

Work conditions and accidents in three industries

by Jorma Saari, D Tech,¹ Jari Lahtela, MSc(Eng)²

SAARI J, LAHTELA J. Work conditions and accidents in three industries. *Scand j work environ health* 7 (1981): suppl 4, 97-105. Four studies conducted in the light metal, electrotechnical and printing industries are described. The purpose was to determine the applicability of the systems approach to occupational accidents. The data consisted of 291 accidents and 701 controls. The stable characteristics of the workers or the environments were not good predictors of accidents. The clearest differences between the accidents and the controls involved the worker's situational experience, the frequency of task occurrence, the familiarity of the tasks, and the mobility of dangers. The complexity of the information exchange between man and his environment, as well as the perceptibility of environmental dangers, contributed to the occurrence of accidents.

Key terms: experience, dangers, systems approach, tasks.

The mechanisms of accidents are still, to a large extent, unknown although various accident models have been proposed. An accident model is a necessary tool for accident prevention. It is a base for determining countermeasures and for evaluating their effectiveness.

Two main approaches towards the causes of accidents have prevailed. The first scientific accident theories (accident proneness and accident liability) tried to explain accidents in terms of man. People were more or less prone or liable to accidents (5, 10, 16). Preventive measures were therefore directed towards man (eg, selection of workers or attempts to change a worker's behavior, for example, risk-taking behavior).

The other approach concentrated on the characteristics of the environment. The cause of an accident was a danger in the environment (eg, unguarded parts of machines, slippery floors, obstacles on the floor, etc) — in other words, an unwanted

transfer of energy (13, 27). Accidents could be prevented if dangers were removed from the environment.

Both of these approaches are static and concentrate on single components of the whole system. They neglect the interaction between man and his environment. In accident prevention the main concerns are the components of the system and not the correct functioning of the interaction of the different components.

In aircraft designing and other sophisticated but clearly limited and defined systems, man-machine-system models have been applied to prevent accidents (2, 9).

Similar models have been proposed for occupational accidents. Surrey (29) introduced a comprehensive information-flow model, although earlier considerations exist (4, 17, 23, 24). Later models were elaborated by several authors (1, 6, 7, 8, 11, 12, 14, 15, 25, 26, 28). Most of the proposed models are, however, theoretical considerations. To date, there have been few attempts to test the model with empirical data from industry.

We have conducted a series of empirical studies which have considered accidents in the following way. In every industrial workplace there are sources of energy (dangers) which may cause injury if man comes into contact with them. Therefore,

¹ Tampere University of Technology, Tampere, Finland.

² Department of Physiology, Institute of Occupational Health, Helsinki, Finland.

Reprint requests to: Prof J Saari, Tampere University of Technology, PO Box 527, SF-33101 Tampere 10, Finland.

the information exchange between man and his environment should occur without disturbances. A disturbance may lead to a chain of events which, in turn, create contact with danger. The worker should therefore be aware of the dangers. He should be able to take the dangers into consideration when he makes decisions; he should also be able to avoid the dangers when performing actions.

It is possible that disturbances occur in the information exchange between man and his environment if the environment and the tasks have been poorly designed. A disturbance may arise due to, eg, different factors, as presented in fig 1.

The occurrence of an accident does not depend solely on existing dangers at the workplace. It also depends on the capacity and possibility of the individual to perceive and control the dangers, as well as on all the other information processing necessary to cope with a particular situation. For example:

(a) Dangers at the workplace might be difficult to perceive, as illustrated by the following:

- the danger might have to be monitored continuously because the location of the danger changes, especially if the change is not caused by the worker, eg, a tool left on the floor;
- the danger might not be continuously in a dangerous state; eg, an unguarded shaft or a machine operated only occasionally;
- the danger might not be within the range of operation of the senses, eg, not in the field of vision;
- the signal-noise ratio might be poor, eg, a minor slippery spot on the floor with no

color or other perceptual clues or a hot material which shows no perceptible change of color due to heat.

(b) The amount of information to be handled during work might be excessive, as illustrated by the following:

- reduction of the information to be processed might not be possible because the environment is unfamiliar or the operations to be performed are unfamiliar;
- the main task might require intensive concentration and thus prevent the worker from monitoring the dangers;
- there might be too many operations to be performed, which would prevent their being properly learned;
- there might be too many sources of information to be followed;
- the amount of reasoning is high, eg, a worker continuously has to plan new work methods, select proper tools, etc.

