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Probabilistic reliability analysis of dynamic behavior of human driver

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Abstract: The aim of this work was to develop a methodology for measuring and evaluation of dynamic behavior of the driver, to determine the differences between the behavior of unwearied and fatigued driver and to propose a development of a mechanism for continuous detection of dangerous situations, like going out of the traffic line. The most suitable characteristics for fatigue detection were determined and used for comparison with data obtained from test drives performed within 24 Hours. In the given environment if certain parameters are known for a given unwearied driver, characteristics of fatigue can be detected by the means of measurement, analysis and comparison.

Keywords: driver fatigue, dynamic behavior, human driver, human reliability, driver controller

1. INTRODUCTION

The human operator in an *MMS* system performs working and controlling operations at various stages of difficulty. The knowledge and description of the operator are among the necessary preconditions for the creation of accurate *MMS* models, which facilitate the analysis of critical points and the detection of hazardous system states as well as wrong operator actions.

The understanding of the overall human role and the operating principles related to human activity within a system is required for the successful evaluation of the safety and reliability aspects and enables further advancement in the communication between a human being and a machine (Bubb, H. (1992)). Based on his or her own experience, the human being executes and implements regulatory interventions, whose quality depends on the operator's knowledge and practice. In the described context, the human is a self-learning adaptive regulator with properties analogical to commercial regulators, which normally perform interventions based on mathematical description and analysis.

However, there is a significant aspect of difference between the human operator and a commercial regulator: the human mind. This specific property enables the operator to integrate their brain, whose functions cannot be later excluded or overridden, into the regulation process (Rasmussen, J. (1985)).

2. RELIABILITY IN SYSTEMS WITH HUMAN OPERATOR

System reliability is a function of all the elements, which define system operation; in particular, for complex systems, in addition to reliability function of system technological components, it is necessary to consider all the aspects of information technologies and human interactions (Yamamura, T., Yata, K. (1989)).

Each human activity has very specific working methods which cannot be unified or merged and it is not possible to assign them the same tabular values. Between the technical and human reliability there are basic differences especially in a way of information (data) processing and in a way of a goal reaching (Cooper, S. (1996)).

The human uses actively his mind to reach a goal or to accomplish an object and he leads his behavior with a goal every time. On the basis of actual state analysis he can choose also other tools or procedures different of those which were recommended or ordered. The human has an ability to monitor and modify his behavior permanently.

A probability of wrong execution of some object by the human can be high. However the probability of not reached final result is still very small (Bartsch, H. (2001)).

2.1 Human reliability assessment

A quantitative evaluation of human reliability is based on the total probabilistic safety analysis (PSA) of whole system *MMS* (Hollnagel, E. (1998)). A part of this analysis is also the human reliability assessment (HRA) which brings information about:

- the safety and readiness magnitude of the technical system with respect to the human interventions,
- the range and magnitude of human faults in the comparison to technical faults,
- the possibilities that lead to an increase of the reliability and the safety of the system.

Human Reliability Assessment (HRA) is the part of reliability discipline, which studies the human performance in operating actions. Human reliability is usually defined as the

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probability that a person will correctly perform some system-required activity during a given time period (if time is a limiting factor) without performing any extraneous activity that can degrade the system (Hollnagel, E. (1998)).

Human Error Probability (HEP) is probability to do an action out – of tolerance during the observation period (Reason, J. (1990)). Mathematically the human error can be quantified as:

$$HEP = \frac{n}{N} \text{, that} \quad (1)$$

n – the number of incorrectly accomplished tasks,

N – the total number of accomplished tasks.

Human Success Probability (HSP) is probability to do correctly an action during the observation period, see:

$$HSP = 1 - HEP \quad (2)$$

Many practically important distribution functions can be described with only two parameters. It is known, for example, expected value and standard deviation for the normal distribution. When evaluating the human reliability is assumed a lognormal distribution. It is determined by median M and kurtosis coefficient K. For the 5th and 95th percentiles are related as (3):

$$5.\ percentiles = \frac{M_{HEP}}{K} \text{, that} \quad (3)$$

$$95.\ percentiles = K \cdot M_{HEP}$$

M_{HEP} – the median probability of human error HEP,

K – the kurtosis coefficient of lognormal distribution.

