Safety in and around the house with particular reference to stairs

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1 Introduction

Accidents in the home form a large proportion of the total number of accidents in our society, as we shall see in Section 3 of this article. The question that we would like to address therefore is: who is concerned with reducing the number of these accidents and how could they be prevented?
In trying to answer this question we shall focus our attention on "falls from stairs". This type of accident happens very frequently and can illustrate our problem quite well.
Section 2 of this article is concerned with the questions as to who may be interested in home safety (considering the example of stair safety) and what positions various groups occupy in this field.
Section 3 discusses general statistics on home safety, while Section 4 highlights the accident models and a recently developed approach to analysing accidents in the home as a general risk problem.
Section 5 applies that "accident scenario approach" to stair accidents, and in Section 6 we explain how optimalization of safety and costs can be calculated.
Section 7, finally, presents the general conclusions.

2 Safety and domestic staircases

2.1 *Who is interested in safety of domestic staircases?*

The answer to this question could be: anybody or any institution who will be paying for the consequences of stair falls, that is paying in a broad sense, with their lives, health, future or money.
A list of payers can be drawn up quite easily:
- anybody who uses domestic staircases and therefore is at risk: inhabitants, visitors, personnel employed in the home;
- local and national authorities, as they are expected to protect the citizen from harm, to assure the quality of life, and to reduce costs of health care;
- employers, social welfare funds, etc., who pay for lost time of workers who have had a domestic accident;
- owners of houses, as they could be held responsible for neglecting repairs to staircases;

- and, in one way or another, architects, builders and their advisers, who in some cases clearly do not pay much attention to the proper design of staircases and their surroundings.

This list is quite impressive. So we could expect at least somebody to take action to make staircases safer. As this is not so, at least not till now, in the Netherlands, the question arises as to why there is this lack of interest. It seems that four reasons can be given:

1. everybody thinks staircases are as safe as possible;
2. too many people are responsible for safety;
3. making staircases safer would cost too much;
4. nobody knows how to make stairs safer, that is, to make safe use of a given staircase or to improve staircases to make them safer.

The last-mentioned reason, to begin with, simply is not true.

It has been shown that members of the public are as capable as "experts" of assessing the dangerousness of a given set of stairs. And what is common sense to the public in recent years has been proven by way of scientific research: It has been proven, for example, that "dog-leg" staircases cause fewer accidents and that adequate lighting and well positioned handrails make walking on stairs easier and above all safer [1, 2, 3, 4, 5, 6, 7]. Also it is clear that if people would not hurry, carry large objects, walk in their stockinged feet, walk on stairs in the dark, etc., there would be much fewer incidents and accidents. It may be true that some of this evidence has been produced only recently and has not yet been quantitatively assessed, e.g. "How much light is enough?" etc.; so research on specific topics is still needed. But, generally speaking, one cannot say that there is insufficient knowledge about safety of stairs.

2.2 *The danger of domestic staircases*

The first reason given: "everybody thinks stairs are safe", could alternatively be put as: "nobody knows how many accidents on stairs happen every day". For if the total number of victims from stair falls seems quite impressive, falls occur only every 200,000 or so uses, so the individual user or family may only know from newspapers about the actual magnitude of the problem.

Fatal diseases, road accidents, falls from stairs, affect individuals, but seem to impress only a small circle of people around the victim. And also he or she who decides to eat healthy food, to drive carefully, or to switch on the light before walking on stairs, will not immediately perceive a considerable decrease in risk nor completely *eliminate* risks.

On the other hand, in every household living in dwellings with stairs, enough *incidents* occur to create an awareness of the danger of stairs. The response to this awareness may differ from one household to another: some families keep strict rules about stair use: do not leave things on the stairs, do not try to use stairs when somebody else is on them, do not play on stairs, etc. Also they may take preventive measures, providing stair treads with anti-slip surfaces, fences to keep children away from them, etc.

The total population of the Netherlands is about 14,000,000, the total number of falls from stairs which need medical attention is about 200,000, and if we assume that the average number of stair uses per day is 10, which seems reasonable, we arrive at one fall with injuries in every 260,000 uses.

Probably the extent to which people are interested in safety on "their own" stairs will depend largely on their experiences and will therefore be very different from one household to another - and from one moment to another, depending on the "freshness" of memories -.

However, at a nationwide level it is becoming clearer and clearer that stairs in and around the home come first as a feature involved in domestic accidents, causing at least one hundred fatal and tens of thousands of non-fatal injuries every year. This evidence has been produced in recent years by PORS, the system for recording home and leisure accidents in the Netherlands, which has been in use since 1983.

This evidence has led the Netherlands Ministry of Housing to initiate research projects on stair safety, which are currently being carried out at the Delft University of Technology and the Organisation for Applied Scientific Research (TNO).

2.3 *Responsibilities and costs*

The second reason on our list: too many people are responsible for safety, could be complemented by adding: so nobody will see it as his or her particular duty to look after safety measures. As the division of responsibilities in the whole building process with its many participants is rather complex and in many cases lacks a clear definition, safety is likely to be one of the least popular aspects.

As most accidents on stairs cannot be explained by one dominating cause, there will be many fingers pointing in many directions when it comes to blaming someone. So it is not hard to understand that the one at the end of the line - the user/victim - will be blamed in the first place for his or her carelessness, even if the fall occurred on dirty, steep stairways, with worn treads and burnt-out light-bulbs, and the handrail gave way when the person tried to safe himself.

Then what about the third reason: making stairs safer would cost too much?

People are limited in their scope for changing a dangerous situation: changing the carpet on your stairs is one thing, changing the stairs themselves, or moving altogether, is another. Homes with two or more storeys, besides the disadvantage of having inside stairs, have many advantages: there is a clear distinction between different areas inside the home and often these homes are larger, have a garden, etc., which in the first place makes them attractive for families with children.

If making stairs safer would mean making them less steep, this would take up more space and either make houses more expensive or leave less space inside them, two consequences that are among the most "unpopular" with occupants.

Yet another group of possible victims of stair accidents are those who have a job which necessitates them visiting other people's homes: the postman, removal workers, home-attending nurses, household workers, firemen, ambulance drivers and so on. Often they have to carry out extra heavy tasks, like carrying stretchers. The actual number of workers that have an accident on domestic stairs is not well-known and it may be only a fraction of the total number of stair accidents, because their exposure to the hazard as well as their number is relatively small. But it is still interesting to consider this group, because this raises the question of working conditions with all its legal and financial implications, which remain "hidden" or are non-existent when people fall from their "own" stairs.