(c) The motor responses might require excessive precision, speed or force.

The objective of the studies briefly described in this report was to assess the extent to which the features of systems and information flow models can be observed in industrial accidents. This paper presents results obtained from four consecutive studies which concern some variables.

Material and methods

This paper describes a series of studies which were basically similar in methods. However, the models and hypotheses tested were modified from step to step according to the results of the previous study. The samples were as follows: (i) the light metal industry (referred to in the text as light metal industry 1), 76 accidents and 72 controls (18, 19); (ii) the electrotechnical industry, 31 accidents and 106 controls (22); (iii) the light metal industry (referred to in the text as light metal industry 2), 130 accidents and 223 controls (20, 21); (iv) the printing industry, 54 accidents and 300 controls.

Altogether there were 291 accidents and 701 controls. For each study a number of companies located close to Helsinki were selected. Table 1 gives some background

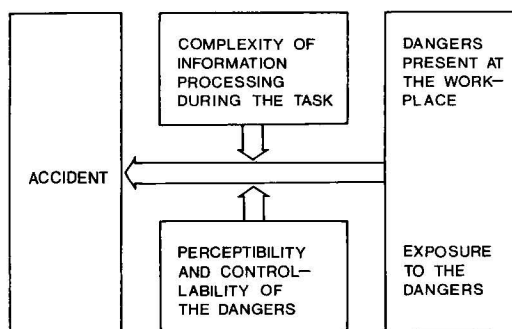


Fig 1. Factors related to occupational accidents.

information on these companies. In the first two studies the companies were observed for three months and in the last two studies for six months. The accidents were studied as soon as possible, within one week of occurrence. The companies were visited at least once a week.

The controls were the jobs of every sixth, tenth or fifteenth worker from the same companies. In the third study, the companies were selected to represent either a high or low accident frequency (20, 21) so that comparisons would be possible also within the control group.

The number of variables fluctuated between 120 and 235. The accidents were described by some additional variables. The variables covered the following areas: dangers, machines and tools used, work environment, jobs and tasks, the worker, and the company and its department.

Results

Types of accidents

The types of accidents are given in table 2. The relative figures (accidents/1,000 annual workers) cannot be compared directly between samples (except in light metal industry 2 and the printing industry). Table 2 gives rise to the following observations:

1. Accidents involving moving people or moving materials were clearly less frequent in the printing industry than in the light metal industry. Accidents involving people moving were also less frequent in the electrotechnical industry than in the light metal industry, while flying objects were more frequent.
2. The "caught in" types of accidents were as frequent in light metal industry 2 as

Table 1. Background information on the companies studied.

	Industry			
	Light metal 1	Light metal 2	Electro-technical	Printing
Number of companies	9	7	6	10
Total number of employees	1,032	1,584	1,502	2,197
Accident rate (accidents/10 ⁻⁶ man hours)	21—315 ^a	77—232 ^a	29—117 ^b	21—69 ^a
Average accident rate	127 ^a	136 ^a	32 ^a	45 ^a
Accident rate according to official statistics in 1972 ^c	94.4		47.8	19.7

^a Absence of more than 1 d.

^b Registered accidents.

^c Absence of more than 3 d.

Table 2. Types of accidents expressed in accidents/million man hours and in percentages (in parentheses).

Type of accident	Industry			
	Light metal 1 ^a (N = 76)	Light metal 2 ^b (N = 130)	Electro-technical ^a (N = 31)	Printing ^b (N = 54)
Persons: falling, stumbling, etc	26.2 (16)	20.4 (15)	6.1 (15)	9.2 (20)
Objects: falling, flying	21.6 (16)	25.8 (19)	19.8 (42)	5.0 (11)
Machine: caught in moving parts, bumping into sharp edges, etc	41.6 (25)	16.3 (12)	9.1 (19)	16.7 (37)
Tools: slipping, loosening of grip, etc	28.5 (17)	10.9 (8)		2.5 (6)
Product: bumping into sharp edges, etc	21.9 (13)	35.3 (26)		1.7 (4)
Others	21.9 (13)	27.2 (20)	12.1 (5)	9.9 (22)
Total	166.4 (100)	135.9 (100)	47.1 (101)	45.0 (100)

^a Based on registered accidents.

