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Defects and Defect Costs in Construction

- A study of seven building projects in Sweden

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Abstract

In this paper, results from a study of defects occurring on construction sites are presented. Seven building projects were monitored during the production phase. 2,879 defects were collected, analysed and fully described. Their cost corresponds to 4.4% of the production cost. The time to correct them corresponds to 7% of the total working time. The defects are further analysed according to origin, type and position, as well as according to element of building and activity. Most defects could be ascribed to design and to production management. Common defect types were lack of coordinating design work, mistakes in production planning, erroneous workmanship and late deliveries. The defect cost was high in roofs and in concrete drilling. The possibility to reduce the cost of defects is discussed.

Keywords: Defects, defect costs, human error, building projects

1 Introduction

The environment of construction is constantly changing and the authorities actions continuously give new conditions. At the same time, competition between companies becomes stronger. There is an obvious need of continuous improvement within construction.

Besides external demands, the principal driving force behind improvement is knowledge of improvement possibilities. A study of defects and their consequences gives motives for implementing improvement work. Studies show that the cost of defects in construction is in the range of 5-10% of the production cost. Knowledge of the causes of these defects is necessary for choosing adequate measures.

Thus, a number of studies of defects in construction have been performed, national as well as international. However, the environment of construction is changing rapidly, as well as differing between different cultures. Therefore, it is important to repeat such studies. Most studies are broad and unsophisticated surveys, i.e. not scientifically based. There is a great need of more extensive and deepened studies.

The following study concerns defects found on the construction site during production. It was performed in cooperation between the Department of Building Economics and Construction Management at Chalmers University of Technology

and “R&D West”; a regional working group of construction companies in Sweden. The study is a continuation and deepening of a study carried out in 1986-90 by the same R&D group (see Augustsson *et al.*, 1989, Hammarlund *et al.*, 1990, Josephson, 1990, and Josephson, 1994). The main aim is to find possibilities to improve the construction process. The practical aim is to elucidate the size of defect costs and the causes of the defects. The theoretical aim is to increase the knowledge of why defects actually occur.

In this paper a presentation is made of the study: in what proportions defects occur in a construction project, what the defects actually cost, what origin they have, what type of defects occur, in which elements of the building they occur, and in which type of activities they occur.

2 Defect

It is difficult to define a defect exactly. However, in real situations it is often simple to judge what is a defect and what is not. We distinguish between erroneous action and manifest defect, i.e. the result of an erroneous action. A manifest defect is a non-desired condition in the product or process. We start from the SS 02 01 04 (1987) standard, which defines defect as “the non-fulfilment of intended usage requirements”.

Some usage requirements are given by law and regulations, building standards, etc., and in contract documents, site meeting records and other project documentation. However, all requirements cannot be specified. Every individual also has non-expressed basic needs. There are also many details, which are difficult to specify. These demands are referred to as “usage” requirements. Sometimes the specified requirements are wrong. In such cases we rely on responses from project participants. Non-fulfilment of these requirements gives rise to defects.

The changes, which are made because of new or changed client needs during production, are not regarded as defects.

3 Defect cost

The defect cost is defined as the value of resource consumption for rework as a consequence of a defect. Work time, materials and equipment time are consumed to correct the defect. Time is lost in waiting as a consequence of a defect. The cost is calculated irrespective of who pays.

A distinction can be made between direct and indirect defect costs. Direct defect costs can be internal or external. Internal costs concern defects discovered before delivery, while external costs concern defects discovered after delivery.

Indirect defect costs can be divided in customer-incurred cost, customer-dissatisfaction cost and loss-of-reputation cost (Harrington, 1987).

- *Customer-incurred cost* occurs when an output fails to meet the customer’s expectations. This is cost for the customer caused by the supplier’s mistake.

- *Customer-dissatisfaction cost* arises when a customer is lost as a result of a job, which he/she is not satisfied with.
- *Loss-of-reputation cost* occurs when customers are lost as a result of bad reputation.

It is relatively easy to measure the corrective costs of internal and external defects. Other defect costs are often difficult to measure. For example, it is very difficult to judge whether a delay of a construction project is caused by a specific defect or not. Indirect defect costs – except customer-incurred cost – can hardly be measured with tools available today.

