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Determination of Level of Automation for an Adequate Human Performance

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ABSTRACT

The automation system has hugely grown during the last years, and it is the major trend of the 21st century. The automation system can provide superior reliability, improved performance, and reduced costs for many functions. The human-machine design could not be out of this development and technological advancement. Human-machine design takes into account the human factors and human and machine limitations and abilities through the levels of automation. Therefore, it is primordial to consider in the design of such systems, the automation level for adequate human performance. This paper has the purpose to present a preliminary approach for evaluating human performance during a car parking activity with and without car parking assistance (an automated system) and also to analyse the impacts associated with parking assistance in the human error contributing factors. The method for determining the level of automation is based on four generic functions intrinsic to man-machine domain, which's are: monitoring, generating options, selecting options, and implementing. The human performance analysis is proposed through the Bayesian Networks approach supported by Fuzzy Logic whose application is to model the performance shape factors and checking, through a causal inference and diagnosis, which factors most influence the performance of the tasks in a specific level of automation. The result indicated a positive aspect, the activity with a higher chance of occurrence of a human error in procedure without the parking assistance system was the activity with the parking assistance with higher automation level. The analysis recommends that the alarm and panel design should be revaluated since different alarms and equipment are used to offer the same information, causing the make decision slower and complacency. The button which turns on the parking assistance system also is the one that selects three types of manoeuvres; in addition, the throttle can be used for controlling the manoeuvres, and both information should be part of the training before using parking assistance. Despite workload increases with the parking assistance, the human error chance decreases.

Key Words: Level of Automation, Human Error, Bayesian Network, Fuzzy Logic and Parking Assistance

1. INTRODUCTION

The automation system has hugely grown during the last years, and it is the major trend of the 20th century, and it can provide superior reliability, improved performance, and reduced costs for many functions. Due to benefit that promises the automation system has been implemented in some complex systems (e.g. aircraft cockpit, room operations, car driving, and etc). Meanwhile in these environmental there is not have a full autonomous system and it is still needed the human interaction in performing those system operation. Automation refers to the full or partial replacement of a function previously carried out by the human operator. This implies that automation is not all or none, but can vary across a continuum level, from the lowest level of fully manual performance to the highest level of full automation (Parasuraman, Sheridan, and Wickens 2000). Researches and accident investigation reveal advanced automation can have a negative impact on human factors, the complacency has been identified as a contributing factors in numerous aviation accidents and is proving synonymous with automation in related literature, and it may be likely a causal relationship exists between complacency and human error in advanced automation. The intent of automation is to minimize pilot workload and increase safety, however, evidence indicates that when automation does not function as it should, the pilot(s) can become overloaded and overwhelmed, experiencing a complete loss of situational awareness. Information processing is significantly affected and cognitive resources are strained (Brown 2017). The two recent fatal accidents involving the brand new Boeing 737 Max 8 fourth generation airplane reignited the discussions on the suitability of the increasing aircraft automation levels. Although the data presented in this study demonstrate that the automation phenomenon increased flight safety, some relevant research indicates that high levels of automation may have undesirable outcomes, and contribute for the increment of accidents rates (Crespo 2019). FAA's Flight Deck Automation Working Group report highlighted that automated features inconsistencies characterized as unexpected or unexplained response were registered in 46% of the accident reports and 60% of the reports on major incidents for occurrences happened after 1996 with final official conclusions available by July 2009 (Kathy Abbott, David McKenney 2013). Other recent accidents with automated vehicles have moved the driverless-car industry into a new period of more cautious optimism and testing procedures. The fatal crash of an Uber Technologies Inc. test autonomous vehicle March 2018 and separate crashes involving Tesla driver-assistance system has shown there is a long way to go technologically, in terms of liability as well as public opinion and end user acceptance (Jenssen SINTEF et al. 2019). The position of the National Transportation Safety Board on the autonomous car accident is that it came about because of a combination of an "inadequate safety culture" at the developer and "automation complacency," which it describes as the failure of the human safety driver to monitor an automation system for its failures. These accidents have been associated with operator vigilance and complacency leading to loss of situation awareness (SA) and manual skill decay. It has been hypothesized that by keeping the human involved in system operations, some intermediate Level of Automation (LOA) may provide better human system performance and SA than that found with highly automated systems (Blömacher, Nöcker, and Huff 2018). In order to determine the level of automation for human performance adequate, this research will be started by preliminary approach for evaluating human performance during a car parking activity with and without car parking assistance (an automation system) and also to analyse the impacts associated with parking assistance in the human error contributing factors. The method for determining the level of automation is based on four generic functions intrinsic to man-machine domain, which's are: monitoring, generating options, selecting options, and implementing. The human performance analysis is proposed through the Bayesian Networks approach supported by Fuzzy Logic whose application is to model the performance shape factors and checking, through a causal inference and diagnosis, which factors most influence the performance of the tasks in a specific level of automation.