^b Accidents with more than 1 d of absence.

in the printing industry. In light metal industry 1, accidents of this type were much more common, — due to the automatic production lines in some of the companies studied.

3. Bumping into sharp edges constituted a dominant distinction between samples and fields.

4. Low accident rates did not express themselves as a reduction in particular types of accidents but rather as a reduction in several accident types.

Workers

Age. The age distribution of the workers in the light metal and printing industries was fairly similar (table 3). This similarity applies both to the control and accident groups. The electrotechnical industry differed from the others. In it young workers (20—29 a) were a large group. Workers younger than 29 a comprised more than half of the labor force in this industry.

Two tendencies can be observed in the distributions. Workers under the age of 29 a were overrepresented in the accident groups of all the industries. On the other hand, workers over the age of 50 a showed the same percentage in both groups except in light metal industry 2.

Experience. The distributions of occupational experience varied from study to study (table 4). The first study in the light metal industry indicated that more accidents occurred to workers with experience of less than 5 a. In light metal industry 2, the result was the opposite. The distributions in the printing industry were similar to both groups.

Data concerning worker experience in the particular company was available only for the last two samples, light metal industry 2 and the printing industry (table 5). The trend was similar in both industries. Workers with short experience in the company were overrepresented in the accident groups.

The different types of experience show

Table 3. Age distribution of the workers in the accident and control groups (%).

Age (a)	Accident group				Control group			
	Light metal industry 1 (N = 76)	Light metal industry 2 (N = 130)	Electro-technical industry (N = 31)	Printing industry (N = 52)	Light metal industry 1 (N = 72)	Light metal industry 2 (N = 223)	Electro-technical industry (N = 106)	Printing industry (N = 300)
> 20	4	5	16	2	7	7	6	3
20—29	43	42	45	40	30	30	47	33
30—39	20	26	10	27	27	27	18	32
40—49	15	14	13	14	20	17	19	15
> 50	18	12	15	17	16	19	11	17
Total	100	99	99	100	100	100	101	100

Table 4. Occupational experience of the accident and control groups (%).

Experience (a)	Accident group				Control group			
	Light metal industry 1	Light metal industry 2	Electro-technical industry	Printing industry	Light metal industry 1	Light metal industry 2	Electro-technical industry	Printing industry
< 1	30	14	26	8	28	16	14	6
1—5	40	45	32	31	29	51	51	34
> 5	30	41	42	61	43	33	35	60
Total	100	100	100	100	100	100	100	100

Table 5. Length of experience of the accident and control groups in the company studied (%).

Experience (a)	Accident group		Control group	
	Light metal industry 2	Printing industry	Light metal industry 2	Printing industry
< 1	14	10	10	6
1—5	54	46	49	39
> 5	32	44	41	55
Total	100	100	100	100

Table 6. The proportions of workers with experience longer than 5 a (%).

Experience > 5 a	Accident group		Control group	
	Light metal industry 2	Printing industry	Light metal industry 2	Printing industry
Present occupation	41	61	33	60
Present company	32	44	41	55
Present job	28	35	— ^a	41

^a Information was not collected.

an even trend. Table 6 shows the percentages of workers with different kinds of experience of more than 5 a. Overall occupational experience did not seem to predict the occurrence of accidents well, while experience in the company related more closely to the occurrence of accidents. Experience in the job in question gave a result along the same lines, at least in the printing industry.

Data concerning task experience was available only from the first study in the light metal industry (18). In this study task experience appeared to be the most related to accidents. On the basis of the indirect information available from the other studies, the result was the same for other samples as well.

Experience seems to have the best predictive value when it relates to the actual situation and not to the more general knowledge and skills of the worker. Thus, experience influencing safety performance obviously has something to do with the awareness of the state of the work system at a given time. It enables a worker to utilize his expectations in his decision making and actions, because the worker has knowledge of the probable hazards involved, as well as the direction and rate of the evolution of hazards.

Dangers

A detailed description of the dangers at the workplaces was made in all the studies. Dangers refer to potential sources of energy transfer, eg, unguarded moving parts of machines, obstacles on the floor, falling objects, etc.