Defect studies

Most studies focus on direct defect costs and are limited to costs for correcting defects. The cost of defects occurring during production is stated to be 2-6% of the cost of production (Jackson, 1987, Ball, 1987, Hammarlund *et al.*, 1990). The cost of defects occurring during the maintenance phase is stated to be 3-5% of the production cost (Tolstoy, 1984, SBR, 1988, STATT, 1989, Pintér, 1989). Studies on costs of defects occurring during the early phases of a project are unusual.

The origin of defects occurring during production is principally in production, but also in design (Herbert *et al.*, 1969, Kullstedt and Wirdenius, 1976, Bonshor and Harrison, 1982, Hammarlund *et al.*, 1990). The origin of defects occurring during maintenance is principally in design, but also in production (Reygaerts *et al.*, 1976, Matousek, 1977, Tolstoy, 1984, SBR, 1988, Pintér, 1989).

If direct as well as indirect costs of defects are taken into consideration, the defect cost probably corresponds to at least 10% of the turnover for most contractors and stays in the same range for most projects.

The results vary with regard to how the defect cost is distributed, according to type of defect, to elements of the building or to activities. The main reason is probably that different systems for classification are used.

4 Method

Seven building projects, performed by seven different companies, were studied. The projects were monitored continuously; six during a six-month period and one during four months (project E). In all projects the contractor used his own personnel as well as sub-contractors to perform the work. Some characteristics of the projects are presented in Table 1.

The aim was to register all defects occurring in the seven projects during the observation period. Therefore, one observer was placed at each site, five men and two women. They had no other task than to register, follow-up and describe defects observed.

By making rounds on site, the observers had daily contact with all personnel, both the building contractor's personnel and the sub-contractor's. When necessary, they contacted the client, designers, material manufacturers, etc. They took part in meetings and read all the documentation concerning the project.

Table 1: The projects studied.

Project no	Client	Type of project	New construction or refurbishment	Type of contract	Production cost (MSEK)	Time (months)
A	Municipality	Museum	New/Refurb.	General contr.	30	12
B	Municipality	School	New	General contr.	130	13
C	Own project	University	New	Traditional Design-Build	100	16
D	Real estate c.	Housing	New	Trad. D-B	21	14
E	Municipality	Industry	Refurbishment	General contr.	15	4
F	Municipality	Fire station	New	Trad. D-B	55	15
G	Insurance c.	Shopping centre	Refurbishment	General c.	30	13

Each observer was trained in the method by the researchers and introduced at the site by company representatives. During the study the observer and the researchers had continuous contact. At special meetings, the observers compared notes and exchanged experiences.

The observers were engineers with a B.Sc or a M.Sc. degree. They had between 0 and 30 years of construction experience. An earlier study showed that young people with only slight experience of construction were the most successful in this type of data collection. People with more experience tended to perceive some extraordinary situations as normal and therefore failed to describe them as defects (Josephson, 1990).

Each defect was described using a special form. Approximately 20 questions were coded. They were supplemented with detailed descriptions of causes, erroneous action, manifest defect, consequences and corrective measures. The defect cost was estimated. Sketches, drawings and photographs were appended. Simultaneously, project documents were collected by the observers and key persons interviewed by the researchers.

5 Results

Four per cent of production cost

A total of 2,879 defects were registered. Some of them consisted of several similar defects. The correction cost amounted to SEK 7,250,000, which corresponds to 4.4% of the cost of production for the observation period. Compared to the profit margin in the Swedish construction industry – averaging approximately 2% - the defect cost is very high.

In total 22,000 hours of work were used to correct the defects, corresponding to 7.1% of the total hours of work during the period. Assuming that every person works eight hours per day, 34 minutes per day are used to correct defects. In the

figure for work hours, the contractors' workers as well as the sub-contractors' workers are included. The defect cost corresponds to SEK 23 per work hour.

Design and management errors dominate

The defects were classified due to origin. Approximately 25% of the defect cost originated in lack of design and insufficient production management. Production management includes the contractors' project management and site management. Another 20% of the defect cost originated in either workmanship or material delivery. Smaller shares of the cost originated with the client or machines, Figure 1. The sub-contractors' work is included in production management and workmanship.