2. LITERATURE REVIEW

2.1 AUTOMATION TO AUTONOMY AND AUTONOMOUS

Machine, especially computer, are not capable of carrying out many functions that at one time could only be performed by humans. Machine execution of such functions or automation has also been extended to functions that humans do not wish to perform, or cannot perform as accurately or reliably as machines. How particular functions are automated, and the characteristics of the associated sensors, controls, and software are major concerns in the development of automated systems (Parasuraman, Sheridan, and Wickens 2000). An automated or automatic system is one that, in response to inputs from one or more sensors, is programmed to logically follow a pre-defined set of rules in order to provide an outcome. Knowing the set of rules under which it is operating means that its output is predictable. It is generally accepted that an automated system is one that does not make choices for itself, but follows a script in which the choice out of all possible courses of action has already been made. If the system encounters an unplanned-for situation, it stops and waits for human help. Autonomy is the ability of a system to govern itself by making decision, implementing the choice made, and checking the evolution of such actions taken. An autonomous system, however, does make choices on its own. It tries to accomplish its objectives locally, without human intervention, even when encountering uncertainty or unanticipated events. However, autonomous systems do have an automatic and automated decision-making process (Insaurralde and Lane 2014). The definitions and the understanding of relation among the term automation, automatic, autonomy and autonomous can be represented in the Figure 1 below.

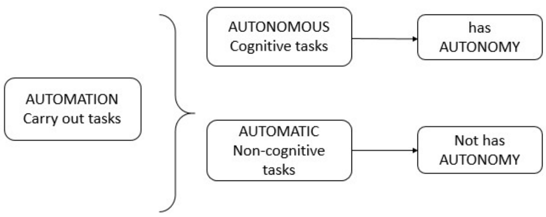

Figure 1 – Automation Illustrative Means

2.2 LEVEL OF AUTOMATION

The automation refers to the full or partial replacement of a function previously carried out by the human operator. This implies that automation is not all or none, but can vary across a continuum level, from the lowest level of fully manual performance to the highest level of full automation. Table 1 shows a 10-point scale, with higher levels representing increased autonomy of computer over human action, based on a previously proposed scale. For example, at a low level 2, several options are provided to the human, but the system has no further contribution to the decision about which option should be chosen. At level 4, the computer suggests one decision alternative, but the human retains authority for executing that alternative or choosing another one. At a higher level 6, the system gives the human only a limited time for a veto before carrying out the decision choice. (Parasuraman, Sheridan, and Wickens 2000)

Table 1 – Level of Automation

LEVEL OF AUTOMATION	FUNCTIONS			
	MONITORING	GENERATING	SELECTING	IMPLEMENTING
1	HUMAN	HUMAN	HUMAN	HUMAN
2	HUMAN/MACHINE	HUMAN	HUMAN	HUMAN/MACHINE
3	HUMAN/MACHINE	HUMAN	HUMAN	MACHINE
4	HUMAN/MACHINE	HUMAN/MACHINE	HUMAN	HUMAN/MACHINE
5	HUMAN/MACHINE	HUMAN/MACHINE	HUMAN	MACHINE
6	HUMAN/MACHINE	HUMAN/MACHINE	HUMAN/MACHINE	MACHINE
7	HUMAN/MACHINE	MACHINE	HUMAN	MACHINE
8	HUMAN/MACHINE	HUMAN/MACHINE	MACHINE	MACHINE
9	HUMAN/MACHINE	MACHINE	MACHINE	MACHINE
10	MACHINE	MACHINE	MACHINE	MACHINE

As noted in the Table 1 two agents, the computer (machine) and the human work separated, or both working together, define the level of automation of different types of functions in a human-machine system, basically input and output functions; the Figure 2 presents these functions.

