

A HAZOP approach to Allocation of Functions

Abstract for ALLFN '97: Revisiting the "Allocation of Functions" - New Perspectives

Author: Bridget A Leathley
Company: RM Consultants Ltd, Suite 7, Hitching Court,
Abingdon Business Park. ABINGDON. OX14 1RA
Telephone: 01235 555755
Fax: 01235 525143
e-mail: leathley@luthien.demon.co.uk

Abstract

Drawing on commercial use of human factors in safety and risk management, this paper proposes a method for allocating tasks to humans or to technological systems based on a HAZOP (Hazard and Operability) method. HAZOP was originally developed to review process plant designs in order to identify (and therefore protect against) hazards, producing safer, more efficient and more reliable plant. The classical method involves a chairperson who guides a team of people representing different disciplines through the design of the plant in a systematic way, considering possible deviations from the design intention for each element of the design. Initially, HAZOP studies involved only people with engineering knowledge. In more recent years, these studies have included human factors experts to identify hazards due to human error.

This paper will outline the use of HAZOP and HAZID (Hazard Identification) techniques in a number of situations, and will propose further extensions to their use to cover the allocation of functions between people and technology. In particular, one HAZID study is about to take place within the aviation industry, looking at the changes in hazards that may occur if data-links are used to transmit information from air traffic control (ATC) to a display in the aircraft. Such information is currently transmitted verbally (via a radio link) from ATC controller to aircraft pilot. The study is therefore comparing the hazards of an existing system, with those of a proposed system which will place a much higher dependence on technology. This work should be complete in March, and the results should indicate the feasibility of developing this technique as a method for making decisions about the allocation of function.

HAZOP approach to allocation of function in safety critical systems

Bridget A Leathley

RM Consultants Ltd, Suite 7, Hitching Court, Abingdon Business Park. ABINGDON. OX14 1RA, UK.

ABSTRACT

Drawing on commercial use of human factors in safety and risk management, this paper proposes a method for allocating functions to humans or to technological systems, based on a HAZOP (Hazard and Operability) study. HAZOP involves a 'structured brainstorm' and was originally developed to review process plant designs in order to identify (and therefore protect against) hazards, producing safer, more efficient and more reliable plant. Initially, HAZOP studies involved only people with engineering knowledge. In more recent years, these studies have included human factors experts to identify hazards related to human error.

This paper outlines the use of HAZOP techniques in a number of situations, and proposes extensions to their use to cover the allocation of functions between people and technology. In particular, a study within the aviation industry looked at the changes in hazards which may occur if a new system is introduced in which technology takes on additional functions. The results of this study indicate that it should be feasible to develop the HAZOP technique as a method for making decisions about allocation of function.

1. Introduction

Hazard and Operability studies or 'HAZOPs' have for many years been used to identify and assess hazards in systems in a variety of industries. This paper starts by outlining the traditional use of HAZOP (section 2). A number of uses for HAZOP relevant to Human Factors are then described (section 3). Uses include a recent study within the aviation industry where the technique was used to make comparisons between the existing situation, in which information is transmitted verbally via a radio link between an Air Traffic Control (ATC) officer and aircraft pilot, and a possible future system, in which datalinks are used to transmit information from ATC to a display in the aircraft (section 4). This study therefore compared the hazards in a existing system with those of a proposed system where the technology takes on additional functions. The paper develops these ideas to discuss how these techniques could be used to make decisions about allocation of function.

The term HAZOP has come to be interpreted as a family name for a group of techniques which includes HAZID (Hazard Identification) and HAZAN (Hazard Analysis) as well as HAZOP itself. This convention will be used in this paper for simplicity, with the type of study described in each case. The classical method of HAZOP involves a chairperson who guides a team of people representing different disciplines through a representation of a process in a systematic way, considering possible deviations from the design intention for each element of the process. One of the reasons for the success of the HAZOP family of techniques is that hazards are identified (and assessed) through the interaction of a group of people, rather than by an individual, or even by a number of individuals reviewing design

documentation separately. By choosing an appropriate set of people, from relevant disciplines, a wider range of hazards are identified. In particular, the brainstorming technique is good at identifying mis-comprehensions and hazards at the interface between disciplines or groups, for example, between maintenance and operations. To balance this, some cautions about the expectations of the HAZOP process must also be expressed, and these are mentioned in Section 6.