To determine the probability of human error HEP is based in particular:

- from literary sources for similar comparable activates (generic date),
- an observation of incorrect actions in the analyzed system or similar MMS.

There exist many methods for human reliability probabilistic assessment (Cooper, S. (1996)), Reason, J. (1990)) that have the same goals- a quantitative analysis of human behaviour, an identification of possible wrong activities, and identification of weak places of the system together with creation of preconditions for suitable helping steps.

2.1 Fatigue of human driver

The fatigue is the transitory period between awake and sleep, if this period is uninterrupted, can lead to sleep. The fatigue is defined in literary sources as a state marked by reduced efficiency and a general unwillingness to work or a disinclination to continue performing the task (Fairclough, S. (1999)), (Brown, I. (1994)).

The fatigue can be classified into physical and mental categories. Mental fatigue is believed to be psychological in nature. It is a functional state, one of several intermediate conditions between the two extremes of alarm and sleep. The physical fatigue is considered synonymous with muscle fatigue (Faber &Votruba, (2003)).

Car driving is one of the most frequent activities performed by people. This activity is very dangerous, as injury or death hazard may arise from a technical defect or human failure. The driver fatigue is a serious problem in transportation systems and is believed to be a direct cause of the road related accidents. It is a well-known fact that most traffic accident result from failure of human factor (Faber & Votruba, (2003)). Global statistics demonstrate that up to 30% of traffic accidents are caused by driver fatigue (Miller, J. C. (1996)).

The driver under a fatigue influence reacts slowly; its abilities to evaluate in time and correctly any danger situation are decreased. The fatigue and attention decrease is mostly expressed on the long monotone ways on highway, where the vehicles are running on high velocity. A driver failure can have a critical impact in these situations. Fatigue has numerous causes, each with a specific incidence and relationship to traffic accidents. The factors most commonly associated with driver fatigue are monotonous environments, sleep deprivation, chronic sleepiness, drug and alcohol use (Nilsson, T. (1997), (Fairclough, S. (1999). The (Lal, S. K. L. (2001)) classified the different approaches that have been used to measure fatigue.

2.2 Fatigue and its symptoms

Human fatigue cannot in practice be measured using well defined units. There is no uniform methodology for assessing the degree of fatigue. It can discern several types of fatigue, depending on where fatigue occurs or what caused it.

Muscle fatigue is perceived as feeling the pain and is clearly identified. On the other hand sensuous fatigue is in many cases not felt nor perceived by the affected person. There are the individual's subjective feelings, which are ambiguous and difficult to quantify. The most frequent example of this type of fatigue is visual fatigue. Mental fatigue manifests indifference to the assigned functions or attempts to interrupt work activities. These symptoms lead to inability to concentrate on the task performed; the thoughts are distracted to other subjects (Bitnner, R., Smrcka, P. (1998)).

Fatigue caused by adverse factors has its origins in the environment. This is, in the case of a driver, particularly the excessive noise, vibrations etc. The fatigue leads to degradation of the control ability of the driver, slows physiological processes and can be seen as an overall downturn of the organism. Fatigue can be also seen as change in the dynamic performance of the human element in the control system (Jalovecky, R. 2009).

Very dangerous manifestation of fatigue is a micro sleep decline of attention, which occurs when there is an excessive burden on the mental abilities mostly during monotonous activities. The micro sleep as well as a regular sleep is a very complex neurophysiologic phenomenon; sleep as well as micro sleep is not fully understood yet (Bittner, R., Smrcka, P. (2000)). The micro sleep has a strongly individual character. It is influenced by both genetic and individual's overall fitness and health (Vysoky, P. (2001)).

Monitoring driver fatigue is mostly done on drive-simulators, which are not completely identical with the conditions in the real traffic and driver.

3. CONTROL ACTION OF THE DRIVER

Driving a vehicle is a complex activity. However, currently there does not exist any universal driver model capable of simulating the total of driving activities across all control levels (feedback control, coordination level based on the application of rules, knowledge-based cognitive level). Driver simulation models can be classified into two basic categories that result from the description of driving-related activities. These two classes based on the mode of vehicle driving are as follows:

- transverse driving, which is defined by both the quality of road holding and the car position inside the traffic lane,
- longitudinal driving, which is determined by the control of the car speed and acceleration in a linear direction.