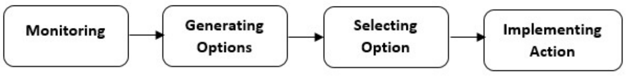

Figure 2 – Man-Machine Interface Functions

The input functions are monitoring and generating options (information) and output functions are selecting options (make decision) and implementing action. The Figure 2 presents the first stage, which refers to the acquisition and registration of multiple sources of information. This stage includes the positioning and orienting of sensory receptors, sensory processing, initial pre-processing of data prior to full perception, and selective attention. The second stage involves conscious perception, and manipulation of processed and retrieved information in working memory. This stage also includes cognitive operations. The third stage is where decisions are reached based on such cognitive processing. The fourth and final stage involves the implementation of a response or action consistent with the decision choice (Parasuraman, Sheridan, and Wickens 2000). The use of intermediate LOA may provide an approach to human-centred automation; that is designed and implemented to be compatible with human capabilities. Traditionally, automation design decisions have focused on optimizing the capabilities of the technology (technology-centred automation). Driven by a desire to reduce costs (through the reduction of human workload) such efforts usually assign a computer or mechanical controller to perform those tasks technically possible, and remove operators from the control loop by placing them in the job of system monitor. The monitoring is a role for which humans are generally ill-suited (Endsley and Kaber 1999).

3. HUMAN-MACHINE INTERFACE AND INTERACTION

The term man-machine system denotes a system in which people have a monitoring and/or control function. The term man-machine interface refers to points of interaction between people and the system. At the interaction point occurs the communication between human and machine. In the information exchange process also occurs the cognition process. In the cognition process is involved from human side and also from machine side, the three of four functions, monitoring, generating options, and selecting options, being that implementation would be the physical. Based on this understanding, comes up the model presented in the Figure 3 below.

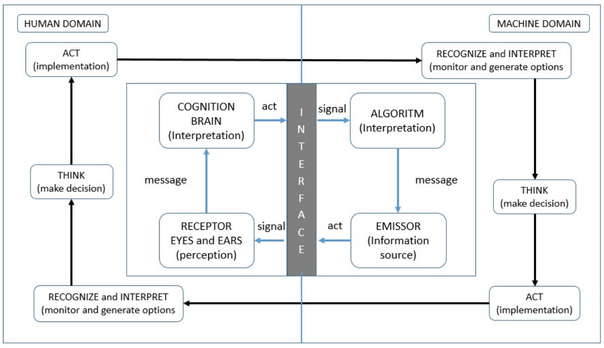

Figure 3 – Human-Machine Interaction

The model was based and adapted on interactive model between human and computer and by system limits (Helander 1998). The Figure 3 presents the interaction between human-machine through an interface; it is in the interaction that happens the communication and the information process, where the four functions monitoring, generating options, selecting options and implementing actions occur in the human and machine domains. This way, for each action of a task through an interface, it can have the human and machine interacting separated or together within four functions determining the level of automation of those actions into task.

3.1 HUMAN ERROR AND AUTOMATION

A human error is an action or decision involved in a deviation from an accepted standard, which was not intended to, but led to an undesirable outcome. It is necessary to study the human interactions with the system for predicting or mitigating the effects of errors on the system. As mentioned, the automation reduces costs and workload, performing those tasks technically possible and removing human from the control loop by placing them in the job of system monitor. This out-of-the-loop performance problem has been attributed to numerous factors including vigilance decrements and complacency loss of operator situation awareness. Situation awareness is related to perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. Situation awareness has developed as a major concern in many other domains where people operate complex, dynamic systems, including the nuclear power industry, automobiles, air traffic control, medical system, teleoperations, maintenance, and advanced manufacturing systems. Achieving situation awareness is one of the most challenging aspects of these operators' jobs and is central to good decision making and performance (Endsley 2018). The loss of situation awareness is the human error most common and occurs when the automation acts independently of the human and without his awareness. The human error analysis is to determine incompatibilities between the automated system and human ability whilst identifying automation vulnerabilities to the human operator.

3.2 HUMAN RELIABILITY ASSESSMENT - HRA

Human reliability is defined as the probability that a task will be successfully completed by personnel at any required stage in system operation within a required minimum time (if the time requirement exists) (Swain and Guttman 1983). Human reliability analysis is a structured and systematic manner of estimating the probability of human error in specific tasks and identifies within the system weaker human interface. The HRA procedure consist into five steps according to Figure 4 below. (Chandler et al. 2010)

Figure 4 - Human Reliability Analysis

3.3 PERFORMANCE SHAPE FACTOR

In modelling human performance, it is necessary to consider those factors that have the most effect on performance. Some of these performance shaping factors (PSFs) are external to the operator and some are internal. The external PSFs include the entire work environment, especially the equipment design and the written procedures or oral instructions. The internal PSFs represent the individual characteristics of the person--his skills, motivations, and the expectations that influence his performance (Swain and Guttman 1983).

