

Research on Quantitative Method about Driver Reliability

Yihu Wu, Jiajia Li, Dan Yu, Haitao Cheng

School of Traffic Transportation Engineering, Changsha University of Science and Technology
Changsha, Hunan, China
Email: w2309@163.com

Abstract—The influence factors of reliability for drivers in different running stage are analyzed in the paper, firstly, based on Behavior-causing Theory. Then a new quantification method on transience reliability for drivers is advanced by a new definition “reliability degree”, whose error rate is calculated by the response time of drivers, and the influence factors how to influent the transience reliability degree is also researched. The whole reliability of drivers could be described by the new method. The results show the new method could not only statistics the reliability but also describe the relationship between reliability and time.

Index Terms—traffic engineering; reliability of drivers; reliability degree; error rate; influence factors

I. INTRODUCTION

Driver, the role as a vehicle controller, is extremely important. His errors can induce traffic accident directly. The reasons of traffic accidents show that about 92%-95% accidents are caused by driver's errors, non-expected behavior and unconsciousness state of drivers. Research on the reliability of the driver in the process of driving plays an important role in core problems such as traffic microscopic simulation, intelligent vehicle, and road traffic accident prevention and environmental assessment, that it has very important practical significance on analysis of traffic accident-causing, guidance and training for vocational assessment driver. In modern society, especially while the speed of vehicle increasing and road traffic conditions complicating, the driver has to always adopt to the changes, being quick, correct and accurate, not tired to perceive - judge - deal well with all kinds of traffic information, to ensure safety of driving. In the traffic system consisted of human, vehicle and road, the reliability of driver must be included in the projection of the system safety performance.

Driver reliability refers to the ability that the driver could complete driving task successful in the prescriptive reaction time and prescriptive driving environment. To a certain extent, running state of vehicle is external mechanical performance, which could be on behavior of driver's driving behavior. Given a quantitatively calculation for driver reliability not only provides theory basis for controlling of traffic accidents, but also has vital significance on evaluation and modify the car design idea

of dynamic man-machine system. Wang Wuhong[1] from Xi'an jiaotong university, Zhang DianYe[2] from Southwest jiaotong university, Dong Cong[3] from Beijing university of aeronautics & astronautics and LiuYuZeng[4] from Sichuan police academy have proposed the driver reliability evaluation method based on the analysis of the main influence factors of the driving safety driving ability. But these methods don't consider the factors which are changing with time. So they are only suitable for analyzing the data distribution of driving reliability, not suitable for describing the reliability in driver's driving process, whose influence factors change with time. In recent years, the foreign scholars focuses on discusses kinds of characteristics of driver and manipulate the relation between risky behavior and the occurrence probability of accident based on a lot of questionnaire. Tillman [5] and Hobbs [6] think that a person's personality could decide his driving style, so the driving characteristic was studied with the traffic accident. One of the most influent theories is EPQ (Eysenck Personality Questionnaire) theory proposed by the famous British psychologist Eysenck [7]. It refers to that people's oriented, easy variant and antisocial personality has huge relation with occurrence probability of traffic accident. The researchers like to evaluate the driver's possibility of traffic accidents by analyzing the scores of difference characters. Based on the data about driver reaction time series and Behavior Cause Theory, a new method of driver reliability quantitative method is advanced in the paper.

II. BASIC IDEAS OF QUANTITATIVE METHOD

In the theory of System Reliability Engineering, it uses the reliability R to measure the reliability of the system, which is a probability index to judge whether complete scheduled function in the referred condition and time. It has statistical significance only, has no relation with the state of research object in that moment [8]. The entire probability in a driving task is consist of a series of single operation reliability (called transient reliability), the measure value of which has close relation with the status of driver at each moment. So it is unreasonable to use R to represent the reliability, simply. So $A(t)$, the probability of normal vehicle operation in any moment under refined condition, is defined to measure driver's transient reliability.

The system reliability engineering The system reliability engineering theory measure reliability of the system by the reliability data, which is to complete function of probability in the referred condition and time. It has statistical significance only, has no relation with the state of research object in that moment. The entire probability in a driving task is consist of a series of single operation reliability (called transient reliability), the measure of which has close relation with the status of driver at that moment, and can't use R to state simply. So certainty factor $A(t)$, the probability of normal vehicle operation in any moment under refined condition, is defined to measure driver's transient reliability.