According to the results of the first two studies, the number of dangers was lower at accident places than at control places (18, 22). If this was the actual situation, then the information processed by workers should have a central role in controlling and regulating the occurrence of accidents when workers are exposed to dangers.

It was concluded that the characteristics of the dangers might influence the likelihood of accidents. This hypothesis was operationalized into two variables: (i) the danger is or is not fixed to one location and (ii) the danger exists or does not exist continuously.

The next step in the studies was to compare companies with a high accident frequency with low accident frequency companies, which formed the control group of light metal industry 2. The result was that fixed dangers were less frequent than mobile dangers in the companies with a high

accident frequency (20). Otherwise the result was somewhat in contrast to the previous results, namely, dangers were more prevalent at workplaces in companies with a high accident frequency than in the other companies.

Light metal industry 2 gave results similar to the first two studies. Dangers were less prevalent at accident sites than at workplaces on the average (table 7). The printing industry gave somewhat different results. Either there was no dif-

Table 7. Occurrence of dangers in light metal industry 2.

Group	Danger									
	Unguarded parts of machines				Flying pieces		Falling or stumbling			
	Fixed		Mobile				Fixed		Mobile	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Accident	33	96	22	107	27	102	46	84	52	78
Control	91	131	45	177	87	135	165	58	147	49
χ^2	8.46		0.54		12.37		50.76		51.41	
RR	0.49		0.81		0.41		0.19		0.19	
RR, RR (95 %)	0.31—0.81		0.46—1.42		0.25—0.67		0.12—0.30		0.12—0.30	

Table 8. Occurrence of dangers in the printing industry.

Group	Danger											
	Unguarded parts of machines				Falling objects		Flying pieces		Falling or strumbling			
	Fixed		Mobile		Fixed		Mobile		Fixed		Mobile	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Accident	16	38	6	48	—	54	15	39	—	54	25	29
Control	77	223	7	293	4	296	37	263	3	297	94	206
χ^2	0.37		9.94		0.73		8.69		0.54		4.58	
RR	1.22		5.23		0		2.73		0		1.89	
RR, RR (95 %)	0.64—2.31		1.87—14.64				1.40—5.34				1.05—3.38	

Table 9. Types of jobs done by the accident and control groups (%).

Type of job	Accident group				Control group			
	Light metal industry 1	Light metal industry 2	Electro-technical industry	Printing industry	Light metal industry 1	Light metal industry 2	Electro-technical industry	Printing industry
Productive								
Operating machines	62	40	87	78	84	37	89	54
Manual work		34		8		45		35
Inspection		2		—		4		3
Transportation		8		7		4		2
Maintenance	26	10	10	—	7	7	4	2
Repair	11	5	—	7	8	3	5	4
Other	1	1	3	—	—	—	3	—
Total	100	100	100	100	99	100	101	100

ference or the dangers were more prevalent at control workplaces (table 8). Mobile dangers seem to be more prevalent in accident cases than in control cases, especially in the printing industry, the final results for which cannot yet be presented because the analysis has not been finished.

Jobs and tasks

The general character of the jobs studied is given in table 9. No major differences between the groups could be found except in light metal industry 1. The general tendency was that productive jobs were underrepresented in the accident groups and maintenance or repair overrepresented. Especially in light metal industry 1, maintenance was greatly overrepresented in the accident group, obviously due to a higher degree of automation of the production lines studied.

The differences between the accident and control groups become much clearer when the types of tasks are examined (table 10). Ordinary tasks are the main contents of jobs. Thus, if the main contents are in maintenance tasks and the person was carrying out maintenance work during the observations or when the accident occurred, the task was classified as an ordinary task. The category of ordinary task therefore involves repair and maintenance tasks in addition to productive tasks.

Especially in the printing industry, very few accidents occurred in ordinary tasks. The same trend is visible in the other samples as well. The removal of disturbances was an important accident task in light

metal industry 1 and in the printing industry; this finding reflects the higher degree of automation in these two types of companies.