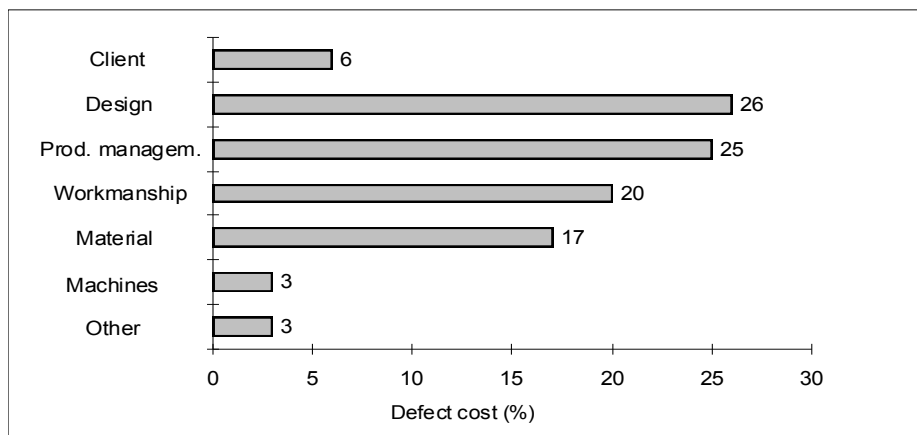


Figure 1: Defect costs (%) by origin.

Client

Client, in Figure 1, comprises all activities performed by the client's organisation, including project and construction management, and by the user organisation. There were different types of clients in the projects: municipalities and private clients, one-time clients and professional clients.

A total of 126 defects originating in clients were registered. The correction cost amounted to approximately SEK 430,000, corresponding to 6% of the total defect cost. Changes and extra orders occurred to a great extent. A few of them can be seen as defects. Other defect types found were: nonsuitable choice of material or method, wrong information or not updated drawings (when refurbishing), Table 2.

Examples of client defects:

- The room's layout is changed after the walls have been plastered and painted. The user organisation got a new manager, with own ideas.
- A smoking-room is removed. The user put forward new wishes.

Design

Design includes all work made by architects, structural engineers, services engineers etc. as well as co-ordination of design work.

A total of 645 design defects, with consequences for the site, were registered. They cost approximately SEK 1,830,000 to correct, which corresponds to 26% of

the total defect cost. The largest part of the design defect cost, 42%, could be ascribed to the architect. 20% of the cost originated in the structural engineer's

Table 2: Types of defects.

Origin	Type of defect	Defect share by origin	
Client	Changes	34%	
	Extra orders	20	
	Bad choice of material or method	15	
	Wrong information	15	
	Other	16	Sum 100%
Design	Lack of co-ordination	28%	
	Unsuitable design	18	
	Faulty design	13	
	Incomplete drawings	10	
	Other	33	Sum 100%
Production management			
	Mistakes in planning	24%	
	Faulty work preparation	18	
	Faults in materials administration	16	
	Wrong setting out	16	
	Other	26	Sum 100%
Workmanship	Erroneous workmanship	65%	
	Faulty materials handling	16	
	Faulty machine handling	7	
	Insufficient cleaning	5	
	Other	7	Sum 100%
Material	Late deliveries	37%	
	Faulty manufacturing	30	
	Material hard to work with	8	
	Deliveries with wrong type	7	
	Other	18	Sum 100%
Machines	Machine breakdown	49%	
	Machines not working satisfactorily		23
	Manufacturing defects of the machines	16	
	Machines delivered with defects	7	
	Other	5	Sum 100%

work. 7-8% of the cost originated in each of design of ventilation, plumbing, and electrical services.

The most common type of defect was lack of coordination, which resulted in conflicting drawings, 28% of the design defect cost. Unsuitable design and faulty design caused 18% and 13% of the design defect cost, respectively. By faulty design is meant that designed solutions are impossible to accomplish on site. By unsuitable design is meant solutions, which are possible to accomplish, but which are considered to be obviously unsuitable. Other common types of defects were incomplete drawings, incorrect measures and indistinct drawings.

Examples of design defects:

- Pipes collide with sliding gates. Plumbers' and architects' drawings not co-ordinated.

- Not enough space allowed for wardrobe to fit in. The real measure does not correspond with the theoretical measure.

Production management

A total of 805 defects originating in production management were registered. Production management comprises the main contractors', as well as the sub-contractors', management, both on site and at main office. The defect cost amounts to SEK 1,750,000. This corresponds to 25% of the total defect cost, of which 14% for the contractors' and 11% for the sub-contractors' management. The most common type of defect was planning mistakes, 24% of the production management defect cost. Other common types of defects were faulty work preparation, faults in materials administration, wrong setting out and obviously unsuitable choice of method. The distinction between planning and work preparation is not exact, although by planning is meant project planning, including scheduling, while work preparation is the preparation for a specific operation.