Set the error rate of driver as $\lambda(t)$ at any time t , the single operation time is Δt , which include the time of information perception, decision-making and vehicle handles. So the theory reliability of the driver $A_T(t)$ at random time t could be written as the equation below:

$$A_T(t) = e^{-\lambda(t)\Delta t} \quad (1)$$

Corresponding, the theory no- reliability level of the driver at random time t is as following:

$$F_T(t) = 1 - A_T(t) = 1 - e^{-\lambda(t)\Delta t} \quad (2)$$

Considering each operation will be subject to interference from multi-dimensional information in the driving process, driver's error rate is not constant [9]. So the actual credibility of the driver must be revised base on the theoretical calculation formula. As the growth of running time, the reliability of driver will changes [10]. So the entire driving process is divided into n stage according to the different influence factor. The influence factor of reliability level for the i th stage is $A_i, B_i, C_i \dots (i=1,2,3 \dots n)$, respectively; the correction coefficient of corresponding factor is $a_i, b_i, c_i \dots (i=1,2,3 \dots n)$, and the theory reliability level of the driver at random time t could be based on the equation below:

$$A(t) = \begin{cases} 1 - (a_1 \cdot b_1 \cdot c_1 \dots) \cdot (1 - e^{-\lambda(t)\Delta t}), & (\text{phase } 1) \\ 1 - (a_i \cdot b_i \cdot c_i \dots) \cdot (1 - e^{-\lambda(t)\Delta t}), & (\text{phase } i) \\ 1 - (a_n \cdot b_n \cdot c_n \dots) \cdot (1 - e^{-\lambda(t)\Delta t}), & (\text{phase } n) \end{cases} \quad (3)$$

So the overall reliability R of driver in one driving duty can be depicted base on the reliability level $A(t)$ and its mean E and variance σ^2 .

All above are basic ideas of how to the quantify driver reliability, and the contest about the solution of driver's error rate and the coefficient of influence factor would be introduced in details as follows.

III. CALCULATION OF ERROR RATE

Vehicle driver's reaction time is an evaluation index of reliability, which can calculate the non-response probability in one's operation [11]. In this paper, supposed that the errors generated in the driving process are caused by driver's response delay and the wrong response operation can be regarded as the driver's non-response to correct operation, and the non-response probability is 1. Therefore, driver's non-response

probability $P(t_r)$ and error-rate $\lambda(t)$ can content with $P(t_r) = \lambda(t)$, we can get it by the following method [12]:

We suppose the series of driver response time is $T_r = (t_{r1}, t_{r2}, \dots, t_{ri}, \dots, t_{rN}), i=1,2, \dots, N, t_{ri} < t_{r(i+1)}$, and F_i means response probability of i drivers. Choose logarithmic normal distribution function to describe the driver's non-response probability within t seconds:

$$P(t_r) = 1 - \Phi((\ln t_r - \mu) / \sigma) \quad (4)$$

In which, $\Phi(\bullet)$ is standard normal distribution function, μ is mean value of logarithm and σ is standard deviation of logarithmic.

Caring out normalization processing to formula (4), and taking the driver's response median as $T_{1/2}$, then

$$\Phi^{-1}(F(t_r)) = \frac{1}{\sigma} \ln t_r - \frac{1}{\sigma} \ln T_{1/2} \quad (5)$$

$$\text{Keep } y = \Phi^{-1}(F(t_r)), x = \ln t_r, a = 1/\sigma, b = -\frac{1}{\sigma} \ln T_{1/2}$$

.Since each group (t_{ri}, F_i) only corresponds to a group (x_i, y_i) , x and y have a linear relationship. The following can be obtained:

$$\begin{cases} \sigma = 1/a \\ T_{1/2} = \exp(-b\sigma) \end{cases} \quad (6)$$

Then the driver non-response probability is equal to the error-rate:

$$P(t_r) = 1 - \Phi((\ln T_w / T_{1/2}) / \sigma) = \lambda(t) \quad (7)$$

Figure.1 shows the changing situation on a driver's reaction time in driving process with time by detection. Obviously, we can get from the figure that the driver's reaction time can be divided into three sections and calculate error-rate in each section. The result of $\lambda(t)$ at each time is shown in table 1. From the table we can get that the error-rate and variance in second section is smallest among the three sections, so driver's state in second section is the most stable and reliable.