Here another group of "payers" comes in: social welfare funds and employers. Working people who fall from stairs either in their own home or "on the job" in someone else's home will have to be replaced, which is not the case with housewives, children and unemployed persons. "Costs" of stair falls resulting in identical injuries may therefore differ from one case to an other.

For the authorities the question of cost-effectiveness of safety measures of stairs is a very delicate matter. On the one hand, the quality of housing is one of the most important issues of government policy, which at the same time is directed at reducing the costs of health-care facilities. On the other hand, housing funds already take a relatively large share of the national budget and even if the cost per unit can be limited, it will considerably increase the cost of housing production.

The possibilities of intervention by the government are largely a matter of political consensus: no doubt things are easier if the cost-effectiveness of measures is felt right at the spot where the money is spent: but the Ministry of Housing will not derive much benefit (other than immaterial) from investments for safety-measures. Fewer incidents will, above all, mean a reduction of costs in the area of health care, i.e. a benefit for the Ministry of Health.

In the year 2030 the population of persons over 65 years old will have doubled [8] and fewer and fewer of the older peopple will let themselves be "put away" in nursing homes: if their homes are good, they may be able to live there for many more years, possibly getting some help from day-care centres, etc. In many dwellings the main obstacle to such a decision will be the stairs: if only they had been just a little less steep, better lit, etc.

Furthermore, government policies are directed at reducing the need for specially designed houses for the handicapped, making normal housing easier to live in, or adapting it to the needs of these people.

Also, the government wants to save money by reducing time spent in hospital beds, firstly by making homes safer, secondly by making it easier for patients to be treated for their illness in their own homes.

But many homes even among those recently built may present a lot of problems for certain categories of people in the near future, and if policies do not change we may be confronted with a large social, if not an ethical and moral, problem.

This situation could be changed by the implementation of product-liability legislation in Europe in the near future: then costs of stair accidents may affect owners, architects and builders in a more direct way and therefore make them more interested in taking preventive measures instead of only fullfilling the minimum demands of building regulations. This may at least reduce the "lack of attention" concerning the design of staircases and their surroundings, which in our opinion must be considered a major factor underlying stair falls. Naturally regulations must be to the point and based on research findings, but they alone cannot bring about a change in current design practices or change the way the building process is organized, or avoid the obvious blunders that still affect the quality and safety of a certain percentage of newly-built dwellings in the Netherlands.

3 Accident statistics

3.1 *Concise overview of available databases concerning accidents in the Netherlands*

A large number of Netherlands statistical data relating to accidents are collected, classified and published by the Central Bureau of Statistics (CBS), which obtains its information from a variety of sources, including:
- data of fatal injuries from death certificates issued by doctors;
- data of accident victims admitted to hospitals, collected by the Stichting Medische Registratie (Institution for Medical Records) (SMR);
- data concerning assistance given in outbreaks of fires and other disasters; this information is obtained through the fire brigades.

Besides the CBS there are also other organizations that collect and publish data relating to accidents - particularly with regard to certain types of accident. Some examples are:
- the recording of data concerning admissions to nursing homes by the Stichting Informatiecentrum Gezondheidszorg (Information Centre for Health Care) (SIG);
- the recording of accidents which are presumed to have been caused by electricity, by the Association of Electricity Generating Plant Operators in the Netherlands;
- the recording of serious accidents in the private sphere in which electricity is involved, by the Labour Inspectorate;
- the recording of accidents with gas by the VEG Gas Institute;
- the recording of accidents within the scope of PORS (Private Accidents Recording System), by the Consumer Safety Institute.

Through PORS the required data have, since 1983, been obtained by collecting information - in 14 hospitals throughout the Netherlands - concerning victims of accidents in the private sphere, i.e., accidents not connected with work or traffic. As a result, a clearer picture can now be obtained of the type of accidents that occur in the private sphere, the places where they occur, and the seriousness of the injuries caused by them. In this connection it must be borne in mind that about 82% of the fatal injuries and 47% of the medically treated injuries in private accidents are found to be due to accidents in or around the home. Hence a substantial proportion of the private accidents occurs within this limited sector of the private sphere. The data which become available through PORS are accordingly of considerable importance in the context of studies relating to safety in and around the home.
In addition to the above-mentioned sources, which issue a continuous supply of information, supplementary information is incidentally obtained by means of random samples and studies. Such studies have been carried out by, among others, the Veilig-

heidsinstituut (Safety Institute), the Stichting Vergelijkend Warenonderzoek (Institution for Comparative Investigation of Merchandise) and the consumer organizations. For further information the reader is referred to [9, 10].

3.2 *Some statistical data*

A comparative overview of the numbers of victims of industrial, traffic and private accidents is given in table 3.1.

With regard to this table it is to be noted that the number of admissions to hospital indicated comprises 70% of the total number of admissions and that the number of fatal injuries comprises 54% of the total number of fatal injuries due to accidents, i.e., 2% of all deaths in the Netherlands in 1981. Besides the large number of admissions to hospital due to private accidents, it must be borne in mind that something like 70,000 patients per year are treated in the out-patient departments of hospitals after meeting with accidents in the private sphere. The total number of private accidents in 1981 was over 2 million, of which roughly 1 million occurred in and around the home. Tables 3.2, 3.3 and 3.4 give information on private accidents, based on results of the above-mentioned PORS records [11]. More detailed overviews, such as given in Table 3.4, are necessary

Table 3.1. Key figures for accidents in the Netherlands [9]

type of accidents	died	admitted to hospital	total recorded fatal and non-fatal injuries/accidents
industrial accidents	62	3,071	75,515
traffic accidents (including air and water traffic)	1,876	25,868[3]	53,505[1]
private accidents	2,230	67,929[2,3]	2,308,315

[1] Total number of recorded accidents, involving one or more persons, on public roads.
[2] Estimated number of victims of private accidents admitted to hospital.
[3] Figures for 1980.

Table 3.2. Age and sex of accident patients treated in hospitals in the Netherlands, determined from a random sample with $n = 70615$ [11]

age, years	sex: man %	sex: woman %	total in sample %	estimated total in hospitals in the Netherlands
0–4	4.1	3.0	7.1	47,300
5–19	21.6	14.6	36.2	242,300
20–34	18.6	9.0	27.6	185,000
35–59	10.2	8.9	19.1	128,200
60+	2.8	7.0	9.8	65,600
not known	0.1	0.1	0.2	1,600
all ages	57.4	42.6	100.0	670,000*

* The 95% confidence interval for all private accidents which were treated in hospitals in the Netherlands in 1985 is within the limits of 670,000 ± 144,000.