Examples of production management defects:

- Work with ventilation, electrical services, plumbing and glass, as well as the furnishing and plastering of internal walls is going on simultaneously in a room, which has to be finished on the same day.
- Window opening too wide. The foreman misunderstood the drawings when setting out.

Workmanship

A total of 730 registered defects originated in workmanship. Workmanship includes the contractors' work as well as the sub-contractors'. The correction cost was 1,390,000 SEK. This corresponds to 20% of the total defect cost, of which 13% for the contractors and 7% for the sub-contractor.

It was difficult to classify workmanship defects. Defects dealing with handling of material or machines, cleaning, safety and communication with site management could be distinguished. Other defects were gathered under "erroneous workmanship". These other defects dominated, causing approximately 2/3 of the workmanship defect cost. Defects in materials handling and machine handling caused 16% and 7% of the workmanship defect cost, respectively. The remainder could be ascribed to lack in cleaning and lack in communication with site management.

Examples of workmanship defects:

- A prefabricated wall is fixed at a faulty angle to the floor. The wall is reassembled and latches are adjusted.
- A carpenter overturns a temporarily stored window when erecting partitions. Two window panes broken and a window-frame cracked.

Material deliveries

In total, 314 defects were registered, concerning manufacturing and deliveries of material. The defects cost SEK 1,230,000 to correct, which corresponds to 18% of the total defect cost.

One single defect dominated; a delayed delivery of a lift caused huge problems in one of the projects. The supplier had to pay for the delay. Consequently, the largest part of the material defect cost pertained to lifts, 34% of the defect cost in material deliveries. Thereafter followed prefabricated concrete elements, 13%, bricks, 8%, and interior fittings, 7%. Doors of wood, concrete and gates had lower shares of the defect cost.

Two types of defects dominated among the material defects: late deliveries and faulty manufacturing, 37% and 30% of the material defect cost, respectively. The late delivery of the lift explains why such a large amount of the cost is caused by late deliveries. If this defect is excluded, faulty manufacturing will totally dominate. Other types of defects were material hard to work with, deliveries with the wrong type of material, deliveries with incomplete material, deliveries with wrong quantity, and transport damages.

Examples of defects in material deliveries:

- A necessary colour pigment missing when manufacturing carpets. The schedule has to be modified – a delay of two weeks.
- Bricks delivered with a high moisture content. Bricklaying is complicated by floating mortar as a result of the non-absorbing bricks.

Machines and equipment not built in

A total of 110 defects originating in manufacturing, letting or deliveries of machines and other equipment not built in were registered. They cost SEK 190,000 to correct, which corresponds to 3% of the total defect cost.

The largest part of the machine defect cost, 52%, occurred in hoists, of which tower cranes alone caused 22% of the machine defect cost. Defects in power, heating and ventilation equipment caused 13% of the machine defect cost, of which the major part concerned the supply of electricity.

The largest part of the defect cost occurred due to the breakdown of machines, 49% of the machine defect cost. Then followed machines not working satisfactorily and defects from the manufacturing of the machines, 23% and 16% of the machine defect cost, respectively.

Examples of machine defects:

- Concrete removal equipment breaks down. It is handed in for service. Another machine is delivered.
- Crane does not switch off automatically when overloaded. No warning signal can be heard.

Other

A total of 54 defects with other origins were registered. They cost SEK 210,000, which corresponds to 3% of the total defect cost. The major part concerns theft and damage caused by non-employees. These problems occurred in all projects.

Defect cost per element of building

The defect cost for a specific element of the building has been related to the production cost for the element during the observation period. The following results are from five projects. For two projects, the data were unreliable.

The defect cost was largest for roofs, 9% of the production cost. Also for the loadbearing structure and internal space enclosure, the defect costs were larger than average for the whole building. External walls, building services, internal coverings, cladding and lining and fittings, earthworks and demolition or making of holes had lower defect costs, see Figure 2.