2. Standard HAZOP

The earliest use of HAZOP is attributed to ICI in the UK, for use within the chemical and petrochemical industry. Rather than keep it to themselves, the technique was published (ICI, 1974) and adopted and adapted by other industries throughout the world. In outline, HAZOP involves the following steps:

1. Produce or obtain a description of the system - this is normally a flow diagram, or a plant layout drawing.
2. Describe the intention for each part of the system description (for example, 'valve 1 should control flow from tank 1'). Summarise each intention as a parameter, for example, 'flow'. Other common examples of parameters include TEMPERATURE, and PRESSURE.
3. Select appropriate guidewords (for example, NO, MORE, REVERSE). Pairings of parameters and guidewords are formed to suggest questions.
4. Invite a team of people covering relevant disciplines to the HAZOP meeting. An experienced chairperson should be appointed to lead the sessions, and a second person (known as the HAZOP secretary) appointed to document the findings.
5. At the meeting, the chairperson should systematically apply the selected guidewords and parameters to each part of the system description, and invite participants to identify:
 - possible hazards;
 - possible causes and consequences for each hazard;
 - existing controls (which may be controls of the occurrence of the hazard, or limitation of the consequences of the event);
 - the current risk (based on consequences and likelihood);
 - whether further actions are required.

A short example will illustrate this. Figure 1 shows part of a simple process flow diagram.

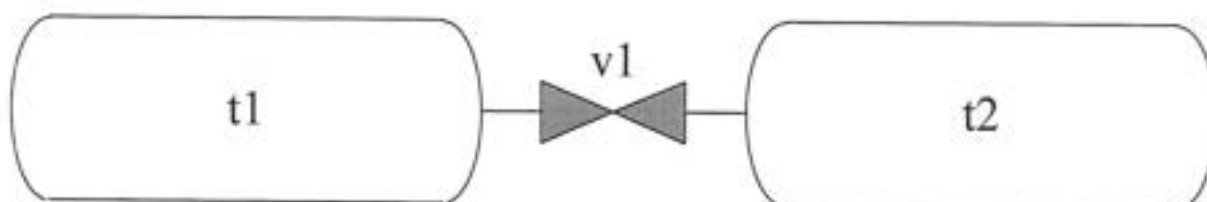


Figure 1: Section of a process diagram

The intention in Figure 1 is that the valve (v1) should be open for some fluid to flow from tank (t1) to tank (t2). The first parameter word is therefore FLOW. By pairing the parameter 'FLOW' with the guideword 'NO' one question at the meeting might be 'What could happen if there was NO FLOW through v1?'. If the fluid is a coolant, the meeting might establish that

this would lead to a high temperature in $t4$. The causes might include $v1$ being left closed after maintenance, or becoming blocked over time. The valve is likely to have other functions, such as deliberately shutting off under certain conditions. Questions would be asked about this and other intentions of the valve. When parameter - guideword combinations were exhausted for $v1$, the HAZOP meeting would move onto another part of the system, until all system components had been studied.

Existing controls in the design can be taken into account in assessing the risk. If the risk is too high, additional controls can be considered in order to bring the risk down to an acceptable level. In the early stages of design, the process may stop at the hazard identification stage, with no attempt to quantify the risks. In other cases it may be appropriate to make estimates of the risk only in qualitative terms such as 'high, medium, low'. One reason the technique became so popular appears to be its flexibility - the technique can be used at different levels of detail as the design progresses, with effort concentrated on those hazards believed to present the highest risks.

Table 1 shows a possible form of presentation of the results of the first part of the HAZOP process described above.

Table 1: Example of standard HAZOP table

<i>Element</i>	<i>Intent</i>	<i>Guideword</i>	<i>Consequences</i>	<i>Causes</i>	<i>Controls</i>
$v1$	Flow	No	temp. in $t2$ increases	$v1$ becomes clogged	maintenance
				$v1$ left shut after maintenance	maintenance checks

3. Human Factors HAZOP

It is recognised that the source of many accidents is human error, and that human reliability is an influence on many of the controls applied to technical system. Even in the example of the standard application of HAZOP in Section 2, the possibility of errors by maintenance staff was identified as one possible cause of the identified hazard, and adequate maintenance and checks on maintenance were identified as controls. Specific HAZOP methods have been developed to take better account of the roles of people within systems. For example, Schurmanm and Flegler (1994) present guidewords and parameters targeted at identifying hazards related to human actions, and the influence of organisational style, management attitudes, training, procedures and human-machine interfaces. So, for example, the guideword MISSING might be applied to the parameters PERSON and ACTION to ask what are the consequences if a particular person is not available at a given point in the process, and what happens if an action is not performed.

Our own experience of using HAZOP within Human Factors projects includes the identification of hazards within emergency evacuation situations on offshore installations (Gould & Au, 1995 and Au & Gould, 1997). In this case, the system description shows the sequence of events in the evacuation, escape and rescue process (Figure 2). The solid arrows show the 'normal' or preferred process for EER in the event of a major incident. The dashed arrows show alternative paths, for example, when the muster points are not available.