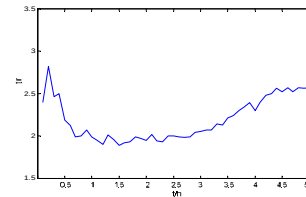


Fig 1. Changes Curve of driver's reaction time

Table 1 Distribution of error-rate $\lambda(t)$ (time/s)

	I	II	III
E	0.017	0.00028	0.0080
80 quantile	0.021	0.00031	0.0075
90 quantile	0.019	0.00029	0.0083
variance	0.003	0.00005	0.0005

IV. ANALYSES ON MODIFICATION COEFFICIENT

A. Choose on Influent Factors

In driving process, the disruption of different stages is different. Each stage should be got the differential treatment. Select 10 factors as primary factor, including the driver's operating time (A), operating frequency (B), risk level (C), personality (D), circadian (E), noise (F), vibration (G), climatic environment (H), information complexity (I) and driver recoverability (J). Principal Components Analytic Method (PCA) would be used to screen these factors base on different characteristic at different stages.

Thinking to the relationship among all above 10 factors is nonlinearity, while traditional PCA method is a linear dimensionality reduction techniques in one-class, it need to be improved. Covariance matrix of the traditional PCA is the key access to calculate, the matrix contains the linear relationship between each feature vector, which is in expression of similarity measure- distance measure. In which, distance measure considers the distance between two vector arrows, its function is the difference of two vector with each corresponding component; Similar measure is based on the direction of two vector whether close or not. Therefore, when the original variable presents the misalignment relations in traditional PCA, and the covariance matrix is the same function with the fuzzy measure matrix. And fuzzy similar measure matrix $(r_{ij})_{p \times p}$ is chosen to replace the covariance matrix to carry on factor screening [13] in this article:

Established for a given data set

$$\text{for } \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1p} \\ X_{21} & X_{22} & & X_{2p} \\ \vdots & \vdots & & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{np} \end{bmatrix}, \text{ the initial matrix of driver}$$

data in this paper is

$$X = \begin{pmatrix} A_i & B_i & C_i & D_i & E_i & F_i & G_i & H_i & I_i & J_i \\ \text{I} & 0.3 & 0.4 & 0.6 & 1 & 0.9 & 30 & 40 & 1.7 & 0.4 & 0.945 \\ \text{II} & 2.0 & 0.43 & 0.5 & 1 & 0.9 & 30 & 33 & 1 & 0.7 & 1 \\ \text{III} & 4.3 & 0.37 & 0.6 & 0.9 & 0.7 & 25 & 20 & 14 & 0.55 & 0.930 \end{pmatrix}$$

1. Calculate fuzzy similar measure according to

equation below, sitting for a non-negative definite matrix.

$$(r_{ij})_{p \times p} = \frac{\sum_{k=1}^m x_{ik} \cdot x_{jk}}{\sum_{k=1}^m \sqrt{x_{ik}^2} \sqrt{x_{jk}^2}} \quad (8)$$

2. Calculate orthogonal matrix U ,
keeping $UTU^T = \Lambda = \begin{bmatrix} \lambda_1 & & & \\ & \lambda_2 & & \\ & & \cdots & \\ & & & \lambda_p \end{bmatrix}$,

and $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$.