3.4 GENERIC MODEL

This generic model represents the human in a complex system.(Bayma and Martins 2017).

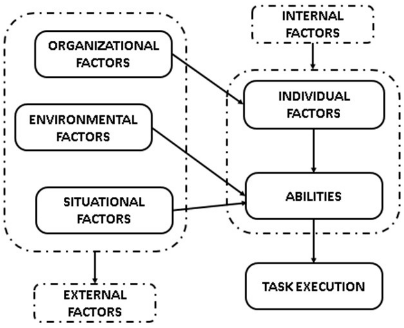

Figure 5 - Generic Model - Performance Factors Influence

The generic model proposed in

Figure 5 represents the influences propagation of the external factors on the internal factors that influence in the task execution. The structured dependence relationship proposed in this diagram allows a greater assertiveness in the analysis of the probable causes of the human errors in the task execution.

3.5 BAYESIAN NETWORK APPROACH TO HUMAN RELIABILITY ASSESSMENT

Bayesian networks are graphical models for reasoning based on uncertainty, where nodes represent discrete or continuous variables, and the arcs represent the direct connection among them. A Bayesian network is a directed acyclic graph, which is defined by qualitative and quantitative components. Qualitative component is represented on the graph topology and quantitative component is formed by the conditional probabilities (Schleder 2012). The nodes which the arches come from are called of parents nodes, the nodes where arrive the arches are called of children nodes. Quantitatively, each child node *Xi* receives conditional probabilities *P(Xi|parents(Xi)*) expressing the influence of parents nodes (Maturana 2010). Given the probabilities of parents nodes set *Ai = (A1, A2…A*n), influencing the probability of child node *Ei*, the conditional probability child node *Pr(Ej| A1∩A2∩…An)* is the result of influence of parents nodes probabilities in the child node probability. By assuming that the probabilities of parents nodes set *Ai = (A1, A2…An)*, are independents then the marginal probability of child node *Pr(E)* can be calculated applying the total probabilities theorem. This result can be written as:

$$Pr(E) = \sum_{i=1}^{n} Pr(A_i)\, Pr(E|A_i) \qquad \text{Eq.1}$$

After having the domain of probabilities of events, the Bayesian analysis can be used for updating a priori information based on any evidence *(E)* (parents or child). The updated priori probability *Pr(A*) is known as posteriori probability *Pr(Aj|E),* given a probability of evidence *Pr(E|Aj).* This relation is known as Bayes Theorem.

$$Pr(A_j|E) = \frac{Pr(A_j) \cdot Pr(E|A_j)}{\sum_{i=1}^{n} Pr(A_i)\, Pr(E|A_i)} \qquad \text{Eq. 2}$$

The Bayes Theorem is a mean of updating of knowledge regarding an event by evidence related to any event in the network. The human reliability assessment by Bayesian network approach presents the following contributions: Identifying errors of contextual manner, estimation of probabilities, graphic structure that represents relations of causes and effects among variables, subjective inferences (Mosleh and Chang 2004).

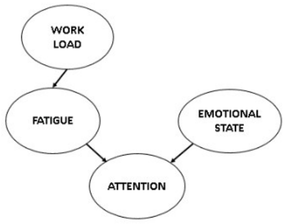

Figure 6 - Bayesian Network - Attention Variable

Figure 6 presents an example of Bayesian network in which the attention variable is influenced by fatigue and emotional state variables, and in turn fatigue is influenced by work load, that is, the attention variable of the individual is influenced directly by fatigue and by emotional state and indirectly by work load.

3.6 FUZZY LOGIC

The Fuzzy logic can be applied in the Bayesian network for getting the conditional probabilities by combining of nodes parent probabilities. This combination is possible by Boolean logic commonly used in the artificial intelligence. The Fuzzy Logic Modelling is utilized in modelling of uncertainties for which statistical data are not available. Fuzzy logic is a multiple values logic, which allows intermediate values defined between conventional evaluations as true / false, yes / no, low / high, etc. Notions such as too much or too fast can be formulated mathematically and processed by computers. The fuzzy logic is based on the fuzzy set theory and it can be defined as a collection of elements in a universe of information, where the limit of the set contained in the universe is ambiguous, vague and diffuse. This set is defined as:

$$A{:}X \rightarrow [0,1] \qquad \text{Eq. 3}$$

This type of set allows its members have different degrees of pertinence (pertinence function) in the interval [0,1]. The Eq. 3 presents the pertinence interval [0,1], where 0 means that one element does not pertain to a set and 1 means that one element has complete pertinence to a set. Values between 0 and 1 represent pertinence degrees. In the Fuzzy logic, one element pertains to a set with certain pertinence degree, becoming this element partially true or partially false (Nascimento and Mesquita 2010). The pertinence functions more used are functions trapezoidal and triangular. In this paper, trapezoidal and triangular functions were used for achieving the conditional probabilities of Bayesian network conditional probabilities tables.

