model is appended on the road. The road can simulate deformation by penetration between rigid bodies.

In the vehicle and pedestrian or the vehicle and two-wheelers crash accident, the vehicle has larger mass and stiffness compared with pedestrian or two-wheelers. So the deformation of the vehicle can express by penetration of multi-rigid body. So the vehicle model can be simplified as the multi-rigid body and hinge [10]. The vehicle weight parameter set by the accident identification report. The friction coefficient between wheels and road gets according to the accident vehicle braking test. Other friction coefficients are set by experience.

The National Safety Traffic Highway Administration (NSTHA) and the Japan Automobile Research Institute (JARI) have given the standard percentile pedestrian dummy model in the car-pedestrian crash simulation [11,12]. The standard dummy model has defined the pedestrian dummy contact and friction biomechanics characteristic, which get according to statistics rule of road traffic accident. But in the given case of the traffic accident, the parameter of standard dummy model has not uniform quantitative standard.

The dummy friction biomechanics characteristics include the friction coefficient between dummy and car, dummy and road, and the definition of contact characteristic curve. The standard dummy model adopts ellipsoid manikin, and pre-defines physical contact characteristic of each part [13]. The friction characteristic between dummy model and the external environment need to be defined according to different accident requirement.

The dummy friction characteristics are constituted by external friction characteristic and internal friction characteristic. All internal friction characteristics have been defined on the basis of the standard dummy model test. But the external friction characteristics, that are the friction characteristic between dummy model and environment, need to be defined according to the incident case file.

In order to facilitate the friction characteristic definition between dummy model and the outside world, all type's standard dummy models have been pre-defined the body parts as contact response unit with the outside world. For example, in the car-pedestrian crash traffic accident, the friction characteristic between human and the environment is defined in the CONTACT function [14]. For the friction characteristic between human and road, the dummy model plays a role as a whole. So usually, it only defines the whole friction characteristic.

The friction characteristic definition of dummy model is different with the different application scene. The principle that the friction coefficient selects of the dummy model is that:

(1) The friction characteristics between dummy model and multi-rigid body or between dummy model and finite element body use the dummy surface feature definition.
(2) The friction characteristics between dummy model and flexible body use the combined characteristic definition.
(3) The contact function between dummy model and external environment is used to replace the friction characteristic. As a result, in vehicle and pedestrian crash accident it commonly uses dummy model contact characteristic replace friction characteristic.

2.2. The integration system of simulation and optimization

The process integration and design optimization (PIDO) system can automatically obtain the input and output parameters of accident simulation and the simulation process information [15]. And it can execute simulation process, automatically display and explore design space. As a result, it can acquire the key simulation parameters. And it can quickly compare the various design options and acquire the best result of accident reconstruction.

As shown in Fig. 1, the optimization process includes the input parameters' selection, the integrated computation of simulation and optimization, the output parameters' extract and analysis. Before the optimization cycle begins, the input parameters are generated by the optimization algorithm. And these input parameters will replace the corresponding variables in the simulation input file. Every optimization cycle start numerical simulation system by the command-line inside the optimization system. Then it starts simulation calculation until the end of the calculation. The simulation program will send signal to the optimization system to stop this optimization cycle. When every step optimization cycle ends, the optimization system will extract the pre-setting output parameters from simulation system. Then it verifies the optimization termination conditions that determine whether the optimization process terminates or not.

2.3. Design of experiment for traffic accident simulation

The DOE is used to analyze the parameters that have main influence to simulation result. And through the RSM it can visualize the result so that the problem is easier to be understood. The traffic accident simulation optimization uses Latin-Hypercube Design (LHD) method to carry out design of experiments [16]. LHD is a multi-dimensional stratified sampling method. First of all, it defines the sample size according to the precision request. Then, the value range of every variable is divided into n columns and randomly takes out only a sample in every column. Last. The contribution of input parameters can be obtained by fitting n group simulation result using the least square method.

According the engineer experience to select the initial value of input parameters and setting the preliminary simulation result as the initial condition, it can establish the optimization analysis process. Then through design of experiments, it analyzes the correlation between input parameters and simulation result. And it builds response surface model to analysis the input parameters contribution to the result of the accident simulation. Ultimately, it can gain the most likely value and value range of the input parameters that meets the goal of optimization.