Table 3.3. Patients admitted to hospital in the Netherlands in consequence of private accidents [11]

type/cause of accident	%	estimated total in hospitals in the Netherlands
fall from stairs/steps	4.6	31,000
fall from ladder	0.5	3,600
fall from building/structure	0.4	2,800
fall from height	11.3	76,000
fall at same level	36.0	241,000
fall, unspecified	0.9	6,100
cutting, piercing object	9.0	60,000
falling, thrown object	5.5	37,000
bumping, jamming	20.0	133,000
fire, uncontrolled	0.0	200
heat, fire sources	1.7	11,000
explosions	0.2	1,300
ingestion of noxious substance	0.4	2,700
inhalation of noxious substance	0.0	300
foreign objects	0.5	3,500
asphyxiation	0.0	200
electric current	0.0	40
fall in water	0.1	400
radiation	0.1	700
injury by animal	3.7	25,000
grit in the eye	1.4	9,500
forces of nature	0.0	0
others	3.4	22,000
not known	0.2	1,600
total	100.0	

Table 3.4. Place of accident, according to age of victims [11]

place	age (years, %) 0–4	5–19	20–34	35–59	60+	not known	all	random sample (all ages) *n*	estimated number* (in all hospitals) *n'*
in/around the home	69.1	20.8	31.2	44.3	49.6	37.9	34.5	24,331	230,000
road/highway	15.9	22.1	15.9	21.4	31.6	15.5	20.8	14,661	139,000
factory/industry	0.1	0.3	0.4	0.7	0.2	0.0	0.4	253	2,400
school	1.8	13.1	0.8	0.1	0.1	10.3	5.1	3,625	34,000
institutions	0.8	0.2	0.2	0.4	6.4	1,7	0.9	643	6,100
public buildings	1.5	1.0	1,7	1.9	2.6	0.0	1.6	1,108	10,000
sports facilities	1.4	24.4	37.8	16.9	1.3	19.0	22.8	16,086	152,000
recreational facilities	1.2	6.5	4.2	6.8	2.3	5.2	5.1	3,625	34,000
holiday accommodation	0.5	0.7	0.4	0.8	0.4	0.0	0.6	411	3,900
entertainment facilities	1.1	1.2	0.3	0.2	0.1	1.7	0.7	476	4,500
play facilities	3.1	4.0	0.1	0.1	0.1	3.4	1.7	1,212	11,000
others	0.1	0.1	0.2	0.2	0.1	0.0	0.1	101	1,000
not known	3.5	5.5	6.7	6.2	5.3	5.2	5.8	4,083	39,000
% per age group	7.1	36.2	27.7	19.2	9.8	0.1	100.1		
sample *n*:	4996	25578	19532	13527	6924	58		70,615	

* This column gives the estimated number of treatments for all hospitals in the Netherlands.

for obtaining as much insight as possible into the various aspects involved in safety in and around the home.

3.3 *Interpretation of statistical and other data*

The aims of compiling statistical overviews and the interpretation thereof are:

1. To form a soundly-based opinion on the degree of safety in and around the home, also in comparison with the safety existing under other conditions (at work, in traffic, etc.).
2. To give insight into the cost-benefit effects of measures for the improvement of safety.

The interpretation of the available data is often far from simple. For example, it is necessary to take account of how the statistical numbers or percentages have been determined. With regard to a random sample, as in the PORS investigation, it will thus always have to be considered that extrapolation to national figures, i.e., relating to the country as a whole, involves a degree of uncertainty. In this case the figures are based on the numbers of patients in 14 hospitals in the Netherlands, but these do not include the country's three hospitals with special units for the treatment of burns. Hence accidents causing burns to their victims are bound to be under-represented in the PORS figures. In this context it is to be noted that data relating to patients undergoing treatment for burns are recorded by the Nederlandse Brandwonden Stichting (Netherlands Institution for Burns). It is evident, however, that the combining of data from different sources is justified only if this is done with the necessary care.

Since accident victims killed immediately at the time of the accident are mostly not admitted to hospital, these are also under-represented in the PORS figures. Indeed, this would still be the case if the figures were obtained, not from a random sample, but from a count of all the patients in every hospital in the Netherlands. The accident designated as "fall from stairs" can serve as an example of the difficulties associated with the interpretation of statistical data of accidents with a view to ascertaining the causes thereof. It is evident that the cause (or causes) of the accident cannot be ascertained from purely statistical data in the form of numbers of victims, but that special supplementary investigation is needed for that. To what extent the fall is attributable to circumstances or to combinations of circumstances, e.g., a staircase that is (too) steep or a floor that is (too) slippery, to the layout of the dwelling or to other technical feaures, or to the condition of the victim just before and during his or her fall, may be the subject of such supplementary investigation.

In the Netherlands there are a number of institutions and authorities that occupy themselves with the interpretation of the statistical data concerning safety in and around dwellings and also carry out supplementary research. These include:

- institutions such as TNO, KEMA, KOMO, NNI, the Safety Institute, the Consumer Safety Institute;
- universities;
- government and public welfare services (including hospitals).

3.4 *Necessary supplementary information, besides statistical data*

Important though statistical data are for the assessment of safety and of the possible need for measures to enhance safety, they are in themselves usually not sufficient for the purpose. The reasons for this are:

1. It is, for practical reasons, not possible in the statistical compilations to devote attention to all circumstances and combinations thereof which may affect the probability of occurrence of an accident. (In this context one may think of, for example: types of dwelling as regards dimensions, layout, etc.; size and composition of the household; finishes and fittings of the dwelling; furniture; etc.).
2. The statistical compilations will not include data relating to factors whose importance with regard to safety has not (yet) been identified.
3. Statistical data give information only on circumstances and situations in the past. It is sometimes possible by extrapolation from these to make prognoses for future developments. The statistical data are, however, inadequate for assessing the effect on safety due to more or less abrupt changes in social, economic and technical conditions. These changes in conditions or circumstances may result from, among other causes, the introduction of new materials and construction methods, an increase in do-it-yourself activities, the introduction of new regulations and statutory requirements (e.g., introduction of European codes of practice), etc.
4. There are as yet no generally accepted procedures for determining in each and every case what the minimum requirements and the optimum safety are.