4. APPLICATION AND RESULTS

This case study aim at validating analysis for determining the level of automation based on four generic functions intrinsic to man-machine domains, which are: monitoring, generating options, selecting options, and implementing, and also by application of analysis of Level of Automation (LoA) Table 1 – Level of Automation. After determining the level of automation, this study case also aim at evaluating the adequate human performance. The human performance analysis is proposed through the Bayesian Networks approach supported by Fuzzy Logic whose application is to model the performance shape factors and checking, through a causal inference and diagnosis, which performance factors that most influenced the human error in performing of activities in a determined automation level. It will be evaluated the human performance during a car parking activity *with and without* car parking assistance (an automation system). For the construction of the Bayesian networks was used the academic software Genie 2.2, and for obtaining marginal, it was applied a questionnaire to 20 test subjects and conditional probabilities applied the logic fuzzy technique by Matlab version 2017. The method starts with the familiarization of car parking assistance activities.

4.1. FAMILIARIZATION WITH THE CAR PARKING ASSISTANCE PROCEDURE

The modelling of complex system refers to event set of the car maneuver task *with* parking assistance. The complete maneuver was acquired by video training. 20 test subjects performed task, 08 women (3 over the age of 50) and 12 men (5 over the age of 50). The criteria for selecting test subject was based on author experience with human factor test in the civil aviation. The car maneuver task by parking assistance is divided into 15 activities: 1) To looking for and to find space for parking; 2) To active autonomous maneuver; 3) To choice the side for parking and to show it; 4) To recognize and to capture space; 5) To communicate for moving forward for fitting the right point for stopping; 6) To move the car forward for fitting; 7) To communicate for stopping and to set car reverse; 8) To stop the car and to set reverse; 9) To maneuver the car; 10) To emit reverse sound by the sensors; 11) To communicate for stopping the car and fit it forward ; 12) To stop the car and to move it forward; 13) To maneuver and to align the car; 14) To emit the reverse sound by sensors; 15) To warn "parking concluded". The number of tasks *with* parking assistance is higher than without parking assistance, therefore it is possible to infer that the workload is higher as well.

4.2. FAMILIARIZATION WITHOUT THE CAR PARKING ASSISTANCE PROCEDURE

The same 20 test subjects performed the maneuver with parking assistance also performed the maneuver *without* car parking assistance. The car maneuver task without parking assistance is divided into 4 activities: 1) To looking for and to find space for parking; 2) To move car forward for fitting; 3) To stop the car and to set reverse; 4) To maneuver the car.

4.3. LEVEL OF AUTOMATION ANALYSIS

The level of automation analysis was applied in the car parking assistance procedure, and it started by each activity with its respective interface, questioning which agent or both (human and/or machine) has performed the function monitoring, generating, selecting and implementing. The answers to the questioning are analyzed and compared with Table 1 – Level of Automation. The activity, "To maneuver the car" was the one with the highest level of automation, level 4, as can be noticed the implementing function has participation for both human and machine.

4.4. HUMAN RELIABILITY ANALYSIS WITHOUT PARKING ASSISTANCE

For verifying the effectiveness of parking assistance system, firstly it will be analyzed the human reliability in the maneuver procedure without parking assistance with objective of knowing the interface and the factors that most contribute to human error. Afterwards, it will be analyzed the human reliability in the maneuver with parking assistance for knowing the interface and the factors that most contribute to the human error, and to evaluate the contribution of parking assistance system in relation to human error. For human reliability analysis without parking assistance were selected the activities: 1) To move the car forward for fitting the right position to start the maneuver; 2) To stop the car and to set reverse; 3) To maneuver the car. The Figure 7 presents the influences propagation of the organizational factor on the individual factors that in turn influences abilities, similarly the situational factors also influences abilities, and abilities in turn influences activities, and the combination of the activities result in human errors, which are represented by nodes, ERRORhuman1 and ERRORhuman2. As example it will be presented how was obtained the marginal probabilities of node ERRORhuman2 without parking assistance task. As mentioned in section 2, the conditional probabilities can be acquired by the inference fuzzy system. As Figure 7 once obtained the marginal probabilities of nodes, "ERRORhuman1" and "MONOEUVERcontrol", and with the conditional probabilities of child node, "ERRORhuman2" and with total probability theorem, it was possible to determine the marginal probabilities of ERRORhuman2 according to Table 2 .