Guidewords including FAILED, TOO LATE and CONGESTED were applied to each stage of the EER process to identify potential deviations due to human activities, inadequate management and control, physical failures and adverse conditions. So, for example, the study might start by considering what could cause the alarm (1. in Figure 2) to fail, and what the consequences of this would be. This method should ensure a thorough and systematic identification of the hazards associated with evacuation, escape and rescue.

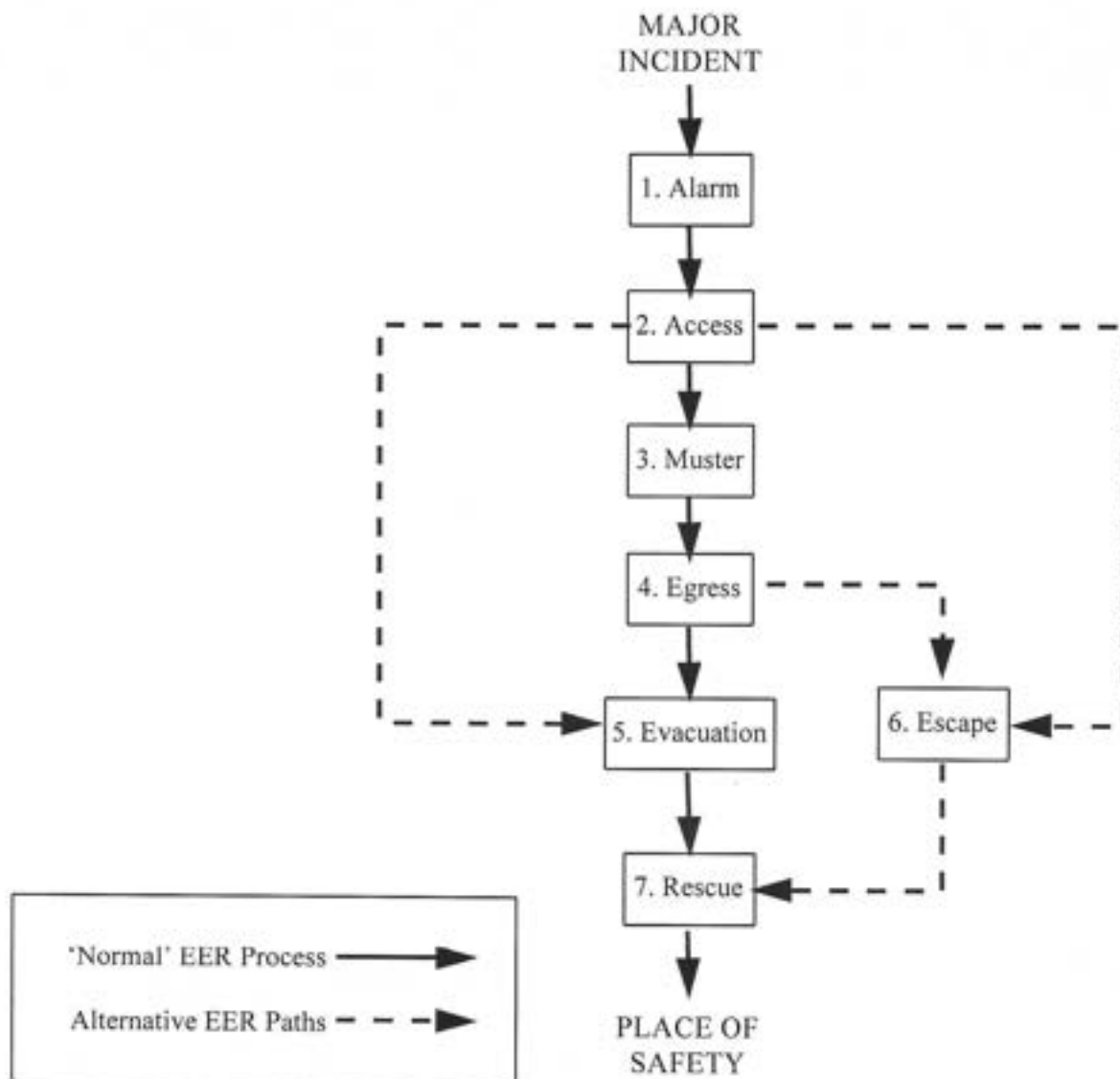


Figure 2: Overview of the Evacuation, Escape and Rescue process (EER)

A further example of the application of a Human Factors HAZOP involved the consideration of aviation hazards. As part of this, an integrated task analysis (ITA) was developed in order to show the relationship between the activities of the aircraft pilot and of the ATC officer. Table 2 shows an example ITA, similar to those used, where the ATC officer gives the pilot instructions known as a 'clearance' which may include information on height, direction and speed. The 'readback' is the confirmation of the clearance given by the pilot to the ATC officer. Note that there is an implied time dimension in the ITA, in that event 1 occurs before 2, 2 before 3 and so on, although nothing is said in the ITA about the time interval between each event.