3. Calculate the contribution rate of the host component Y_j :

$$\frac{\lambda_j}{\sum_{i=1}^n \lambda_i}, j = 1, 2, \dots, p \quad (9)$$

4. Calculate the accumulative contribution rate of the host component Y_j :

$$\sum_{i=1}^n \frac{\lambda_j}{\sum_{i=1}^n \lambda_i}, j = 1, 2, \dots, p \quad (10)$$

5. Select $m(m < p)$ principal components, enabling its accumulative contribution rate to meet certain requirements.

Table.2 expresses the value of contributing rates $\gamma_i (i = 1, 2, \dots, 10)$ and accumulating contribution rate $\gamma(i) (i = 1, 2, \dots, 10)$ for every factor. According to the calculated results, choose the factors that could made the accumulated contribution rate amount to 0.99: for the first stage, it is operating frequency (B_1), information complexity (I_1), personality (D_1), driver recoverability (J_1), risk (C_1), climatic environment (H_1) and circadian (E_1); For the second stage, it is information complexity (I_2), operating frequency (B_2), driver recoverability (J_2), risk (C_2), drive time (A_2) and personality (D_2); for the third stage, it is drive time (A_3), operating frequency (B_3), driver recoverability (J_3), noise (F_3), vibration (G_3) and information complexity (I_3)

Table 2 The PCA analysis result of influence factor

		B_1	I_1	D_1	J_1	C_1	H_1	E_1	F_1	G_1	A_1
I	r_i	0.3341	0.3007	0.1759	0.0976	0.0559	0.0241	0.0053	0.0039	0.0013	0.0012
	$r(i)$	0.3341	0.6348	0.8107	0.9083	0.9642	0.9883	0.9936	0.9975	0.9988	1
II	r_i	0.3527	0.2733	0.2019	0.1011	0.0431	0.0238	0.0121	0.0016	0.0009	0.0004
	$r(i)$	0.3527	0.6260	0.8279	0.9290	0.9721	0.9959	0.9971	0.9987	0.9996	1
III	r_i	0.2588	0.2504	0.2478	0.1236	0.1090	0.0028	0.0031	0.0019	0.0015	0.0011
	$r(i)$	0.2588	0.5096	0.7570	0.8806	0.9896	0.9924	0.9955	0.9974	0.9989	1

B. Confirm the Modification Coefficient

Considering the driver recoverability and the reliability level is proportional, other influent factors are in reverse proportion with the reliability level, we divide all the selected factors into two classes to demarcate coefficient, named one second-class index and

second-class index, respectively.

In driving course, the percentage of the accident in the first phase is about 24.53% ~ 35.59%, in the second phase is about 10.14% ~ 19.74%, in the third phase is about 65.33% ~ 70.89%[14]. It can be understood as the driver could save himself far from accidents by

self-repairing to reduce the probability of accidents for 75.47% ~ 64.41%, 80.26% ~ 89.86%, 29.11% ~ 34.67% in each phase, respectively. So the corresponding coefficient scope of driver repair-characteristic is sited for 0.6441~0.7547, 0.8026~0.8986, 0.2911~0.3467, respectively.

The coefficient quantification value $P_i (i=1,2,3)$ of other influent factor named second-class index could be calculated according to the type (11):

$$1 - \lambda_e = \prod P_i (1 - \eta_i) \quad (11)$$

In the formula, λ_e is the basic error rate, η_i is the percentage of accident. Take the minimum value according to optimistic method, the basic error rate of various stages is 0.015, 0.00017, 0.001, and the accident percentage is 24.53%, 10.14%, 65.33%.

Take the first stage as the example: $1 - 0.0001 = P_1 (1 - 24.53\%) \Rightarrow P_1 = 1.32$

Then, the correction coefficient of the second-class index in the first stage is 1~1.32. Similarly, the correction coefficient of the second-class index in the second stage is 1~1.12; the correction coefficient of the second-class index in the third stage is 1~2.88.

Then the actual computation formula of driver reliability level is amended as follows:

$$A(t) = \begin{cases} 1 - (b_1 \cdot i_1 \cdot d_1 \cdot c_1 \cdot h_1 \cdot e_1) \cdot (1 - e^{-\lambda(t)\Delta t}) \cdot (1 - j_1) & , (t \in \text{phase } 1) \\ 1 - (i_2 \cdot b_2 \cdot c_2 \cdot a_2 \cdot d_2) \cdot (1 - e^{-\lambda(t)\Delta t}) \cdot (1 - j_2) & , (t \in \text{phase } 1) \\ 1 - (a_3 \cdot b_3 \cdot f_3 \cdot g_3 \cdot i_3) \cdot (1 - e^{-\lambda(t)\Delta t}) \cdot (1 - j_3) & , (t \in \text{phase } 1) \end{cases} \quad (12)$$

According to the above quantification scope, the relationships between the value of correction coefficient for every index and driver reliability level are reasonable. The influences of the second-class index can reduce the driver reliability level, so its value is bigger than 1; the influences of the first-class index can increase the reliability level, so its value is smaller than 1.