Table 2 - ERRORhuman2 Marginal Probability

ERRORhuman1	MANOUVERcontrol	ERRORhuman2	
$P(V1_i)$	$P(VI_j)$	$P(T1_j \mid V_i, VI_j)$	$P(T1_j \mid V_i, VI_j)^c$
		ADEQ	INADEQ
P(NO) = 0,49	P(ADEQ) = 0,48	0,485	0,515
	P(INADEQ) = 0,52	0,196	0,804
P(YES) = 0,51	P(ADEQ) = 0,48	0,235	0,765
	P(INADEQ) = 0,52	0,225	0,775

Applying total probability theorem, where *P(T1$_i$)* is ERRORhuman2 marginal probability of error P(YES) or not P(NO) and *P(Vi)* is ERRORhuman1 marginal probability of error P(YES) or not P(NO) and *P(VIj)* is MANOUVERcontrol marginal probability to being adequate P(ADEQ) or P(INADEQ) and *P (T1j |Vi, VIj)* are conditional probabilities

$$P(T1_j) = \sum_{i=1}^{4} P(\mathrm{V}_i)P\,(\mathrm{VI}_i)P\left(\mathrm{T1_j}\middle|\mathrm{V}_i,\mathrm{VI}_i\right) \quad \text{Eq. 4}$$

$P(NO) = 0.49 \times [0.52 \times 0.485 + 0.48 \times 0.196] + 0.51 \times [0.52 \times 0.235 + 0.48 \times 0.225]$=0.28

$P(YES) = 0.49 \times [0.52 \times 0.515 + 0.48 \times 0.804] + 0.51 \times [0.52 \times 0.765 + 0.48 \times 0.775]$=0.72

$$P(NO) = 0.28$$

$$P(YES) = 0.72$$

The same procedure presented above was applied for each node of Bayesian network, resulting in the Figure 7 and Figure 8 below.

4.5. RESULTS ANALYSIS WITHOUT PARKING ASSISTANCE

As mentioned in the section 3.4 it was analyzed the human reliability in the procedure *without* parking assistance system. The results were acquired by applying the software GeNIe2.2 Academic and by assuming that the activity “ERRORhuman2” occurred, the activity “MANOUVERCONTROL” presents the highest variation in 10% in the occurrence probability of the state “INADEQUATE’. The causal analysis proceed by considering that the activity “MANOUVERCONTROL” presents 100% of chance to be in the “INADEQUATE” state, observe that the ability “MAKEDECISION” presented the variation of the occurrence probability of the “INADEQUATE” state in 29%, ability “ABILITYPHYSICAL” presented the variation of the 29% in the occurrence probability of the “INADEQUATE” state and individual factor “TIMECONCERN” 100% in the occurrence probability of the “INADEQUATE” state according to Figure 7 below. By assuming that the activity “ERRORhuman1” occurred, the activity “STOPCAR” presents the highest variation in 45% in the occurrence probability of the state “INADEQUATE’. The causal analysis proceed by considering that the activity “STOPCAR” presents 100% of chance to be in the “INADEQUATE” state, observe that the ability “ATTENTION” presented the variation of the occurrence probability of the “INADEQUATE” state in 26%, and individual factor “EXPERIENCE” presented the variation of the 21% in the occurrence probability of the “INADEQUATE” state, according to Figure 7 below. Summarizing: The human error in the task *without* parking assistance system, the activities: “MANOUVERCONTROL” and “STOPCAR” were the one that most contributed to human error, and the factors that most contributed were: the “MAKEDECISION”, “ABILITYPHYSICAL”, “ATTENTION”, “EXPERIENCE” and “TIMECONCERN” the interfaces were: “BRAKE” and “STERRING

4.6. HUMAN RELIABILITY ANALYSIS WITH PARKING ASSISTANCE

For human reliability analysis with parking assistance were selected the activities more critical and relevant for parking with assistance: 2) To active autonomous maneuver; 3) To choice the side for parking and to show it; 6) To move the car forward for fitting; 8) To stop the car and to set reverse; 9) To maneuver the car. The same procedure for building of Bayesian network for the procedure without parking assistance also it was made for Bayesian network with parking assistance, and the result is in Figure 8.