3.1 Compensation vehicle driving

The basic control circuit for the transverse compensation vehicle driving is shown in Fig. 1. The eye perceives the control process, and the information from the visual field is transferred to the central nervous system by back coupling. The vehicle dynamics are represented by the transmission function Y_M, and the dynamics of the human regulator are expressed by the transmission function Y_H. The driver executes feedback control of the momentary transverse car location *y(t)*; the aim is to achieve a situation when the control divergence *e(t)* is zero and the vehicle continues moving towards the desired position $y_z(t)$.

In practice, as we have mentioned above, vehicle driving is of a complex character: It is a set of partial activities with different properties on the different control levels, see Fig.2. The levels and activities can be described as follows:

• The memorized stereotypes and routine manoeuvres are realized by the R_{pg} precognitive controller based on knowledge, qualifications and idea processes.

• The ability of prediction, which facilitates the estimation of the future trajectory and situation on the roadway. The predictive controller R_ψ participates in the vehicle control. By this controller, the driver holds his car in the required direction $\psi_r(t)$.

• The compensation controller R_y is used for the minimization of the control error *e(t)*. With this controller, the action interferences are controlled based on the visual information about the required location $y_z(t)$ and the actual location *y(t)*, see Fig.2.

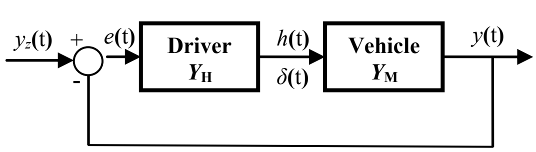

Fig. 1: Basic model of a compensation control of the vehicle.

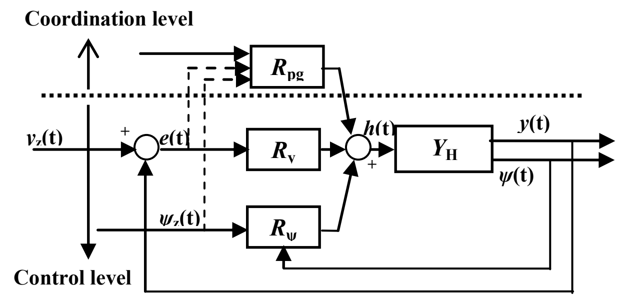

Fig.2. Types of the driver controller (Vysoky (2003)).

In feedback compensation vehicle control, the control circuit has the structure of *eye – brain – hand* and is defined by permanent feedback. The information is obtained predominantly from visual sensation, and its processing is performed in the corresponding centres of the grey cerebral cortex (ectocinerea).

The functions of the feedback predictive controller R_ψ and the precognitive controller R_{pg} are suppressed; their action interferences are not a priority, and they participate in the control only minimally (Vysoky (2003)).

3.2 Dynamic behaviour of driver

The models of driving have been couched either in terms of control or in terms of human factors. There is, however, a need for more powerful models that can match the rapidly growing complexity and complication of modern cars Hollnagel, E. (1998), (Vysoky, P. (2003) described the structure of the „active“ model of driver that enables to predict behaviour and performances in dynamic changing traffic conditions.

Dynamic behaviour of driver reflects the degree of the driver´s fatigue. Any changes of dynamics are reflected at all levels of driver´s activities. It has been demonstrated that an erroneous decisions at higher organizational or cognitive is not necessarily as hazardous as an erroneous reaction at the lowest control level (Rasmussen, 1982).

Simple systems without multiple feedbacks enable easiest analysis of dynamic manifestations and it can be assumed that the values of the selected identifiers will enable demonstrable measurement and acquisition (Boril, J. (2011)). An important condition is that the properties and control capabilities of the driver are stable – i.e. reproducible – throughout the experiment (Jalovecky, 2009).

Driver behaves as an active element in the *man – vehicle* system, with the ability to operate the vehicle, aware of the current situation based on the visual perception and anticipating future development as a result of his/her actions. The capabilities of the driver and his/her strategies develop according to the learned skills and experience, initially involving the learning process only and later on the interventions turn into learned stereotypes (Havlikova, 2008a).