Table 2: Example ITA for Human Factors aviation HAZOP

	<i>Aircraft Pilot</i>	<i>Air Traffic Control Officer</i>
1	Requests permission for manoeuvre (clearance)	Hears request
2	(waiting for response)	Acknowledges pilot's request and advises pilot to 'Standby'
3	(waiting for response)	Makes a decision on clearance
4		Informs pilot of clearance
5	Hears clearance	(waiting for readback)
6	Gives readback of clearance	
7		Listens to readback (corrects if necessary)
8	Complies with ATC decision	
9		Monitors aircraft movements

Guidewords were selected as part of the study, and were applied to each step of the ITA. For example, what happens if the pilot does NOT readback the clearance? Is it possible for the air crew to act on a clearance OTHER THAN the one intended for them? What would be the effect of the aircraft complying with the decision SOONER THAN intended? As before, each element of the system description (in this case, the task analysis) can be systematically examined to identify possible hazards.

4. Using HAZOP to compare two designs (with different allocations)

So far, all the studies described look at just one system, and identified the hazards with that system. What will often happen in large projects is that the technique is applied iteratively - hazards are identified, unacceptable risks targeted for risk reduction measures, and the technique applied again to the (hopefully) improved design. If the risks were found to be worse than before, the new design would be difficult to justify, and the previous version may be preferred. A logical next step, therefore, is to compare two designs within one study meeting. This was done within another aviation project, where the existing system was compared with a possible new system. Currently, most communications between aircraft pilots and ATC officers are carried out verbally using a radio link. One possibility for the future is to have a facility to send text messages between pilots and ATC controllers, with clearances displayed to the pilot on a monitor in the cockpit. This system is known as 'datalink'.

One possible benefit of the datalink system is a reduction in radio congestion, with routine messages sent by datalink, and the radio freed up for non-routine and emergency communications. Another possible advantage is that since clearances will be directed to the display of an individual aircraft, rather than broadcast for all aircraft to hear, the possibility that an aircraft pilot hears an instruction for another aircraft and believes the instruction is for them will be removed. It is also thought by some that messages on a display are less likely to be mis-read than messages on the radio are to be misheard. Disbenefits could be overload of the pilots visual sense; pilots already have several displays to look at in the cockpit, so there are advantages in making use of the additional channel of hearing. An additional concern is

that the ATC officer may lose the completeness of their mental 'picture' through reduced dialogue with aircraft.

Table 3 shows two integrated task analyses similar to those used in the study. In outline, a pilot can read information about clearances from a display on the console between two pilots. If the pilots agree with the clearance instruction, the details can be entered manually (by turning a dial) on a separate control panel in front of the pilots, which we shall refer to as the 'flight control system' (FCS). An alternative option is for the information to be transferred automatically from the display unit into the FCS (on approval from one of the pilots). The two task analyses are shown side by side, one for the current procedure, and one for the procedure as it might be with an advanced datalink system.

Table 3: Example ITA for comparative HAZOP

<i>Current procedure</i>		<i>DATALINK procedure</i>	
ATC officer:	Instruct pilot by voice over radio	ATC officer:	Set up datalink instruction
		ATC officer:	Send datalink instruction
Pilot:	Hear message over radio	Ground system:	Up-link instruction
		Air system:	Send automatic acknowledgement to ground system
		Air system:	Display message to air crew
Pilot:	Give readback over radio	Pilot:	Read message
		Pilot:	Set up datalink response
ATC officer:	Listen to readback (correct if necessary)	Pilot:	Send datalink response
		Air system:	Downlink response
		Ground system:	Send automatic acknowledgement to air system
Pilot:	Enter details into FCS (which causes activation)	Ground system:	Display response to ATC
		ATC officer:	Read pilot response (correct if necessary)
		Pilot:	Approve transfer of data to FCS
		Air system:	Transfer details into FCS and activate

The comparative HAZOP was attempted in two different ways:

1. By carrying out a HAZOP of the current procedure, and then a HAZOP of the proposed procedure, and making the comparison between the results afterwards.
2. By looking at each stage in the current procedure using the HAZOP method, and comparing this with the equivalent step(s) in the possible future procedure.