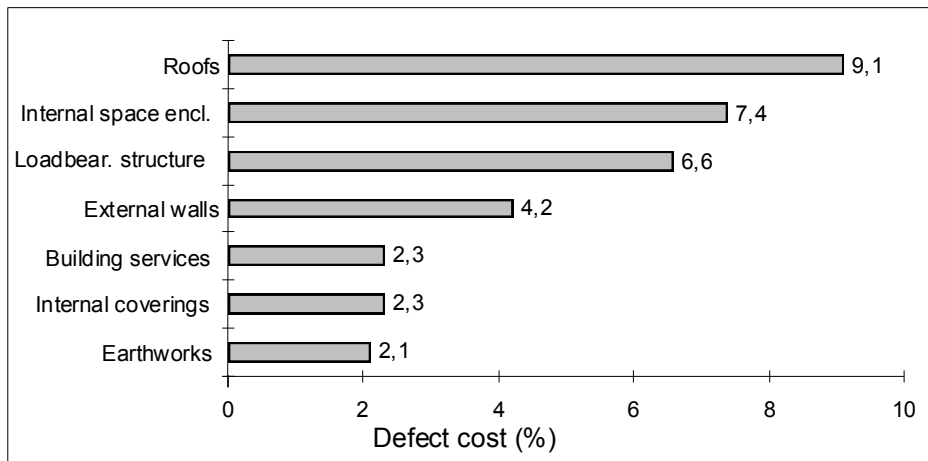


Figure 2: Defect costs per element of building (% of the element's production cost).

During the studies, most work on building services was performed by sub-contractors. Throughout the study, the observers' contact with sub-contractors was less frequent than with the main contractor. Probably, the defect cost for building services is underestimated.

Origin per element of building

For each element of building an analysis was made of the origin of defects.

For each element of building, one or two categories dominated. For roofs, which had the highest defect cost, design defects dominated. For earthwork, management defects dominated. For loadbearing structure, management and workmanship defects were the largest. For external walls, management defects dominated.

Design and workmanship defects were largest in internal space enclosure. For internal coverings, cladding and lining and fittings, material delivery defects were most common. For building services, design and material defects were the largest, see Table 3.

Defect cost per activity

The work activities have been analysed for defect frequency. Some of the activities have been performed by main contractors and others mainly by sub-contractors.

Table 3: Origin per element of building (% of defect cost for the element).

Element of building	Client	Design	Production management	Workmanship	Materials	Machines	Other	Sum
Earthworks	1	5	49	20	2	1	22	100 %
Loadbearing structure	8	18	30	26	13	4	1	100 %
Roofs	0	69	18	8	3	1	1	100 %
External walls	2	16	36	17	23	4	2	100 %
Internal space enclosure	8	31	13	28	13	0	7	100 %
Interior coverings, cladding and lining, fittings	6	18	23	20	30	1	2	100 %
Building services	3	30	16	18	30	0	3	100 %

Activities performed by main contractor

For the main contractors' activities, the respective production costs reported were unreliable. Of that reason, these activities are analysed with respect to defect time. Defect time includes working time used to correct defects as well as time losses due to a defect, for example, waiting. The defect time for an activity is compared to the workers' working time during the period for the same activity. The results of the analysis are presented in Figure 3. The results are based on four projects. In three projects the data were not reliable.

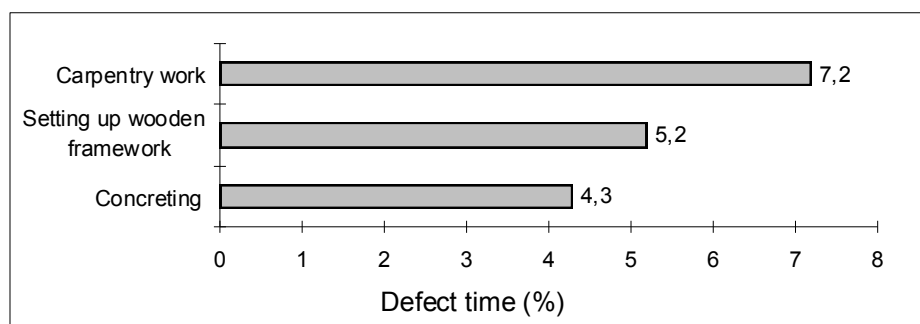


Figure 3: Defect time per activity performed by the main contractor.

Activities performed by sub-contractors

Activities performed by sub-contractors are analysed in respect of defect cost. Cost of defects in a specific activity is related to the pay the sub-contractor gets for the activity during the period. The following results are based on six projects. For one project the data was not reliable.