4.7. RESULTS ANALYSIS WITH PARKING ASSISTANCE

As mentioned in the section 3.6 it was analyzed the human reliability in the procedure with parking assistance system. These results were acquired by applying the software GeNIe2.2 Academic and by analyzing the “ERRORhuman4”, “ERRORhuman3”, “ERRORhuman2” and “ERRORhuman1”, the one that had the activity with highest variation in state “INADEQUATE” was the ERRORhuman2. By assuming that the activity “ERRORhuman2” occurred, the activity “CARmoving” presents the highest variation in 27% in the occurrence probability of the state “INADEQUATE’. The causal analysis proceed by considering that the activity “CARmoving” presents 100% of chance to be in the “INADEQUATE” state, observe that: 1) the ability “MAKEDECISION” presented the variation of the occurrence probability of the “INADEQUATE” state in 47%;

2) the ability "ATTENTION" presented the variation of the occurrence probability of the "INADEQUATE" state in 39%; 3) the ability "INTERPRETATION" presented the variation of the occurrence probability of the "INADEQUATE" state in 33%; and by assuming: 1) the ability "ATTENTION" 100% "INADEQUATE" the interface (equipment) "PANEL" presented the variation of the occurrence probability in 40%; 2) the ability "INTERPRETATION" 100% "INADEQUATE" the interface (equipment) "WRITTENinst" presented the variation of the occurrence probability in 33%; and 3) the ability "MAKEDECISION" 100% "INADEQUATE" the interface (equipment) "GEARBOX" presented the variation of the occurrence probability in 47%, according to Figure 8. Summarizing: The human error in the task with parking assistance system, the activity "CARmoving" was the one most contributed with human error, and the factors that most contributed to this were: the abilities "MAKEDECISION", "ATTENTION" and "INTERPRETATION", and the interfaces were: "GERABOX", "PANEL" and "WRITTENinst'. However the activity "MANOUVERcontrol" still contributing less to human error, and the factor ability that the most contributed was "INTERPRETATION" demanding more knowledge and training for the human.