From what has been said above it follows that, for the assessment of safety and for deciding what measures (if any) are to be applied in a particular case, it is necessary, by means of a study for that case, to obtain extra information to supplement the available statistical data.

4 Accident models and scenarios

4.1 *Accident process models (APA)*

The previous sections highlighted the large number of accidents in and around the home, and the various groups of people who can do something to prevent these accidents. Especially the possibilities of exploring preventive measures in the early phases of the life-cycle of the dwelling are of relevance to reducing the number of accidents effectively over a longer period.

Therefore an instrument for judgement of the safety level of a dwelling or a group of dwellings would be appropriate. With the help of such an instrument it would be possible to discriminate between the relatively unsafe and safe characteristics in a design. This may be helpful in making decisions on preventive measures.

The accident process is undoubtedly to be considered as a multicausal process. The past two decades have seen a development in models to explain human involvement in accidents [12]. The models developed are based on a system approach and are strongly influenced by the concepts of information theory and cybernetics. They are either presented as models of accident causation [13, 14] or as decision models of the accident process [15, 16]. An example of the latter is the Stair Safety and Use model developed by Archea et al. [1]. Further on in this article we shall refer to these models as the Accident Process Approach (APA).

In considering the impact of psychological factors these models take the human information processing into account [17]. A limitation of these models is that they lay their emphasis on human functioning in its technical and organisational context in the operational phase of the system. Conclusions on the influence of e.g. the design of stairs and their surroundings must be drawn from additional analyses. For this purpose accident process models have been developed [18, 19, 20]. These models relate the concluding phase of the accident process - which takes place during the operational phase of the system - to initiatory phases of the life-cycle of the system (choice for a particular type of dwelling, design of stairs, and lay-out and construction of the dwelling under consideration). An example of such an accident process model for stairs is given by Goossens and Heimplaetzer [21].

In brief, APA aims at explaining the time sequence within which an accident occurs. The approach is based on in-depth accident analyses, data from interviews, and so on.

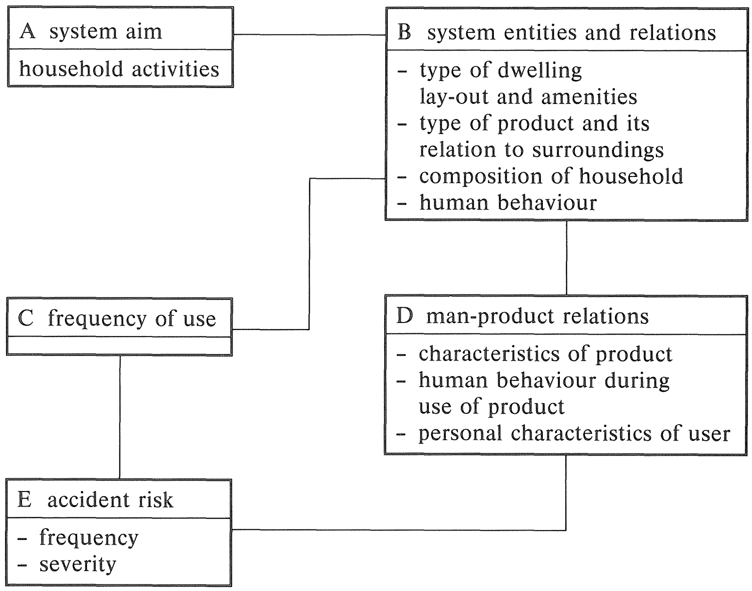


Fig. 4.1. Definition of system and risk factors.

4.2 *Accident scenario approach (ASA)*

Attempts are made to analyse accidents on a higher level of aggregation. This we refer to as the Accident Scenario Approach. ASA is also based on the systems approach, the fundamentals of which have been described elsewhere [20, 21, 22]. According to this approach, every dwelling with its occupants is considered as a system with a system aim (A), system entities and their relations (B), that both determine the exposure (or involvement) of users (C) and the actual man-product relations (D), which are usually found to be close to the concluding phase of the accident process. (C) and (D) determine the frequency and severity of different accident types (E). Fig. 4.1 shows these features in perspective.Given the type of accidents to be investigated – e.g. stair accidents – characteristics of each of these features are to be so defined that:

1. a comprehensive description of the system is given; and
2. all factors which are expected to be associated with accidents are mentioned.

These characteristics, which are summarised in Fig. 4.1, will be referred to as risk factors.

None of the recording systems referred to previously provide data on all of these risk factors. National statistics focus on data about injuries and factors close to the accident. Research projects sometimes provide data on other risk factors as well. However, data on type and lay-out of the dwelling, type of stairs involved in the accident, and frequency of use are scarce.

As a conclusion we can say that ASA and APA have many things in common, but the main difference lies in the fact that APA is a "bottom-up" approach, starting from the concluding phase of an accident, while ASA is a "top-down" approach, overviewing risk factors associated with a specific type of accident. ASA therefore aims at defining the relevant risk factors of a certain type of accidents without taking the sequence of events into account. It uses analyses mostly based on accident data from recording systems and specific research. ASA does not require full descriptions of accidents or exact eyewitness reports with all their disadvantages. ASA operates at a higher level and requires generic information on the contribution of risk factors. Operating at a higher level means that with ASA it is possible to consider characteristics of household and dwelling as risk factors in comparison with accident-free situations, which makes it better feasible to determine design and construction features for prevention.

One disadvantage of ASA as compared with APA is that ASA only explains which risk factors are relevant and not why they are relevant. Eventually – in the phase of finding solutions – specific analyses are therefore additionally required. This may involve techniques derived from APA, but also experimental set-ups, additional questionnaires, and so on. In this case, however, problems will be sharply defined and experiments can be directed towards very specific questions. Another disadvantage is that ASA requires sufficient accident data on the relevant risk factors in connection with various types of dwellings, stairs and households. Collecting these can be very laborious and time-consuming as well.

5 Staircase-study

The risk of having a stair accident is, according to the latest concept in risk analysis methodologies [23], defined as a set of triplets, each of which can be written as:

$$R = \langle S, p, G \rangle \tag{5.1}$$

S describes a particular accident scenario, p is the probability of occurrence of that scenario, and G denotes the consequences in terms of severity. The probability in formula (5.1) expresses the expected value of occurrence of a stair accident, which is an estimate of the true value. This value can be obtained by the use of expert opinions, based on statistical evidence. This evidence may be obtained from data collection on accidents.