V. ANALYSES ON QUANTITATIVE RESULTS

A. Design of Simulation Process

If the experimental conditions allow the driver carry out evaluation scoring, all drivers could be divided into 5 reliability ranks, using fuzzy reasoning to determine the correction coefficient and sitting the contribution rate for each index as its weight. They are strong credible, better credible, credible, weak credible and the incredible. The weight and the representatives of the various ranks are established in table 3. Considering the workload of evaluation scoring is large, computer simulation is used to decided correction coefficient: Supposed the driving process is lasting 5 hours; calculate error rate by reaction time sequence; produce correction coefficient and operating time in suitable scope at random; simulation ends when the reaction time sequence end at the loop or there is an accident.

B. Results Analyses

When the driver reaction time changes according to

Figure 1 in some driving course, the credibility of the driver can be obtained by computer simulation as shown in Figure 3. We can see from the diagram, the change curve of driver reliability conforms to the tub bath curve, which can divide into three stages [15]. The first stage is a period for adaptation, drivers try to be familiar with the environment on the road, and reliability would go up rapidly in fluctuation, lasting approximately 0.20 hours. And the average value of reliability level is 0.9246; the variance is 0.0403. The second stage is a period for stabilization, the driver adapted to environment and has been familiar with the current driving circumstances, the state of mind is good, so the level of reliability would maintenance at high level, the average value is 0.9994, the variance is 0.0015, lasting approximately 2.5 hours. The third stage is a period for loss time. After a long driving, drivers would feel wearily, the fault would increase, and the level of reliability would begin to drop. This stage could be divided into two parts, the level of reliability drops is slower in the first 1.6h, the average value is 0.9982, the variance is 0.0026; the level of reliability drop slope enlarges in the latter 0.9h, the average value is 0.9064, the variance is 0.0519. It is easy to have the accident for the latter 0.9h. In entire driving process, the values of reliability which are higher than 0.999 account for 43.67%, lower than 0.9 account for 18.74%. According to the literature [15], the basic reliability of driver takes 0.9, therefore, we suggests this driver must have a rest to adjustment his condition after driving 4 hours, when his reliability level drops to about 0.9.