4. PROBABILITY ANALYSES OF DRIVER'S TRAJECTORIES

For successful monitoring and control ability of the driver and fatigue detection are essential to prepare a representative set of drivers driving within and without fatigue. Features of test runs were chosen so that drivers gave largely compensating control system of car. It is a monotonous driving where the driver's main activity is to maintain optimum vehicle in the lane without the need to respond quickly to the environmental conditions with minimal interaction with other road users. Position of the vehicle on the road see is continuously monitored by a camera and evaluated as the lateral position y_i from the designated reference guide lines.

4.1 Analyses of the trajectory: data acquisition

All experimental data were acquired by cooperation with Laboratory of Telematics, Czech Technical University in Prague, Faculty of Transportation Sciences.

The aim of the mathematical analyses of the acquired data is to find out the difference of dynamics between a fatigued driver and a driver in a good condition. Before the driver's fatigue can be determined, following parameters must be evaluated and determined for non-fatigued drivers.

The aim of experiments was to monitor the changes of driver dynamics in situations where the driver is influenced by the fatigue. Test drives were performed on a driving simulator. The test drives in a form of repeated 10 km drives were performed within 24 hours. All test drives were time-stamped and these drives are denoted D_{Time}. During the whole 24 hour test day the driver were performing standard daily job activities. Thy results of monitoring and probabilistic analysis the dynamic behaviour of the driver OS without fatigue and under influence fatigue are presented in Fig. 3 – Fig. 10. The time record of drive trajectory $D_{7:00}$

Histograms of lateral positions y_i of the vehicle see Fig. 4, (Fig. 8) represent the most probable distance of the vehicle from the reference line and present the information of the shape distribution function drive trajectory (Havlikova, 2008b). Specifically, the probability $P(-0{,}2<y_i<0{,}2)$ of the vehicle position is at the distance 0,2 m (from the reference line) for driver OS without fatigue twice as that for driver OS with fatigue.

Changes in dynamic behaviour of driver OS are detected in particular histograms of vehicle lateral positions y_i in segments of drive trajectory $D_{7:00}$ (driver without fatigue) and $D_{8:26}$ (driver fatigued), see Fig. 5, Fig. 9. The length of the segment is chosen programmatically; specifically its value is 200 m.

In the case that a driver OS is not influenced by fatigue, the courses of distribution functions $F(y_i)$ for segments drive trajectory $D_{7:00}$ are very similar, see Fig.6. When driver OS succumbed to fatigue during the test drive $D_{8:26}$ and got out of the traffic line, the distribution functions $F(y_i)$ for segments drive trajectory had a different course (the thick line), see Fig. 10.

Fig.3. Test record of drive trajectory $D_{7:00}$, Driver OS without fatigue.

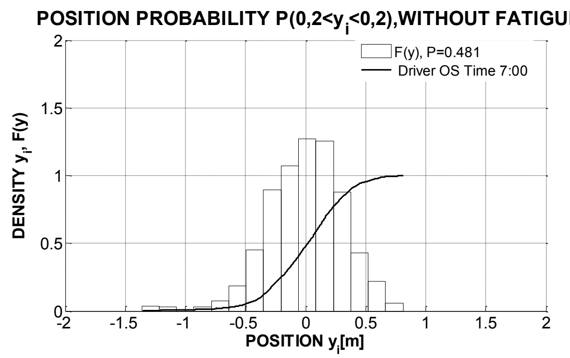

Fig.4. Histogram of vehicle lateral positions y_i, distribution function $F(y_i)$ of drive trajectory $D_{7:00}$, Driver OS without fatigue.

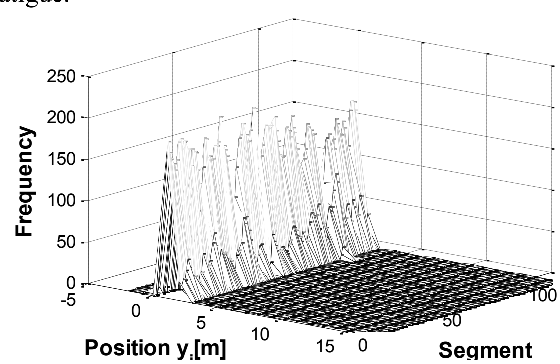

Fig.5. Histograms of vehicle lateral positions y_i in the segments (length 200 m) of drive trajectory $D_{7:00}$, Driver OS without fatigue.