The determination of p calls for some comments. In principle, the probability is expressed as the ratio between the occurrence of a particular scenario and the occurrence of situations in which scenarios are likely to occur. In other words, each time a person uses a staircase in the defined situation the probability of having an accident is expressed by p. One should then not only know the number of accidents but also the frequency of stair use (C in Fig. 4.1). Since p was not known in our case, data collection was directed at assessment of the accident frequencies. In this case p in formula (5.1) must be replaced by the accident frequency FA, which is defined by the number of stair accidents over a given period of time over a certain population at risk per person, and yields

$$R = \langle S, \mathrm{FA}, G \rangle \tag{5.2}$$

On the basis of a questionnaire survey that was carried out by the TU Delft in 1986 data of accidents and risk factors over a nine-month period from 850 households in The Hague [24] were obtained. 77 falls from stairs with and without injuries were reported in 440 dwellings with inside stairs (see Fig. 5.1).

The procedure of defining accident scenarios has been the following:

STEP 1

All accidents are uniquely attributed to features involved in the accident production (which is not the same as injury production): in this case to stairs. In our case the average accident frequency FAV turns out to be equal to 0.081 accidents per year per person over 14 years old. Children are excluded in this experiment and must be dealt with separately.

STEP 2

Accident recording systems provide data on the age and sex of victims (E in Fig. 4.1). According to these, all victims can be distributed over a number of high-risk and low-risk groups. Such a distribution provides information as to how the entities and relations (B in Fig. 4.1) must be defined and what is the relative importance of the frequency of use (C in Fig. 4.1). The following risk groups are defined in our example:

children	FA=0.050 per person per year
women (15–49 years old)	FA=0.14 per person per year
elderly persons (over 64 years old)	FA=0.057 per person per year
others	FA=0.057 per person per year

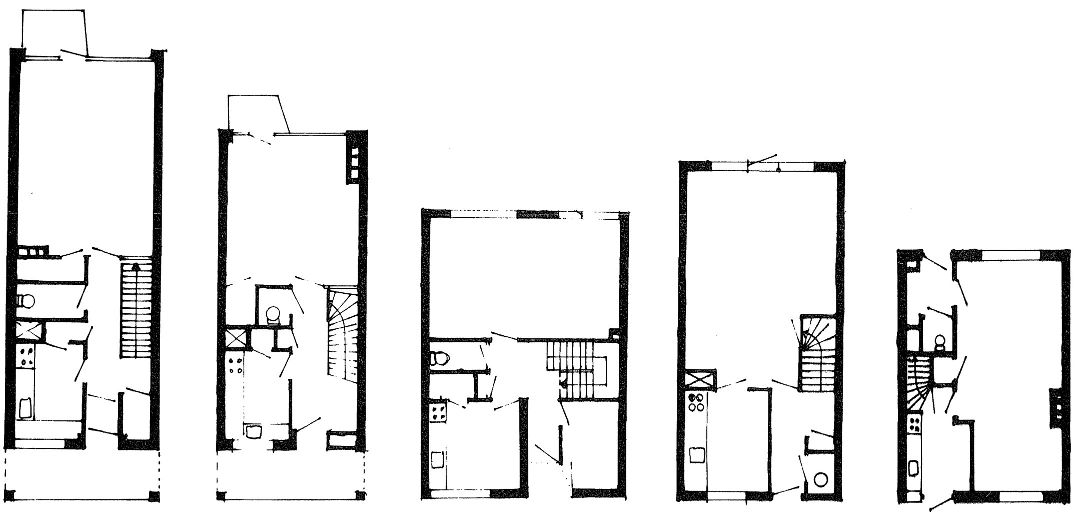
STEP 3

The next step then is to determine the stair accident frequencies FA with respect to the defined entities and relations (e.g. Bx, By). If these risk factors are potentially accidental, then FA (Bx, By) > FAV; if they are potentially preventive, then FA (Bx, By) < FAV.

Table 5.1. Accident frequencies per person per year for the relevant risk factors households and stairs

	households with elderly persons	households without children	households with children
tapered stair	0.12	0.16	0.12
stair with winders in old houses	0.027	0.13	0.28
straight stair	0.027	0.054	0.23
dogleg stair	0.054	0.054	0.20
stair with winders in new houses	0	0.15	0.20

A multivariate analysis technique called PRINCALS [25] developed at Leiden University has been used, which shows [24] that households with children are strongly correlated with falls, while households with elderly persons are not. It also showed a correlation between type of stair and accidents and no correlation at all with other dwelling characteristics. Table 5.1 summarises the results in terms of accident frequencies. Fig. 5.1 shows examples of the stairs mentioned in Table 5.1. From this table, rough high-risk and low-risk accident scenarios can be defined (Table 5.2).



straight stair — tapered stair — dogleg stair — stair with winders in new houses — stair with winders in old houses

Fig. 5.1. Examples of stairs mentioned in Table 5.1.

Table 5.2. Rough accident scenarios for inside stairs

accident scenarios	households	stair	FA (Bx, By)	number of households
S(1)	with children	straight dogleg winders	0.21	76
S(2)	all types	tapered	0.13	47
S(3)	without children	winders	0.15	82
S(4)	without children	straight dogleg	0.054	106
S(5)	elderly persons	straight dogleg winders (old houses)	0.032	119

STEP 4

The fourth step will be to refine the presented rough accident scenarios from step 3 with particular emphasis on risk factors related to the man-product-relations (D in Fig. 4.1). These risk factors can be classified into three groups of variables:

a. variables defined by the properties of the victims/users of stairs (such as eye disabilities);
b. variables defined by stair properties (such as lighting facilities on stairs and daylight access to stairs);
c. variables defined by behavioural characteristics relating user to product and which deviate from intentional use (such as ascending stairs without switching the lights on).

In our case a full analysis has not yet been carried out, but some examples of risk factors of this type are:

- dizziness increased effect by a factor of 2;
- fear of heights increased effect by a factor of 1.5;
- objects in surroundings increased effect by a factor of 1.5;
- taking shortcuts on winders increased effect by a factor of 2 to 3.