The second of these methods proved more natural to the participants in the HAZOP, in that people tended to make comparisons between the two systems even when asked to consider only the current procedure. The guidewords used for this study were: NOT DONE, OTHER THAN and MISORDERED. So, for example, hazards were identified where the message sent to the pilot was NOT DONE. The consequences of not sending an instruction would be the same with both systems - for example, if the clearance was necessary to maintain separation between two aircraft, failing to instruct an aircraft to change heading could result in loss of separation. With existing practice, for the message not to be sent, the ATC officer has only one error to make - that is to forget to give the instruction. In the datalink procedure there are two ways in which the message might not get sent - the first is that the ATC officer forgets to set the message up, and the second is that they set the message up, but forget to send it. This is rather like writing a message, but forgetting to post it. A comparison of these two situations shows that if each error is approximately as likely, the datalink failure is more likely than the failure with the existing system (because there is an additional opportunity for error). The recommendation that arises from this, therefore, is that the user interface must ensure that the ATC officer is reminded of messages that have been set-up, but not sent (so as to make the second error less likely).

As a further example, applying the keyword OTHER THAN to the last step leads to consideration of ways in which details OTHER THAN the correct details can be entered into the FCS. In the current procedure, assuming the pilot has correctly heard the instruction, there is a possibility that the details will be mis-entered into the FCS. In the datalink procedure, if the situation were that the details as transmitted by datalink could be transferred automatically into the FCS (on acknowledgement from the pilot) only a technical error could lead to entry of the wrong details.

Although in some cases a direct comparison of the current and proposed system was not possible (for example, where completely new functions were offered by datalink) the HAZOP technique proved a useful tool for making the comparison. In particular, measures were identified which would need to be taken if the proposed technology were to be used. These included requirements for the user interface (for pilot and ATC systems), for procedures, for evaluation trials, for training, and for organisational issues and systems.

5. HAZOP in allocation of function

Having compared two systems with varying dependence on technology and people, a further variation of the HAZOP technique can now be suggested for looking at issues of allocation of function, that is, the distribution of system functions between people and equipment. Since one of the traditional methods of allocation of function involves task analysis, there is clearly a link here with the evolved method of human factors HAZOP described in the previous section.

Figure 3 shows the top level of a hierarchical task analysis for one of the common exchanges between ATC officer and pilot.

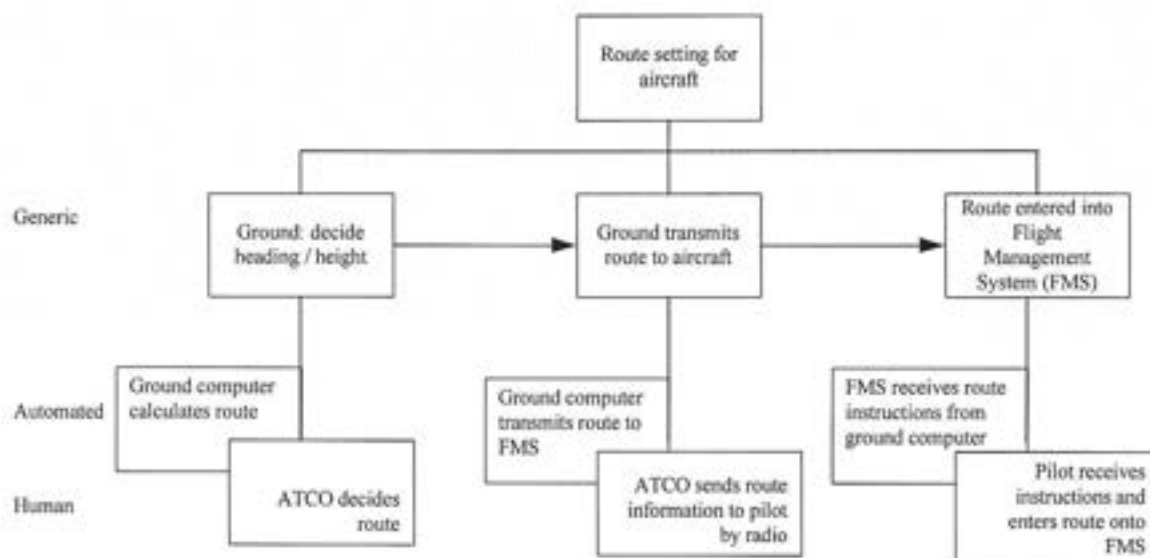


Figure 3: Hierarchical Task Analysis of example exchange

The top box in Figure 3 describes the task - route setting for the aircraft. This includes the three broad functions described in the second row. The example assumes an ATC officer initiated instruction - it is also possible for the air crew to request a particular route. The overlapping boxes show two possible extremes in terms of how each task could be carried out - the most automated solution would be for a computer on the ground to calculate the optimum route, transmit the route details directly to the aircraft FCS, which then flies the aircraft. If acceptable, this would mean that pilots and ATC officers would not need to be involved in aircraft routing. The opposite extreme is for people to do as much of the job as possible, represented by the bottom row of overlapping boxes. The ATC officer decides the route and passes the information by radio to the pilot, who then enters the information manually into the FCS.