Altogether, nonproductive tasks are typical for accidents. When the fact that ordinary tasks also include maintenance and repair tasks is taken into consideration, the number of accidents in productive tasks remains fairly low. In light metal industry 1 only 25 % of the accidents occurred in productive tasks. The same figure was 37 % for light metal industry 2, 58 % for the electrotechnical industry, and 28 % for the printing industry. Thus, accidents occur in nonproductive tasks far more frequently than is proportional to their share of the time worked. Nonproductive tasks are normally less well planned in advance and require more complex information processing than ordinary tasks. In any case they do not allow thorough learning because they are continuously changing.

A very small portion of the accidents occurred in tasks performed at least once per hour (table 11). The electrotechnical industry was the only exception. More than half of the accidents in all the samples occurred in tasks that were done less often than once a day.

Discussion and conclusions

At this stage of analysis, it is too early to draw final conclusions; some tentative ones can however be drawn. From the methodological point of view, it is

Table 10. Types of tasks done by the accident and control groups (%).

Task	Accident group				Control group			
	Light metal industry 1	Light metal industry 2	Electro-technical industry	Printing industry	Light metal industry 1	Light metal industry 2	Electro-technical industry	Printing industry
Ordinary	63	63	71	35	93	92	91	86
Tools, machines and materials (fetching, cleaning, etc)	16	24	23	35	6	5	4	10
Removal of disturbances	13	8	} 6	19	1	1	} 6	2
Other	8	5		11	—	2		3
Total	100	100	100	100	100	100	101	101

Table 11. Frequency of occurrence of tasks in the accident groups (%).

Frequency of occurrence	Accident group			
	Light metal industry 1	Light metal industry 2	Electro-technical industry	Printing industry
At least once an hour	18	16	39	23
Once a day	29	30	6	32
Less than once a day	53	54	55	50
Total	100	100	100	100

clear that comparisons between fields have turned out to be difficult. This difficulty obviously stems from problems in controlling exposure to dangers and the inappropriateness of accidents as a single measure of safety performance (30). The exposure to dangers within a field varies less than between fields. The measurement and control of exposure should be one of the topics of future research efforts.

Another methodological difficulty related to comparisons between fields is that it is difficult to determine whether the differences in safety performance are due to a basically higher degree of safety or to implemented countermeasures.

The sort of statistical method applied in these studies has its limits (3). Accidents may occur in many different ways. Therefore, some causal factors may not become visible in statistical studies. Any causal factor found in this manner must contribute to a large number of accidents. Possible accident mechanisms are so numerous that it is possible, both in theory and in practice, that a statistical study indicates nothing of the causal mechanisms. Laboratory experiments, accident simulations, and in-depth studies are methods that should be used more often in this field.

Averaged and generalized measurements do not seem to shed much light on accident phenomena. In other words, those measurements which describe average characteristics of the work system are not good indicators of the likelihood of accidents. Instead of general characteristics one should measure the situational characteristics of the work system (6).

Therefore, in most cases, no single component as such makes the work system

susceptible to accidents; it is the combination of components and their interactions which contributes to the risk. An accident is a dynamic process. Different components of the work system respond to each other and may compensate for the weakness of other components.

It may be concluded that the accident rate of a given system is determined by its accident potential and its accident promoting or resisting properties. A given accident rate may be a result of different combinations of the two sets of factors. It is a question of which of these two groups of factors should be the subject of countermeasures. Accident potential is a function of the number and the spatial distribution of the dangers in the system. The promoting or resisting factors of accidents relate to information handling and to the worker's behavior. Accident potential is obviously the factor through which the most permanent results can be obtained.

However, knowledge of behavioral and organizational aspects of safety seem to become more important in accident prevention. Traditional techniques of technological accident prevention are, and remain, relevant, but further improvements in safety performance cannot be expected on the basis of them. Automation introduces work situations in which, eg, machine guards cannot be used at all. In such cases prevention must be based on making hazards more recognizable, on properly functioning organizations, and on the safe behavior of people. New technologies presuppose new methods and techniques in accident prevention. And such new methods and techniques are only made possible by a more thorough understanding of the accident phenomenon.