STEP 5

The procedure is then to be completed by taking the probability p and the consequences G into account. This step is essential in rendering the experimental results into a more generally applicable results. In principle

$$p = p\ (\mathrm{FA}) \tag{5.3}$$

The main question is whether

$$p\ (\mathrm{FA}) = q \cdot \mathrm{FA} \tag{5.4}$$

Supposing women, who perform most of the household activities, use the stair three times as much as the elderly do, their probabilities p of having an accident are almost

equal (see STEP 2). Since in our case there is no information on the frequency of use, no predictions of p can be made at this stage.
An estimate of the consequences G can also be made from the questionnaire, in which we separately asked about severe accidents (hospitalised or outpatient/physician treatment). Table 5.3 shows the accident frequencies of severe stair accidents FSA.

Table 5.3. Severe stair accident frequencies

type of stair	accident frequency per person per year
straight stair	0.006
tapered stair	0.015
dogleg stair	0.003
stair with winders in new houses	0.014
stair with winders in old houses	0.023

6 The optimal safety level

6.1 *Using safety levels*

In the preceding chapter it has been considered how accident scenarios relating to, for example, staircases in dwellings can be established. The accident frequencies calculated from the survey of accidents (FA in Table 5.2, FSA in Table 5.3) are, in a sense, a measure of the safety level. The basis for this is formed by equation (5.2), and the safety level will approximately be inversely proportional to the risk R.
Now if it is proposed, say, to replace the conventional staircase with winders by a different stair type - offering a higher safety level - in new houses, it will in the first place be necessary to compare the risk R with the remaining risk RR in the new situations. This has been theoretically analysed by Goossens [26].
For households with children (accident scenarios S(1) and S(2) in Table 5.2) the new safety level is determined mainly by the change in serious accidents. Only the tapered staircase is something of a maverick. For households without children (accident scenarios S(2), S(3) and S(4)) the safety level is moreover determined by the three times lower accident frequency associated with staircases without winders. Again, for households with elderly persons the safety level is mainly determined by the serious accidents, likewise with the tapered staircase forming the exception. With regard to accidents involving elderly persons on stairs in new dwellings there are, however, insufficient data available to make reliable pronouncements.

6.2 *The optimal safety level*

In this context the optimal safety level should be conceived as the economically optimal level. By this is understood a safety level so determined that the sum of the costs for attaining this level and the capitalized risk is a minimum. Expressed as a formula, the total cost is:

$$C_{tot} = C_o + R \tag{6.1}$$

where:

C_o = the cost of attaining and maintaining a particular safety level (the cost of an alternative)
R = the capitalized risk $= p \cdot C_d$, where p = accident probability
C_d = the economic consequence of the accident

According as more money is, in building construction, invested in measures for reducing the probability of accidents, the risk will likewise diminish. It will then be possible to find such a combination of the two cost items that their sum is a minimum. This situation is represented in graph form in Fig. 6.1. The optimal safety level is found at point A.
In general, a particular degree of safety will exist in and around the home on account of regulations that have to be complied with. Failure on the builder's part to comply, or subsequent changes made to the dwelling, are liable to affect the safety level adversely.

6.3 *Methodology for attaining the optimal safety level*

The principle of attaining the economically optimal safety level has been explained in Section 6.2. In actual practice, however, there are seldom sufficient data available for plotting smoothly curved lines like those drawn in Fig. 6.1. As a rule, a quantity of data relating to a number of specific situations is known; it must then be endeavoured, basing oneself on these, to find the optimal safety level for other situations. A practicable methodology for this purpose will be given in the following. The central aim is: how to decide what measures will result in the optimal safety level.

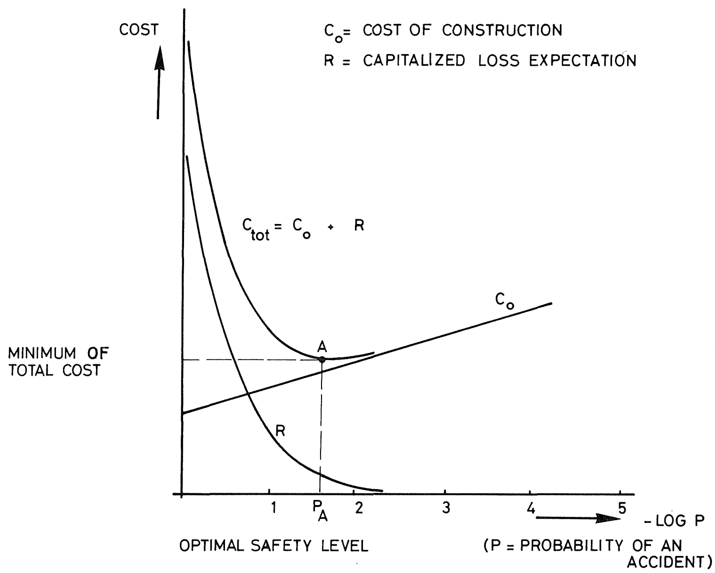


Fig. 6.1 The relation between the probability of an accident and the cost.

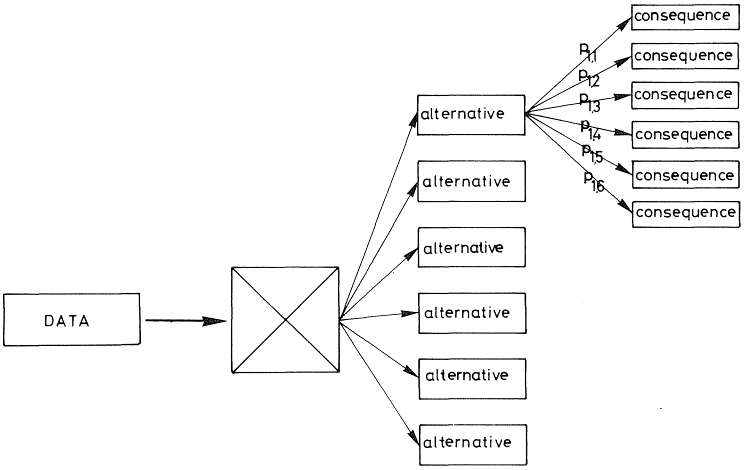


Fig. 6.2 A decision tree with consequences.