A similarity with the traditional method of allocation of function is apparent here in that the extremes of automated and human allocation have been defined. The next step in the conventional method might be to apply a human-machine comparison list (one of a number of standard lists available which make general statements about the comparative virtues of humans versus machines for different types of situations). However, these lists are usually either so general as to be of only limited use, or written specifically for narrow applications. It is also true that technology is changing so quickly, both in terms of capability and cost, that the relative advantages of humans versus machines are also changing, and will be heavily dependent on the application being developed (Sanders & McCormick, 1992). A further concern is that human-machine comparison lists tend to look at each function in isolation, rather than as a whole. The alternative suggested is to subject each of the possibilities shown in Figure 3 to the HAZOP process. Table 4 summarises some points made in such a HAZOP. In each case, the problem identified with the allocation (automated or human) is described.

For each task, the hazards identified can be compared. By making an assessment of the severity and the likelihood of hazards associated with each task, the risks of the function under automation and under human control can be compared in order to establish a preferred allocation of function. The shading in Table 4 indicates where the risk for a given task was considered lower (and thus the allocation may be preferred).

Table 4: Hazards identified in Allocation of Function HAZOP

<i>Generic Task</i>	<i>Guidewords</i>	<i>Automated</i>	<i>Human</i>
1) Ground: decide heading / height	NOT IN TIME	If route planning is calculated by computer, ATC officers will take longer to become aware of the situation and to take action in the event of an emergency	Human is likely to be slower at calculating optimum route, and may not make correct calculation in time
	OTHER THAN	Ground system may be capable of taking into account all relevant information in deciding route.	
2) Ground transmits route to aircraft	OTHER THAN		The human voice on the radio can be misheard or misunderstood.
3) Route entered into FCS	OTHER THAN	Aircraft / ground systems may not have all the information the pilot has as to why a route is unsuitable for the aircraft at that time.	Pilot may make transcription error in entering route
	LESS THAN	Pilot vigilance may suffer if the pilot does not have to consider and enter routes.	

Because of the nature of the task in the example application, Table 4 has considered only psychological task requirements, for example, memory, attention, perception, decision making, planning, recognition, calculation. For other tasks, the physical requirements (for example the strength needed to lift an item) and the spatial or anthropometric requirements (for example the distance over which something needs to be lifted, or the ability to reach a control) would also need to be considered.

From Table 4, an assessment can be made of the suitability of the human or computer for each stage of the process. For the generic task 1) although the computer is likely to be faster at calculating the optimum route (something that a standard allocation of function comparison list would tell us) the identification of the need for the ATC officer to maintain a mental 'picture' of the airspace, and the fact that this could be diminished if the computer did the route setting is important. This could lead to an assessment that for this task, allocation to computer would be more hazardous than allocation to human. For task 2) the improved reliability of the transfer of information implies that allocation to computer is less hazardous than to humans via the radio. For the final task 3), the need to allow pilots to judge the suitability of a route in relation to constraints which may be unknown to the ATC system (for example aircraft performance limits) and to maintain the pilots' vigilance might override any benefits of automated entry of route information into the FCS.

In practical terms, the hazards should be identified during the HAZOP meeting, and where possible, the severity and likelihood of each hazard occurring assessed. Following the meeting it will be necessary to check information about the hazards - for example, checking values for likelihood that were not available during the meeting, talking to others not involved in the discussion who may be able to advise on the maximum severity of a hazard. The analysis and judgement about allocation of function will also take place after the HAZOP meetings, using some degree of subjective judgement.

An additional benefit of the technique is to identify the potential hazards which need to be overcome. It is unlikely that any one solution will be devoid of hazards - what the technique seeks to find is the allocation which presents the least risk. In the example of task 3), having identified the increased possibility of mis-entry of information into the FCS if carried out by the pilot compared to automatic entry, measures can be taken to reduce the probability of that error. For example, it is already the practice for one pilot to check a route set by the other pilot before activating it.