References

- Andersson R, Johansson B, Linden L, Svanström K, Svanström L. On accidents during work. In: *Arbetarskyddsfonden*, ed. *Occupational accident research*. Stockholm 1976, pp 171—180.
- Birmingham, HP, Taylor FV. A design philosophy for man-machine control system. In: Sinaiko W, ed. *Selected papers on human factors in the design and use of control systems*. Dover Publications, New York, NY 1961, pp 67—87.
- Brenner L. 5 accident perceptions. *Hazard prev* 16 (1980): 11, 16—20.
- Buck L. Errors in the perception of railway signals. *Ergonomics* 6 (1963): 2, 181—192.
- Chambers EG, Yule GU. Theory and observation in the investigation of accident causation. *J r stat soc* 7 (1941): 2, 89—109.
- Corlett EN, Gilbank G. A systematic technique for accident analysis. *J occup accid* 2 (1978): 1, 25—38.
- Dunn JG. Skills analysis used for the investigation of accident risk in power-saw operation. University of Aston, Birmingham 1970 (A P Note 21).
- Dunn JG. A safety analysis technique derived from skills analysis. *Appl ergon* 3 (1972): 1, 30—36.
- Goeller BF. Modeling the traffic-safety system. *Accid anal prev* 1 (1969): 3, 167—204.
- Greenwood M, Yule CU. An inquiry into the nature of frequency distributions representative of multiple happenings with particular reference to the occurrence of multiple attacks of disease or of repeated accidents. *J r stat soc* 83 (1920) 255—279.
- Grether CB. Engineering psychology. In: Margolis BL, Kroes WH, ed. *The human side of accident prevention*. Charles C Thomas, Springfield IL 1975, pp 45—91.
- Hacker W. *Allgemeine Arbeits- + Ingenieurpsychologie*. VEB Deutscher Verlag der Wissenschaften, Berlin 1973.
- Haddon W Jr, Suchman EA, Klein DA. *Accident research, its methods and approaches*. Harper and Row, New York, NY 1964.
- Hale AR, Hale M. Accidents in perspective. *Occup psychol* 44 (1970): 2, 115—121.
- Kano H. The genesis and mechanism of human error in accidents resulting latent danger. *J hum ergol* 4 (1975): 1, 53—63.
- Newbold EM. Practical applications of the statistics of repeated events particularly to industrial accidents. *J r stat soc* 90 (1927) 487—547.
- Russel-Davis D. Human errors and transport accidents. *Ergonomics* 2 (1958): 1, 24—33.
- Saari J. Technical prevention of accidents. In: *Arbetarskyddsfonden*, ed. *Occupational accident research*. Stockholm 1976, pp 123—131.
- Saari J. Characteristics of tasks associated with the occurrence of accidents. *J occup accid* 1 (1976/1977): 4, 273—279.
- Saari JT, Lahtela J. Characteristics of jobs in high and low accident frequency companies in the light metal working industry. *Accid anal prev* 11 (1979): 1, 51—60.
- Saari JT, Lahtela JS. Work structuring and safety. In: Sell RG, Shipley P, ed. *Satisfactions in work design: Ergonomics and other approaches*. Taylor & Francis, London 1979, pp 149—154.
- Saari J, Rinne R. Accidents and working conditions in two industrial branches with different accident rates. In: *International Labor Organization*, ed. *Proceedings of the VIII world congress on the prevention of occupational accidents and diseases*, Bucharest, May 17—21, 1977. Geneva 1978, pp 174—177.
- Sell RG. *Ergonomics versus accidents*. Department of Scientific and Industrial Research Information Division, London 1964. (Ergonomics for industry no 5).
- Sell RG. The psychology of safety. *Br j ind saf* 7 (1966) 146—151 + 158.
- Singleton WT. Techniques for determining the causes of error. *Appl ergon* 3 (1972): 3, 126—131.
- Singleton WT. Skill and accidents. In: *Arbetarskyddsfonden*, ed. *Occupational accident research*. Stockholm 1976, pp 107—118.
- Skiba R. *Die Gefahrenträgertheorie*. Bundesanstalt für Arbeitsschutz und Unfallforschung, Dortmund-Marten 1973. (Forschungsbericht Nr 106).
- Smillie RJ, Ayoub MA. A computer simulation approach for analyzing occupational accidents. In: *International Ergonomics Association*, ed. *Proceedings of the 6th congress of the international ergonomics association*, 1976, pp 226—235.
- Surry J. *Industrial accident research*. University of Toronto, Toronto 1969.
- Tarrants WE. *The measurement of safety performance*. Garland STPM Press, New York, NY 1980.