Deciding means making a choice from among a number of alternatives. The choice of an alternative involves probabilities of various consequences. A different alternative leads to a different distribution of probabilities of consequences. This difference plays a part in the decision. These aspects are represented in Fig. 6.2.
It is necessary to have, or to gain, insight into the possible consequences and into the probability of those consequences, given a chosen alternative. This means, too, that there must be insight into all those factors which affect the probabilities. If no statistical material is available, it is possible to work with estimates of the probabilities and the influences affecting them. At a later stage the sensitivity of the estimate can be studied, should that be considered necessary.
Hence the aim is to find:

$$\min \left\{ K_i + \sum_{j=1}^{m} p_{ij} \cdot K_{ij} \right\} \text{ for } i = 1 \text{ to } n \qquad (6.2)$$

where:

K_i = cost of alternative i
n = number of alternatives
p_{ij} = probability of consequence j with alternative i
K_{ij} = cost of consequence j with alternative i
m = number of consequences associated with an alternative

In connection with risk considerations, as in the present study, it is usual to work with scenarios. Since the risks in question relate to accidents in and around the home, we are here more particularly concerned with accident scenarios.
Several of such scenarios are to be distinguished in connection with any particular alternative. One accident scenario may lead to various consequences. If scenarios are used,

some adjustment of Fig. 6.2 is necessary. Fig. 6.3 shows what this becomes for one alternative. It emerges from this diagram that the total cost C_{tot} for alternative i is:

$$C_{tot_i} = C_{o_i} + \left\{ \sum_{j=1}^{m} \left(\sum_{k=1}^{l} p_{s_j,c_k} \cdot C_k \right) \right\}_i \tag{6.3}$$

where:

p_{s_j,c_k} = probability of consequence k with scenario j
C_k = the cost of consequence k
C_{o_i} = the cost of alternative i
m = number of scenarios associated with alternative i
k = number of possible consequences per scenario

Again the minimum must be sought for C_{tot_i} (for $i = 1$ to n, where n is the number of alternatives).

6.4 *The optimization model*

a. The cost of an alternative

The cost of an alternative comprises:

- the cost of attaining a particular safety level C_{o_s};
- the annual cost of maintaining this safety level C_{o_m}.

Then, for a planned service life of N years and a real interest rate of r%:

$$C_o = C_{o_s} + \frac{100\left(1 - \left(\frac{1}{1 + r/100}\right)^N\right)}{r} C_{o_m} \tag{6.4}$$

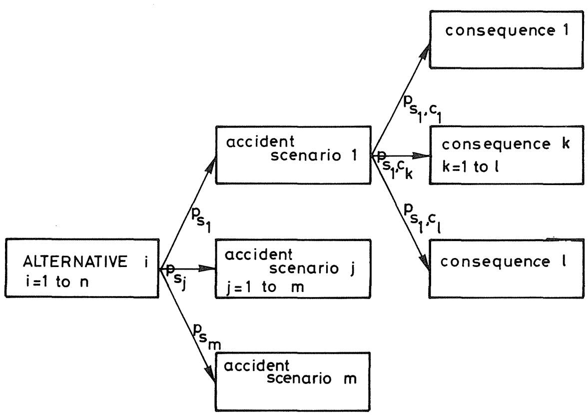


Fig. 6.3 Part of a decision tree with accident scenarios.

b. The capitalized loss expectation

If the loss expectation per year is constant, the capitalized loss expectation is:

$$R = \frac{100\left(1-\left(\frac{1}{1+r/100}\right)^{N}\right)}{r} \cdot \sum_{j=1}^{m}\left\{\sum_{k=1}^{l} p_{s_j,c_k} \cdot C_k\right\} \tag{6.5}$$

c. The total cost

The total cost per alternative i is therefore:

$$C_{tot} = C_{o_s} + \frac{100\left(1-\left(\frac{1}{1+r/100}\right)^{N}\right)}{r}\left[C_{o_m} + \sum_{j=1}^{m}\left\{\sum_{k=1}^{l} p_{s_j,c_k} \cdot C_k\right\}\right] \tag{6.6}$$

6.5 *Worked example*

A worked example of the optimization of the safety level for stairs will be presented in this section.

The alternatives in this case comprise three types of staircase, namely:

- type 1: straight staircase;
- type 2: dogleg staircase;
- type 3: staircase with winders.

These types are shown in Fig. 5.1. The calculations are based on households without small children (i.e., under 14 years of age).

6.5.1 The cost of the alternative

The cost of the alternative is composed as follows:

$$C_o = C_{o_s} + C_{o_r} + C_{o_{m \cdot x}} \tag{6.7}$$

where:

C_{o_s} = the cost of the staircase, inclusive of installation

C_{o_r} = the cost of the space taken up by the staircase: $C_{o_r} = V_r \cdot f_r$, where:

V_r = the space that the staircase takes up

f_r = the average cost of the dwelling per unit volume

$C_{o_{m \cdot x}}$ = the maintenance cost of the staircase over x years

The following values have been adopted (expressed in guilders): see Table 6.1.

The planned service life of the dwelling is 50 years and the rate of interest is $2\frac{1}{2}$%.

6.5.2 The capitalized loss expectation

The probability of, and the loss due to, an accident has been determined from a survey conducted by the University of Technology; see Tables 5.2 and 5.3. It has been investigated what the probability is of a stair accident and what the probability is of a serious stair accident requiring medical treatment. These probabilities are indicated in Table 6.2.

With regard to the seriousness of the accidents requiring medical treatment the classification given in Table 6.3 has been adopted.

For an accident not requiring medical treatment a loss of Dfl. 25 has been taken into account.

The capitalized loss per serious accident will then be per occupant:

$$R = (0.485 \times \text{Dfl. } 700 + 0.425 \times \text{Dfl. } 1{,}250 + 0.09 \times \text{Dfl. } 12{,}500) \cdot \frac{1 - \left(\frac{1}{1.025}\right)^{50}}{0.025}$$

$$= \text{Dfl. } 1{,}995.75 \times 28.4 = \text{Dfl. } 56{,}680$$

The capitalized loss for accidents not requiring medical treatment will be per occupant:

$$R = \text{Dfl. } 25 \times 28.4 = \text{Dfl. } 710$$

6.5.3 The optimal safety level

The loss expectation depends on the number of occupants per dwelling. Therefore the total cost per alternative has been calculated as a function of the number of occupants; the results are given in Fig. 6.4. With regard to the optimal solutions the following can be concluded:

Table 6.1. Cost of staircases and annual maintenance [Dfl.]

type of stair	C_{o_s}	$C_{or} = V_r * f_r$	$C_{om \cdot x}$
1 straight	2160	22.4 × 450 = 10,080	100
2 dogleg	2300	38.4 × 450 = 17,280	150
3 with winders	2450	16.0 × 450 = 7,200	130

Table 6.2. Probability of a stair accident

	probability of	
type of stair	accident	serious accident
1 straight	0.05	0.006
2 dogleg	0.05	0.003
3 with winders	0.15	0.014

These are probabilities per occupant per year.