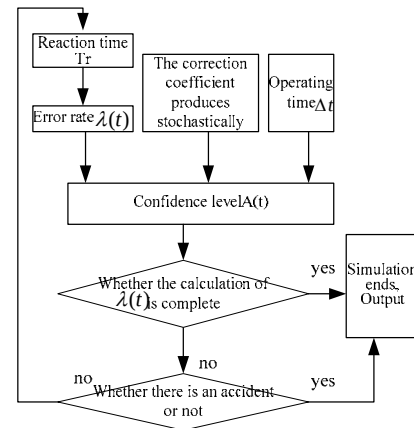


Fig 2. Simulation flow

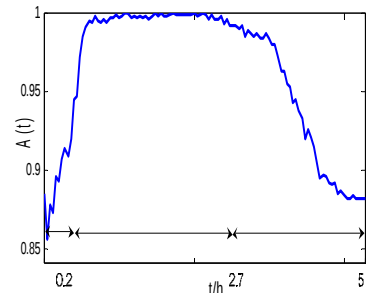


Fig 3. The level of reliability changes in driving

Table 3 The representative value and weigh of reliability fuzzy reasoning

		strong credible	better credible	credible	weak credible	incredible	weigh
Phase 1	B ₁	1.10	1.17	1.20	1.24	1.29	0.3341
	I ₁	1.009	1.14	1.15	1.19	1.22	0.3007
	D ₁	1.12	1.13	1.15	1.16	1.20	0.1759
	J ₁	0.7374	0.7241	0.7137	0.6738	0.6555	0.1040
	C ₁	1.10	1.11	1.19	1.25	1.27	0.0559
	H ₁	1.12	1.20	1.25	1.27	1.29	0.0241
	E ₁	1.15	1.16	1.17	1.18	1.19	0.0053
Phase 2	I ₂	1.009	1.10	1.107	1.109	1.11	0.3527
	B ₂	1.007	1.009	1.10	1.114	1.117	0.2733
	J ₂	0.8724	0.8496	0.8275	0.8137	0.8063	0.2060
	C ₂	1.02	1.07	1.09	1.10	1.11	0.1011
	A ₂	1.08	1.09	1.0	1.1	1.15	0.0431
	D ₂	1.02	1.04	1.07	1.09	1.0	0.0238
	A ₃	1.50	1.90	2.20	2.40	2.55	0.2588
Phase 3	B ₃	1.50	1.90	2.20	2.40	2.55	0.2504
	J ₃	0.3453	0.3386	0.3190	0.3122	0.3017	0.2554
	F ₃	1.45	1.60	1.75	1.90	2.23	0.1236
	G ₃	1.50	1.63	1.80	1.94	2.10	0.1090
	I ₃	1.40	1.55	1.60	1.70	1.90	0.0028

C. Influent Analyses of Each Indexes

(1) Influence on driver reliability from first-class index

Figure 4 shows the influence on driver reliability from driver repairing-characteristic. The figure shows the characteristic of the driver repairing could be able obviously to enhance the level of reliability. The stronger the repair characteristic, driver reliability at various stages is also higher. In the first and third stage, along with the coefficient of repairing-characteristic increases, the tendency of driver reliability level increases bigger; in the second stage, with the coefficient of repairing-characteristic increases, the driver reliability level also has certain enhancement, but the increment of reliability level is not big. This is because the second stage is a stabilization period, driver's faults are few. Although the restoration features would increase the reliability of drivers, it does not mean that its value may reach 1. It indicated that driver's fault or mistakes are unavoidable, which can only be controlled to some extent, can not be completely eliminated.

(2) Influence on driver reliability from second-class index

Figure 5 shows the influence on driver reliability from the second-class indexes, when the driver repairs coefficient is chosen as the mean value. We can see from the diagram, when the second-class indexes change signal in various stages, the change of driver reliability is still stable. When there are two second-class indexes in change at the same time, the impact on the driver reliability is obvious. When there are up to 3 second-class indexes in change at the same time, there is an obviously and substantial decline on driver reliability. It is more likely to have an accident. This shows that drivers have better ability to respond to a single message, but they are difficult in treating complex multi-dimensional information's processing.

(3) Influence on driver reliability level when first-class index and random several second-class indexes have the max value

Figure 6 shows the influence on driver reliability, when the driver repairs coefficient and random several second-class indexes have the max value. We can see from the diagram, when the coefficient of the single second-class index takes the maximum value, drivers can repair errors well. When there are two even more indexes take the maximum value, the situation results in various stages are different. In the first stage, the driver studies to be familiar with the condition of road, so the repairing-characteristics of the driver can not eliminate the errors derived from two second-class indexes reached the maximum value, and when number of index increases to three, the level of the driver reliability drops largely. In the second stage, the driver has adapted to the circumstances of the current path basically. The minds state of driver is good. It has little impact on the reliability when two or three second-class indexes take the maximum. While when the number of index increases to four, the influence increases obviously. In the third stage, there is fatigue caused by long driving, which makes the driver is very sensitive to the second-class index. When two second-class indexes get the maximum at the same time, the reliability level declines remarkable; when the number increases to three, the driver reliability level is lower than 0.9 for a long time, it is extremely easy to cause the traffic accident.

VI. CONCLUSION

(1) Take the driver reaction time as essential data, in order to provide the traffic safety suggestion for drivers, it is necessary to screen the different reliable influence factor at the different driving stage, and quantify the driver reliability level as the trend of changes over time.

(2) The changeable tendency of driver reliability is consistent to the tub bath curve and it could be divided into three stages. There are different influence index for various stages, and the influence degree is also different.

(3) The characteristic of the driver repairs only could enhance the reliability level to a certain extent. It is unable to eliminate the fault completely. When multiple

second-class factors changes simultaneously in particular, the effect of repairing is unsatisfactory.