In total, sub-contracts for 24 activities were procured, for which the payment exceeded SEK 200,000 (1995 prices). The highest defect cost arose in drilling in concrete, 17%. For installation of elevators the defect cost was 12%. For all major work on building services, such as plumbing, ventilation and electricity, relatively low defect costs were registered, see Figure 4.

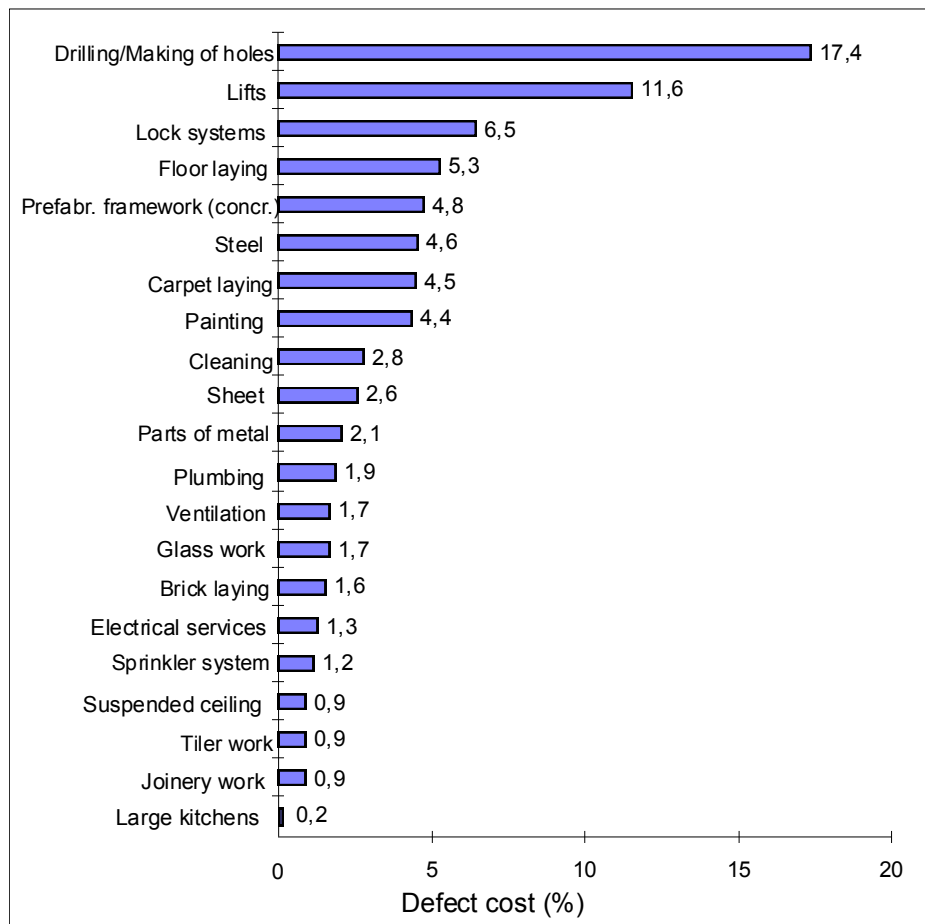


Figure 4: Defect costs per activity performed based on sub-contract.

6 Possibilities of improvement

All defects and their costs cannot be eliminated due to the construction projects being too complicated, the organisations too large etc. However, an analysis of the defects gives a clear understanding that several of them are avoidable. The research project group, which consisted of representatives from the companies and researchers, estimated that approximately half the defect cost can be eliminated by simple means.

Many investments made to reduce defect cost give additional positive effects, such as more effective communication, more efficient production, fewer problems during the usage of the building etc. For example, changes in methods of planning may reduce mistakes in planning, but may also give more efficient planning resulting in more efficient production.

The 80-20-rule

The number of defects and their associated costs follow the 80-20-rule. In figure 5 all defects have been sorted according to size. The defect costs have then been accumulated beginning with the largest defect. The analysis shows that 1% of the defects caused 25% of the total defect cost, 5% caused 52% of the cost, and 20% caused 79% of the defect cost.

The defects and their costs follow the Pareto principle well (Juran, 1988). Irrespective of which aspect the defects are sorted by, there is an 80-20-connection, i. e. 20% of the number of defects caused 80% of the total defect cost. This means that eliminating a limited share of the defects can lead to considerable improvements.