Table 6.3. Treatment of accidents, and cost involved [Dfl.]

treatment by/in	proportion	total cost per accident
general practitioner	48.5%	700.-
out-patient department	42.5%	1,250.-
hospital	9.0%	12,500.-
	100.0%	

1. Because of its high investment cost the dogleg staircase is the least attractive solution, although this stair type has the lowest loss expectation.
2. For a household of up to three persons the staircase with winders is the optimal solution. If the household comprises more than three persons, the optimal solution is provided by the straight staircase.

6.5.4 Some comments and recommendations

1. The values adopted here for the cost of consequences have been derived from provisional results of an investigation carried out by the Consumer Safety Institute. They must therefore be regarded as only indicative. All the same, the results presented in Fig. 6.4 confirm the present trend so far as the choice of stair type is concerned. Staircases with winders are installed in most new single-family dwellings now built.

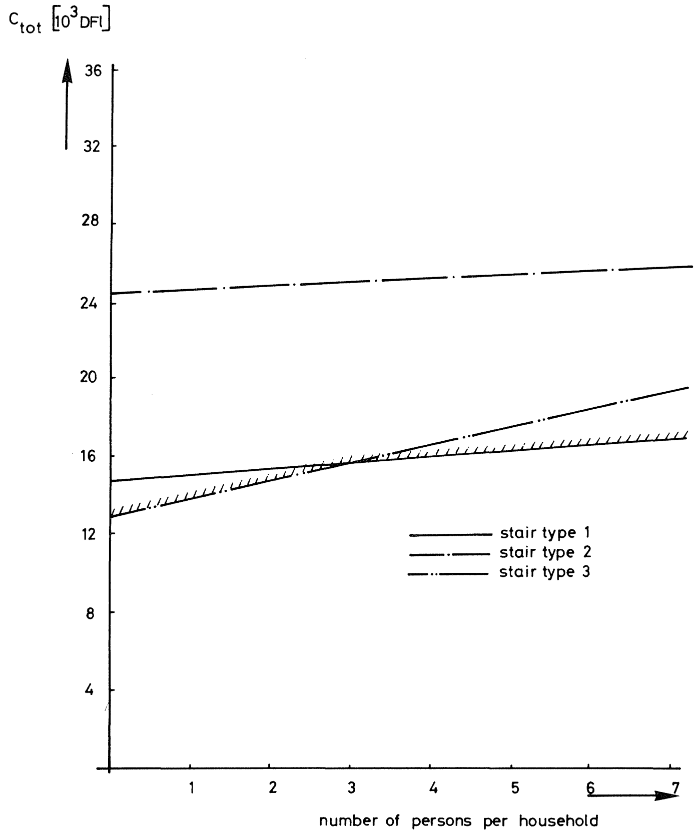


Fig. 6.4 The total cost C_{tot} as a function of the number of persons in a household and the stair type.

2. The cost of a particular solution is dominated by the cost of the space taken up by the staircase. The assumption made here may be too unfavourable for the method of calculation. Nevertheless it is advisable to carry out further investigation of this aspect with a view to suitably accommodating straight staircases in dwellings.

7 Summary and conclusions and further research

As is generally known, many accidents occur in and around the home. With stairs as an example we first showed that many parties might be expected to be interested in the safety of dwellings. Yet it seems that relatively little action is taken in this field.
Reasons for this may be a "fuzzy" division of responsibilities which characterises the process of building and maintenance of dwellings, the relatively low costs involved in the consequences of home accidents and the high budget already earmarked for housing projects. Furthermore, at the level of individual accidents in the home, the perception of such accidents as experience by those not directly involved is low, so that the figures reported in the newspapers appear abstract and not very impressive.
The problem, however, may become urgent as the composition of the population changes, causing more vulnerable groups of people to live in "normal" dwellings. Also, product liability legislation may show some positive influence.
Statistics as an aid to prevention is generally of little use, since the bare figures only indicate which groups are at risk and which products are involved. A link between accident analysis and solutions of prevention is still difficult to make.
We have shown, again for stairs as an example, that the accident process models actually lack sufficient data for an integral approach to stair safety. They can lead to detailed solutions of which the effect in terms of reduction of accidents is very difficult to estimate. We presented an accident scenario approach with which in principle the safety level of a dwelling (in this case only for stairs) can be determined.
Some interesting conclusions for stair safety from this accident scenario approach are:

1. The type of household is a strong influential factor. If children are present, the risk of any type of stair increases for adults.
2. If no children are present the type of stair determines the accident rate. Steep stairs as well as winders appear to have a negative influence.
3. Winders also tend to lead to relatively more severe accidents.
4. Households with elderly people tend to have the lowest accident frequencies. Knowledge concerning the frequencies of stair use could throw more light on the accident probabilities.
5. The accident scenario approach appears to offer the possibility of defining high-risk and low-risk accident scenarios which are relevant to discussing preventive measures.
6. Multivariate analysis techniques seem to be a necessary tool in determining the relevant risk factors of the accident scenarios.
7. The investigation has shown that the optimization model that has been developed is applicable to actual situations. The model can be used also for other accident

scenarios, though the cost items of "the alternative" will have to be adapted to the situations concerned.

8. The staircase with winders is, for the cost values adopted, found to result in the lowest total cost for households with up to three persons. This result thus partly confirms why this stair type is very frequently applied at present, though the reason can now be supported with more economically based arguments. For households with more than three persons the straight staircase is more economical.
9. A very dominant item in the total cost is the amount of space taken up by the staircase. Because of this, for example, the total cost associated with the safest stair type, the dogleg staircase, is considerably higher than that associated with the stair with winders.
10. The loss expectation for an average household with four persons is at most $\frac{1}{4}$ of the total cost. This means that, given the various assumptions that have been made, further research must primarily concentrate on the question whether the way in which the cost of the space taken up by the staircase is now determined is indeed right. For that purpose some designs could be prepared with, for example, straight staircases. Secondly, the possibility of a better estimate of the items determining the loss expectation could be investigated.

A general conclusion is that optimization of safety levels is possible, but further research in this field is necessary to obtain applicable models. As far as the Netherlands are concerned it should be mentioned that a number of investigations will be carried out in the near future. Among these: structural and fire safety, accidents of older people, window cleaning accidents and slipperiness of floor surfaces. They will be carried out in due time.

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