The analysis could be developed to increasing levels of detail as the design of a system proceeds, and the HAZOP technique applied at each level. For example, Figure 4 shows the 'Route entry' task analysed to a further level of detail. This allows us to consider another important aspect of allocation of function, that of allocation between different people involved in an operation.

In the current situation, the pilot who sets the heading, speed, height and other control inputs is known as the flying or handling pilot, and the second pilot as the non-handling or non-flying pilot. However, in the task analysis in Table 3, the functions of entering information into the FCS and activating it were separated, and the possibility allowed that these functions may be performed by either pilot, or under control of the computer. Hence, the distinction between 'handling' and 'non-handling' becomes less clear. In the following examples the terms 'non-handling' and 'handling' will nevertheless be used, assuming that certain decisions have already been made about the allocation of other functions. Allocation between the two pilots and the automatic systems of the functions involved with entering a route into the FCS can now be considered. As before, Figure 4 shows the extremes of allocation, but this time taking into account the division of functions between pilots as well as the equipment.

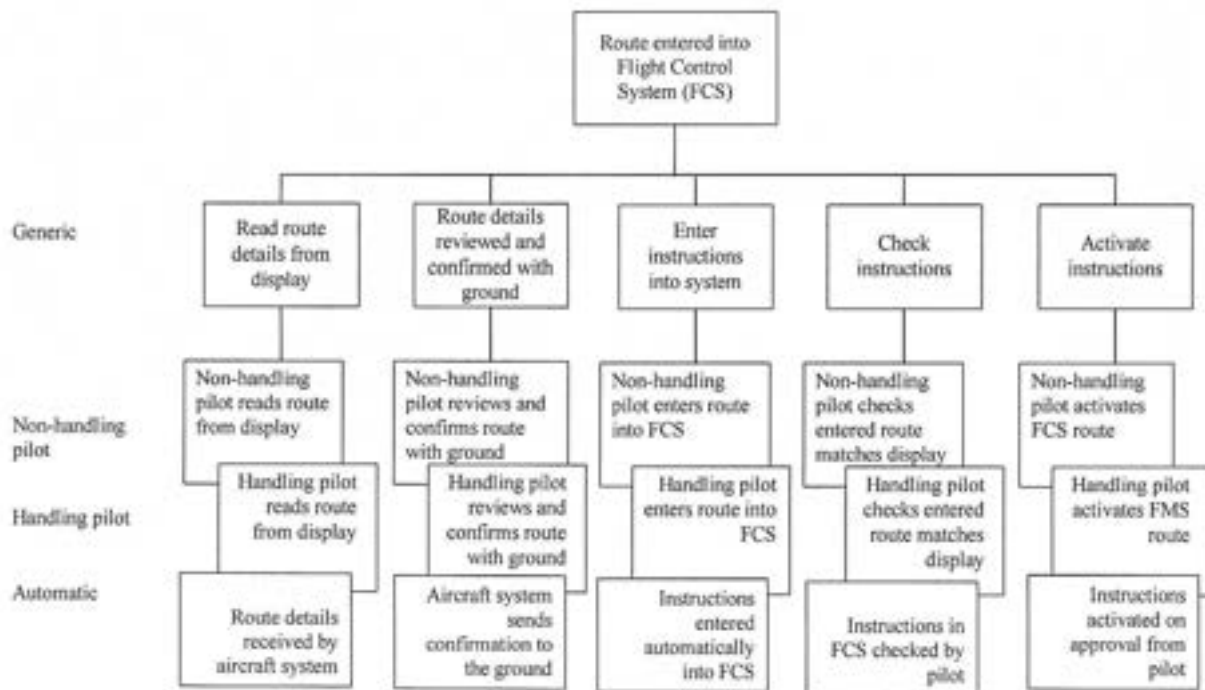


Figure 4: Example of allocation of function task analysis

As with Figure 3, this task analysis would be subject to the HAZOP technique, identifying the hazards of each choice of allocation. Clearly, it makes no sense for one pilot to carry out all functions; in particular, one pilot should check the entry made by the other pilot. Table 5 shows some examples of hazards identified.