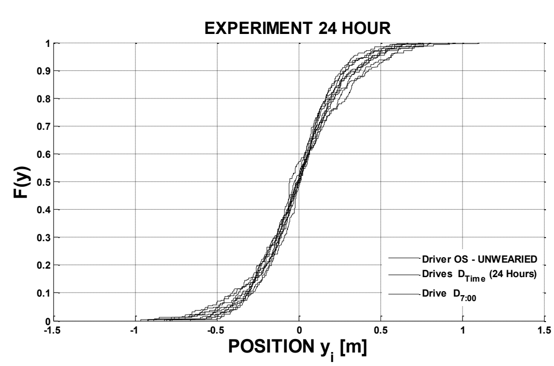

Fig.6. Distribution functions $F(y_i)$ for the segmetns of drive trajectory $D_{7:00}$, Driver OS without fatigue.

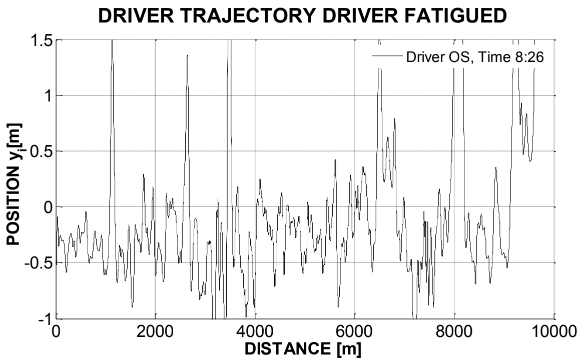

Fig.7. Test record of drive trajectory $D_{8:26}$, Driver OS fatigued.

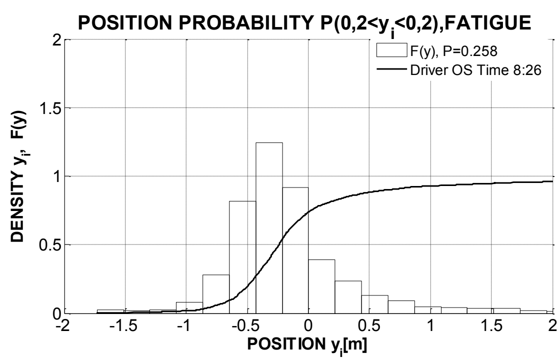

Fig.8. Histogram of vehicle lateral positions y_i, distribution function *F(y)* of drive trajectory $D_{8:26}$, Driver OS fatigued.

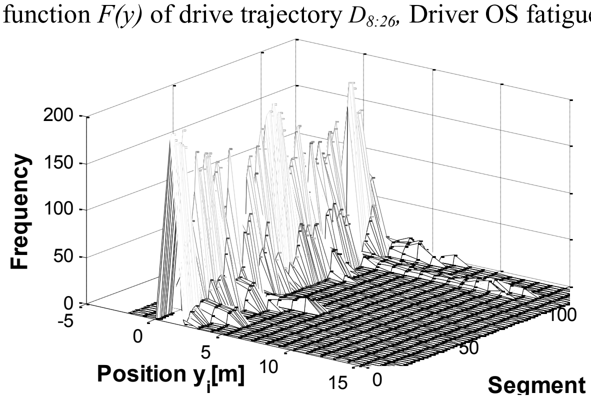

Fig.9. Histograms of vehicle lateral positions y_i in the segments (length 200 m) of drive trajectory $D_{8:26}$, Driver OS fatigued.

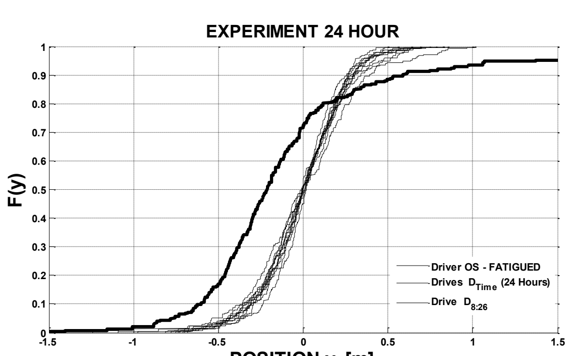

Fig.10. Distribution functions $F(y_i)$ for the segments of drive trajectory $D_{8:26}$, Driver OS fatigued.