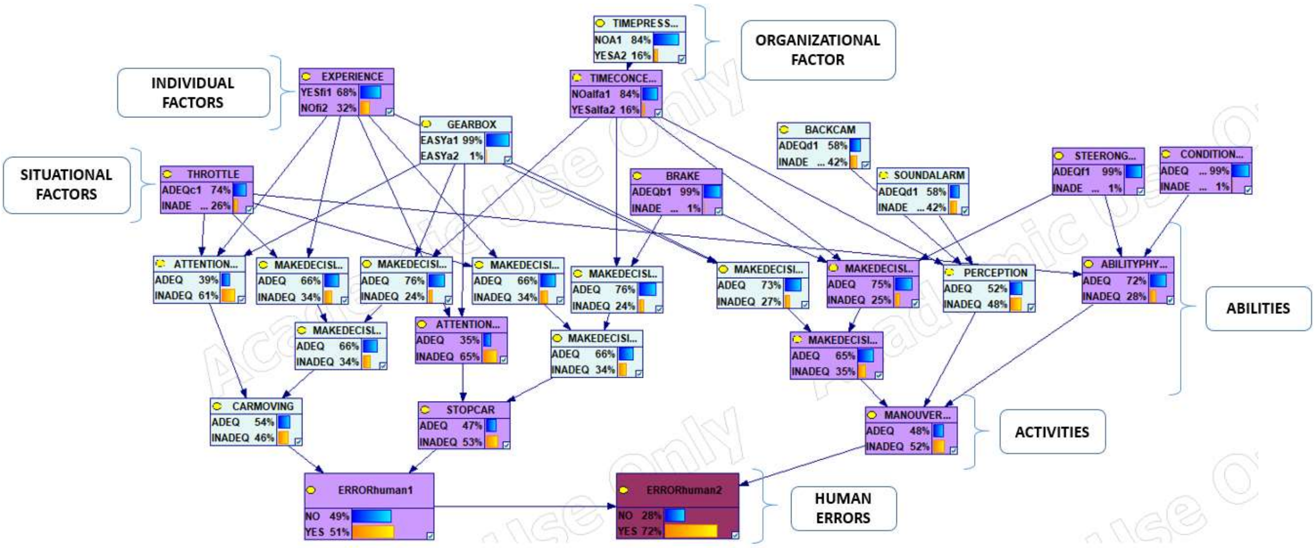

Figure 7 – Maneuver without Parking Assistance

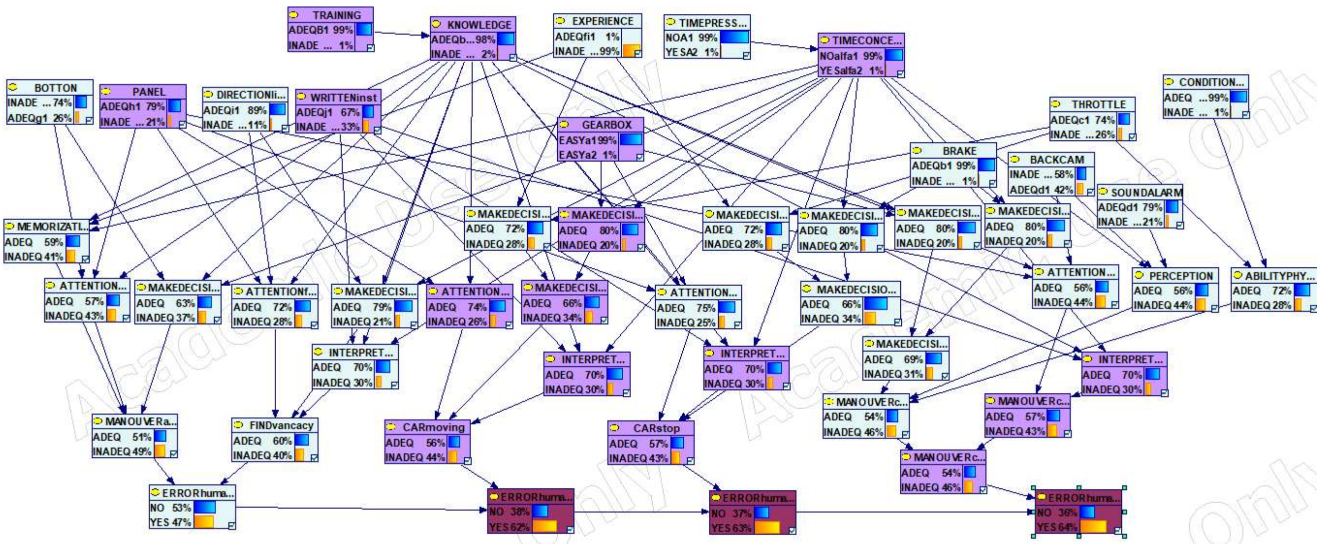

Figure 8 – Maneuver with Parking Assistance with Human Error

5. CONCLUSIONS AND RECOMMENDATIONS

The maneuver with parking assistance system decreased the human error chance (72% to 64%) according to the developed model presented in Figure 7 and Figure 8 .The activity “CARmoving”, (to move and car forward for fitting), was the one that presented the highest variation in 27% in the occurrence probability. Assuming that this human error has occurred, the related interfaces (equipment) are panel and written instruction. Faced with this fact it is recommended that the level of automation is LOA 3, once that LOA 3, the machine implements the activity, once that the human presents higher chances of error interfacing with panel and written instructions in the performing of activity: to move the car forward for fitting. Despite the parking assistance results in an increased workload, it is effective in becoming the car maneuver an easier task for a human, because this activity is not more the one that contributes to human error. Therefore, it is possible to conclude that level of automation 4 is adequate for this activity, however the activity of maneuvering car still contributing less to human error along with factor ability interpretation, however demanding more knowledge and training in the maneuver. During the performance of testing was observed that the car panel configuration presents different means of informing about the maneuver. All means like reverse camera, sound alarm, mirror lateral, and parking assistance panel provide information to stopping the car. The mean for informing about the car behavior should be available in the same equipment provide timely attention getting cues through at least two different senses by a combination of aural, visual indications. Different equipment with different alarms can generate conflicts of understanding, and a very long time to synchronize the same understanding about information which comes from different means, this generates long-term decision making, or complacency about the information. It is recommended integration between the equipment and signals, respecting the dual sense in the same equipment. The results achieved through the application of the method for determining the LoA of a task and to quantify the human error in performing this task highlight the effectiveness of the method and the contribution to decrease the chance of the human error in interface with autonomous systems.

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