ACKNOWLEDGEMENT: this project is sponsored by Hunan Natural Science Foundation P.R. China (NO.08jj3120 and NO. 09C070).

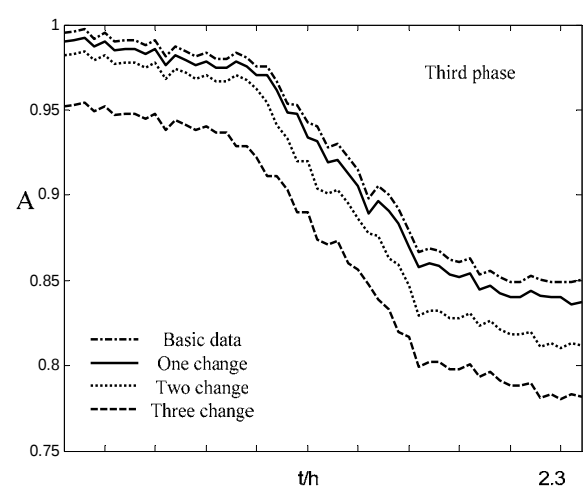
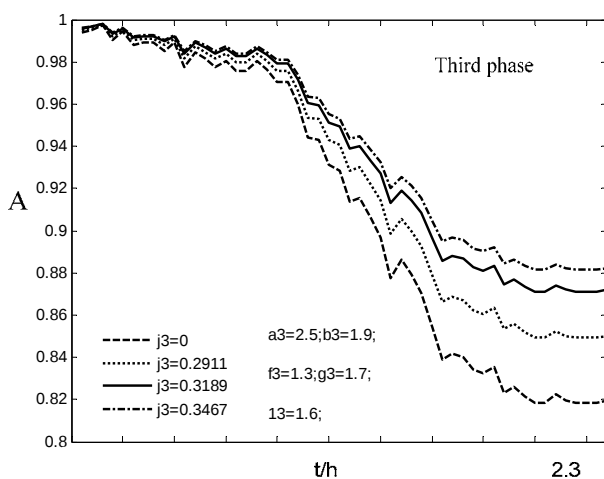
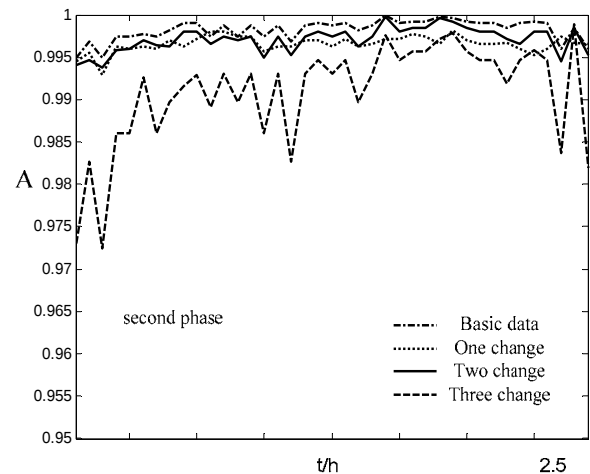
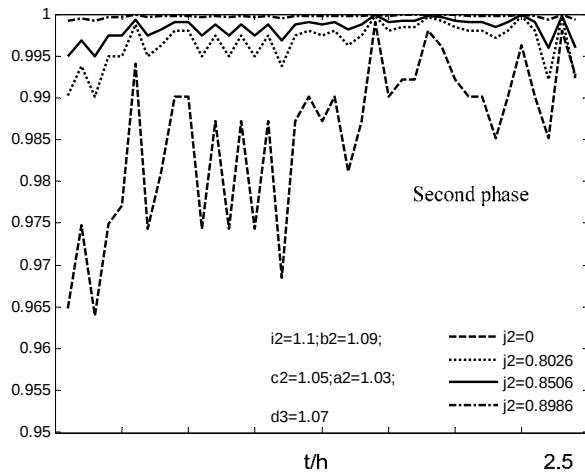
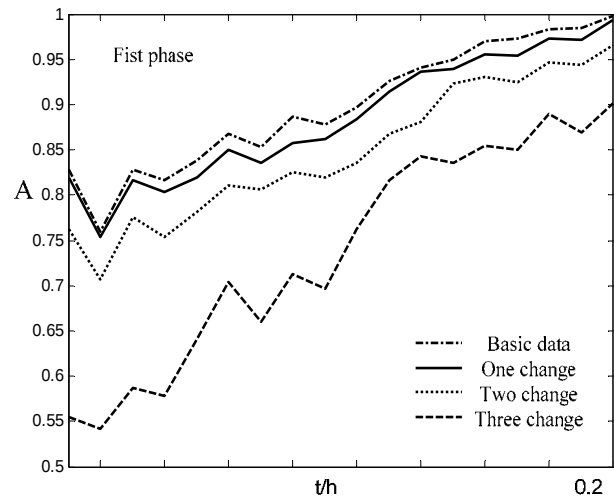
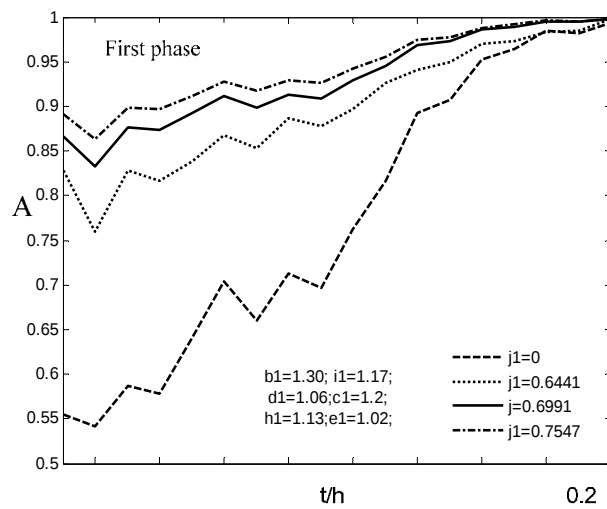