4. CONCLUSIONS

The fatigue factor certainly takes effect in the dynamic behaviour of a driver during the drive. Monitoring and analyses of monotone test drives focused of compensation control of the vehicle proved the differences of drivers' behaviour according the time of the day. The changes of the dynamic symptoms in the drives performed by fatigued drivers at the simulator were demonstrably identified by probabilistic analysis.

Currently, the methodology of continuous monitoring of test drives is developed. Calculations of these characteristics are implemented in monitored drive sections of selectable length, calculated values are recorded and compared by the means of a selected algorithm. However, accurate interpretation and evaluation of changes in driver's behaviour depends on availability of values of important drive characteristics for a given driver in the unwearied state.

These results demonstrate the importance of the inclusion of the human factor to the reliability analysis of MMS.

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REFERENCES

Bartsch, H. (2001). Vorlesungsmaterial, BTU Cottbus, Cottbus, Germany.

Bittner, R., Smrcka P. (2000). Detecting of fatigue states of a driver, International symposium on Medical Data Analysis ISMDA, Frankfurt am Main, Springer Verlag,

Bittner, R., Smrcka, P. (1998). *Fatigue Indicators of Drowsy Drivers Based on Analysis of Physiological Signals*. Springer Berlin / Heidelberg, Volume 2199/2001, p. 62-68.

Boril, J., Jalovecký, R. (2011). *Response of the Mechatronic System, Pilot-Aicraft, on Incurred Step Distrubance*, In Procedings ELMAR-2011: 53rd International Symposium. Zagreb: ITG, pp 261-264, ISSN 1334-2630.

Brown, I. (1994). *Drive fatigue*. Human Factors, 36, 298 – 314.

Bubb, H. (1992). *Menschliche Zuverlässigkeit*, EcoMed, Landsberg.

Cooper, S., Ramey-Smith, A., Wreathall, J., Parry, G. (1996). *A Technique for Human Error Analysis (ATHEANA)* - Technical Basis and Metodology, Description. NUREG/CR-6350. NRC. Washington.

Faber, J., Votruba, Z. (2003). *The Limitation of a Driver and Vehicle Interaction Reliability*. Transportation and Telecommunication in the 3rd Millennium, 10th Anniversary of the Foundation of the Faculty Transportation Science, Praha.

Fairclough, S. H., Graham, R. (1999). *Impairment of Driving Performance Caused by Sleep Deprivation or Alcohol*: *A comparative Study*,Human Factors, The Journal of the Human Factors and Ergonomics Society, 41, issue 1, 118-128.

Havlikova, M. (2008a). Dynamics of the Human Operator in systems MMS (in czech), Automatizace, 51, issue 1, 17-20.

Havlikova, M. (2008b). Diagnostic of systems with a human operator, Doctoral Thesis, Brno.

Hollnagel, E. (1998). *Cognitive Reliability and Error Analysis Method – CREAM*, Elsevier, New York, Amsterdam.

Jalovecky, R. (2009). *Man in the aircraft's flight control system*. Advance in Military Technology, Journal of Science. University of Defence. Brno

Lal, S. K. L., Craig, A. (2001). *A critical review of the psychophysiology of driver fatigue*, Biological psychology, 55, 173-194.

Miller, J. C. (1996). *Commercial Motor Vehicle Driver Fatigue and Alertness Study*, Report No. FHWA-MC-97-002, Federal Highway Administration, Washington, D.C.

Nilsson, T., Nelson, T. M., and Other (1997). Development of fatigue symptoms during simulated driving, Accident Analysis & Prevention, 29, issue 4, 479-488

Rasmussen, J. (1985). *Information Processing and Human - machine Interaction*, An Approach to Cognitive Engineering, New York: North-Holland.

Reason, J. (1990). *Human Error*, Cambridge University Press, Cambridge (GB).

Vysoky, P. (2001). *Central fatigue identification of human operator*, Neutral network world, Vol. 11, No. 5, p. 525-535.

Vysoky, P. (2003). *Dynamické vlastnosti lidského operátora jako řidiče* (in czech). Automatizace, Vol. 46, Issue 12, pp. 796-800. ISSN 0005-125X.

Yamamura, T., Yata, K. (1989). *A basic study on human error in communication network operation*, Global Telecommunications Conference, and Exhibition – Communications Technology for the 1990s and Beyond, GLOBECOM, Vol. 2, pp. 795-800.