Table 5: Example Hazards for Allocation of Function HAZOP at second level of detail

<i>Generic Task</i>	<i>Guidewords</i>	<i>Handling Pilot</i>	<i>Non handling pilot</i>	<i>Automated</i>
Route details read from display	MORE THAN	Handling pilot's workload may be too much to be able to read display		
	OTHER THAN	Either pilot may misread display		
Route details agreed and confirmed with ground	MORE THAN	Handling pilot's workload may be too much to be able to respond		
	OTHER THAN		Non-handling pilot may not be sufficiently aware of current position	Flight control system might not be able to take account of all necessary information in agreeing route
				Aircraft cannot take responsibility for route agreement
Instructions entered into system	LESS THAN	Either pilot may enter only part of the instruction into the FCS (for example, heading only and not height).		
	OTHER THAN	Manual transcription error may be greater if not performed by the pilot with primary responsibility for reading the instructions. In either case, a manual transcription error is more likely than an error in the direct transfer of instructions into the FCS.		
Instructions checked	NOT DONE		May be less likely to challenge handling pilot if believes there to be an error	If checking is automated there could be a common mode failure
	OTHER THAN	Self-checking not considered reliable enough. Entry must be checked by pilot other than the one who entered the data. If automatic entry, it could be checked by either.		
Instructions activated	NOT DONE			Aircraft cannot take responsibility for activation
	NOT IN TIME	May be distracted by other tasks		

Note that Table 5 concentrates on the differences between allocations, rather than on common hazards. For example, a common problem in checking a setting is that (dependent on the circumstances) one person checking another person's entry may not notice an error because they see what they expect to see. Unless the participants believed there was a

difference in the likelihood of this error depending on the allocation, this would not be noted. The example in Table 5 illustrates how the method works, but would need to be developed to a greater level of detail to establish the allocation of function between handling pilot and non-handling pilot and aircraft systems.

One of the other points that Table 5 illustrates is that the further into the process, the more dependent the analysis becomes on previous stages, for example 'entry must be checked by pilot other than the one who entered the data'. An iterative approach is therefore needed, where once an allocation has been decided that appears to meet the criteria produced in the HAZOP, the allocation is revisited with the HAZOP as described in Section 3, ideally with a change in some of the HAZOP team members.

6. Cautions

Although the HAZOP technique is a powerful and flexible tool in a number of situations, it would be unwise to conclude this paper without a few words of caution. As suggested in the introduction, if well designed, with an appropriate system description, an understanding of suitable parameters and guidewords, and with the co-operative involvement of an appropriate number of representatives, a HAZOP can identify a wider range of hazards than would an individual working on their own. However, there is no guarantee that a HAZOP will identify *all* the potential hazards. To be most effective, HAZOP studies are needed at different levels of detail throughout the design, 'construction' and commissioning of a system.

The key role of the HAZOP meeting is to identify the possible hazards associated with each allocation, and the technique is a strong one for doing this. However, the brainstorming approach is less successful at eliciting quantitative data. The meeting may make an assessment of the maximum severity and likelihood of each hazard, but it will often be a more efficient use of time for the analyst to follow up the quantitative information outside of the meeting.

Those embarking on a HAZOP study should also be aware of the practicalities of organising meetings and finding the right combination of people available and willing to take part. Careful preparation is needed to ensure the comprehensiveness of the system model and the appropriateness of the guidewords and parameters. Maintaining the involvement of participants, often over a long series of meetings, requires a skilful chair who must be conscious of the group dynamics, and able to encourage contributions from the cautious, whilst carefully managing the more vociferous. The possibility of 'group think' (Janis, 1972), where the HAZOP team start to think the same way and therefore miss important problems in the system must also be guarded against by introducing new people into the sessions.

A successful HAZOP ultimately depends on the experience and credibility of the HAZOP chair and the competence of the secretary.

7. Conclusions

This paper has provided examples of how a technique originally designed to look at purely technical processes has been adapted to assess issues of human factors. Although not part of the original HAZOP method, task analysis techniques have been used to provide the 'system model' for the HAZOP study. This merging of techniques, and the flexibility and versatility of the HAZOP method suggests a further extension of the method to include the problem of allocation of function. Two examples have been provided from the aviation industry: one for allocation between computer and human, and one for allocation between two people and a computer based system. These examples suggest that a HAZOP approach can be used for allocation of function within safety critical systems.

8. References

- Au, SYZ & Gould, GW, 1997, A Structured Brainstorming Approach to the Assessment of Emergency Response, *HAZARDS XIII Process Safety - The future*, 22-24 April 1997, Manchester.
- Gould, GW & Au, SYZ., 1995, A Methodology for Hazard Identification of EER Assessments. *Offshore Technology Report OTH 95 466*. HSE Books.
- ICI (Imperial Chemical Industries Ltd), 1974, Hazard and Operability Studies, *Process Safety Rep. 2*, London.
- Janis, 1972, *Victims of Groupthink*. Houghton Mifflin: Boston.
- Sanders, MS & McCormick, EJ, 1992, *Human Factors in Engineering and Design*. McGraw-Hill.
- Schurmanm, DL., & Fleger, SA, 1994, Human Factors in HAZOPs: Guidewords and parameters, *Professional Safety, American Society of Safety Engineers*, December 1994.