Fig 4. Influence on driver reliability from repairing-characteristic

Fig 5. Influence on driver reliability from second-class index

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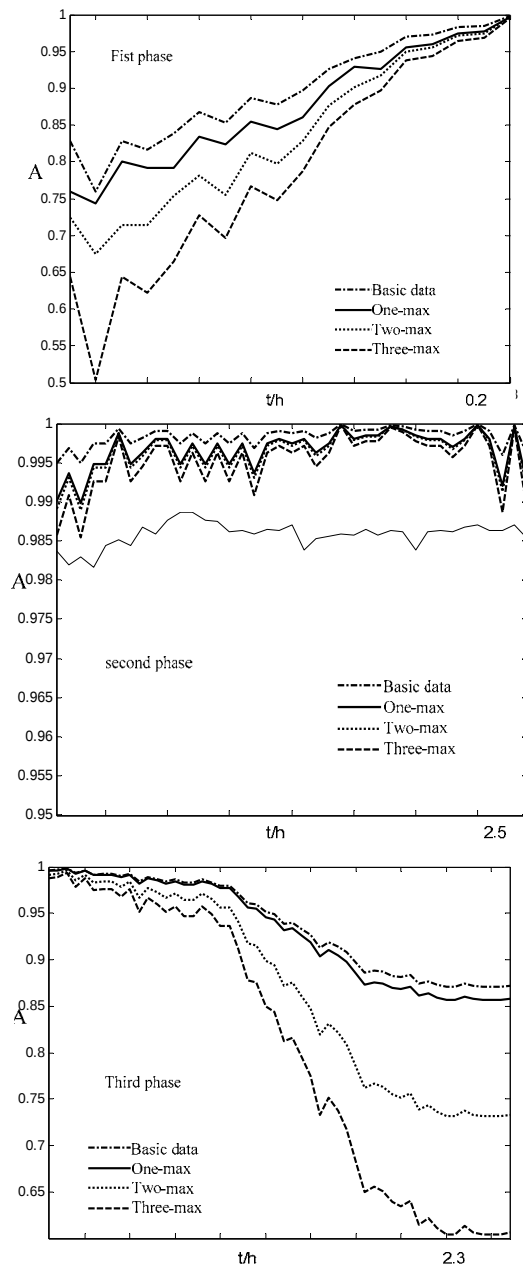


Fig 6. Influence on driver reliability level when first-class index and random several second-class indexes have the max value