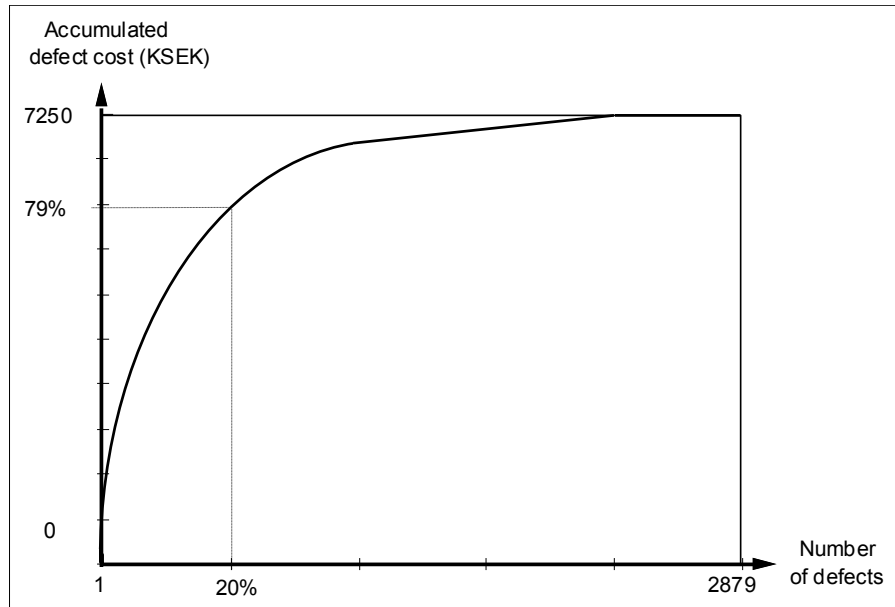


Figure 5: The 80-20-rule.

The possibility to detect defects

An analysis of the possibilities of early detection of defects was made. For each defect, the people involved judged whether it had been possible to discover the defect earlier or not. It was found that 37 % of the defects could relatively easily have been discovered earlier and another 35 % of the defects could perhaps have been discovered earlier. Only 28 % of the defects were judged to be impossible to detect earlier.

90 % of the design defects were judged to be possible to discover earlier. Of the defects caused by production management or sub-contractors, 80 % were judged to be possible to discover earlier. Approximately 60 % of the design defects, the workmanship defects and the material defects were judged to be possible to discover earlier. Of the machine defects, 50 % were judged to be possible to discover earlier, table 4.

7 Discussion on validity and conclusions

The aim of the study was to map defects discovered on the building site during production in order to stimulate improvements. The defect cost for seven building projects of different types was 4½% of the production cost. This is twice as much as the average profit margin.

Table 4: The possibility to discover defects earlier (% of number of defects).

Origin of defect	Could the defect have been detected earlier?			Sum
	Yes, relatively easy	Maybe	No, not at all	
Client	34	24	42	100%
Design	44	47	8	100%
Production management	40	38	21	100%
Workmanship	30	29	40	100%
Sub-contractor	46	33	22	100%
Material delivery	30	32	38	100%
Machine	5	44	51	100%
All defects	37	35	28	100%

The defect cost registered is underestimated. First, the definition used is narrow. Second, the projects studied were relatively large with many simultaneously ongoing activities. An observer is not able to register, follow-up, analyse and describe more than four defects per day. The larger defects are caught, but not the smaller ones. The observers themselves judged that they could capture approximately 60-90% of the real number of defects. Third, relatively many defects were left without being fully corrected. Most defects, 79% of all defects, were fully corrected, i. e. the end solution corresponded with the original solution intended. 17% of the defects were corrected, but not fully, as non-conformances with the original intentions still remained. 4% of the defects were left without any corrections, most often after the clients' agreement. For defects not corrected, no costs are recorded. There is an obvious risk that consequences will arise later.

The studies were made on seven building projects, chosen by the companies themselves. Six projects were described as "normal" or better than "normal" in respect to the fulfilment of the work. One of the projects had more problems than a "normal" project. Consequently, there is a real reason to believe that the results presented are better than for a "normal" project. With this in mind, the involved people in each company considered the results to be valid.

The study showed that there are good possibilities to reduce the defect costs. However, to choose the right measures, knowledge of where defects occur as well as why is needed. In this paper the origin of defects, the type of defects as well as in which elements of building and which activities defects are most common were presented. In a following paper "Causes of Defects in Construction", direct causes as well as underlying causes will be discussed.

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