MAKING LARGE INFRASTRUCTURE PROJECTS SAFE: THE CASE OF THE COPENHAGEN METRO

Ester Jensen[1] and Christian Koch[2]

[1]*COWI Consulting Engineers, DK-2800 Lyngby, Denmark*
[2]*Department of Civil Engineering, Technical University of Denmark, DK-2800, Denmark*

The Danish government has recently and numerous times before pointed at occupational accidents in construction as a priority problem. Not only is the number of accidents occurring in the sector every year problematic, but so is the character of lethal and other serious accidents. The patterns in these accidents highlight once again that prevention has to be a broad orchestration of efforts. Safety measures should start in the design and planning phases, but also encompass quality demands to building components and materials, chemical substances, equipment and demands to training of staff. At the site, safety prevention is a management issue and involves the entire organization, site lay-out, logistics, equipment, training, coordination, communication and personal protective equipment. The paper describes Danish site experiences with an orchestrated safety effort in the construction of the Copenhagen Metro, which escaped fatalities and had less occupational accidents than the building industry on average. The paper analyses the experiences of the various activities and elements put in place, using a taxonomy for the reasons behind the accidents and areas where to insert prevention. A series of preventive measures were used. Those described here are *the environmental management systems, dialogue with interested parties, risk and working environment assessments,* which were established for all construction activities before commencement of work operations. Audits and inspections were held using the system of "Mønsterbyggeplads" (best practice blueprint). Employers' inspections and top management inspections as well as induction systems and education were used. Means of motivation by awareness campaign and joint safety campaign -"Safe Sites"- from the middle of the construction period is assessed. The results from the Metro project point out the need for orchestrated efforts. This is usually more realistic in large construction projects like the Metro. Such an effort has become more feasible due to increased capital concentration among contractors and consulting engineers recently.

Keywords: accidents, Copenhagen metro, safety, prevention.

INTRODUCTION

Denmark is not exactly used to building tunnels. Most roadworks are realized in other ways. Nevertheless over the last years major tunnel works have been carried out in three consecutive projects from 1990 to 2002. The present paper discusses the Copenhagen Metro, which is the third of projects. The preventive safety effort on the Metro project has been inspired by fresh experiences gained through construction of the Great Belt fixed link 1989-1997 (Storebælt) and the Øresund fixed link 1993-2000 (A/S Øresundsforbindelsen). These large infrastructure projects both encompassed the building of bridges and tunnels.

[1] etj@cowi.dk
[2] ck@byg.dtu.dk

Jensen, E and Koch, C (2003) Making large infrastructure projects safe: the case of The Copenhagen Metro. *In:* Greenwood, D J (Ed.), *19th Annual ARCOM Conference*, 3-5 September 2003, University of Brighton. Association of Researchers in Construction Management, Vol. 2, 573-82.

In this sense the safety work contradicts traditional safety efforts. The single project presents a sort of problem, in that each new building is an isolated event, to and from which no experience, nor learning flows in or out. In this case, we have a change to see other effects since a number of professionals and institutions have been operating on all three projects. Moreover, these projects were carried out in a context of increased public and regulatory interest in occupational accidents. The paper is structured as follows. After some methodological remarks, we present a theoretical frame based on safety research and empirically grounded studies of safety prevention in industry. Then we continue to identify a frame for working with safety in construction. The case of the Copenhagen Metro and the orchestrated efforts are then described and analysed. The paper describes on this basis the various efforts carried out in the Metro project. We describe environmental policies system and dialogue with involved parties, design and purchasing, risk and working environmental assessments, audits and inspections, induction and education and safety campaigns. Finally, the results are evaluated and juxtaposed with the development in construction in general.

METHOD

The approach in the paper is multidisciplinary. A theoretical frame is presented, drawing on safety research and empirically grounded studies of safety prevention in industry (Jørgensen 2002, Kamp & Koch 1998). The frame for working with safety in construction has been developed from ongoing research on this issue (Koch 2002). The present paper draws heavily on Jensen & Koch (2003). The case, the Copenhagen Metro, is covered by one of the author's (Jensen) presence as safety engineer on the project for six years. The paper is based on these experiences gained in the employer’s organization mainly during the construction phase consisting of and including the following:

- Environmental policies system and dialogue with interested parties. (Ørestadsselskabet 1998).
- Design and purchasing (Jensen’s experience based on the further work with the design documents).
- Occupational injuries and communication about the injuries (Ørestadsselskabet 2002).
- The joint safety campaign “Safe sites” initiated after a non-satisfactory accident record (COWI Nov. 2002).
- Frequent inspections. 350 documented inspections and approx. the same number non-documented in the employer’s organization).
- Usage of the best practice system regarding inspections in the contractors’ organization (Danske Entreprenører-SID 1998).
- Safety inductions, instruction for work close to tracks, train control systems, etc.

The authors recognize that the issue one author's presence and employment at the Metro is a topic for methodological discussion. We see it is as having both strengths and draw backs, since the presence at the Metro in a substantial timeframe, also strongly enables the insight and understanding of the case.

RESEARCH ON SAFETY MANAGEMENT

For construction sector researchers the stationary bias of the research tradition of safety and safety management is evident. Recent reviews of safety research and practice, even point out that the area is characterized as having a bias towards large bureaucratic organizations with a tendency of keeping alive research and practice traditions alongside each other (Hale & Hovden 1998, Kamp & Koch 1998). Thus machine safety, behavioral cultural approaches and others co-exist as research paradigms and theory-in-use in industry practice. On the basis of empirical research, Kamp & Koch (1998) argue that leading companies' safety practices have developed into an orchestration of various methods. This can be seen as a parallel to research multiplicity and understood as a need for a heterogeneous approach. Kamp & Koch underlines that orchestration of efforts should not be understood as an available toolbox, but more as a long term learning process. The safety coalition in the companies studied is a group of actors promoting safety. This coalition attempts to tackle various interests and concerns over time. Putting a work environment management system in place is within this perspective, but the effort needs to be developed through shop floor engagement, further modification etc. It is likely that one effort partially solves some elements of prevention and accidents, but leaves other risks and problems untouched. Further development of efforts is therefore necessary. However, as already mentioned, all these characteristics, whether they discuss bureaucracy or a long term learning process, carry an implicit stationary bias. It is assumed that the framework is a permanent geographically located entity - the plant or the factory. As we shall see below, the primary framework here is a project, temporary in time and temporary in terms of participants. Safety research also provides us with well-developed sets of methods and theories concerning where the efforts should be made. Jørgensen (2002) develops a taxonomy, a systematic model for risk factors and processes behind accidents on the basis of 13 models within safety research. Jørgensen (2002) proposes the following layers:

- Damages and losses
- Unanticipated events
- Immediate reasons behind
- Deeper reasons behind
- Reasons relating to the management
- External reasons.

According to Jørgensen, a general taxonomy should be appropriated to a context, which is done in this case by collapsing two levels in Jørgensen’s model and by developing criteria for the interpretation of the levels in a construction context. This appropriation is due to the specifics of the construction sector as well as limits of the material used. In contrast to the stationary industry, building projects are temporary organizations, where design and production usually are separated and where a number of companies interact both in design and production. The safety organizations in large projects could/should encompass integration between design and production. Safety measures should start in the design and planning phases, but also encompass quality demands to components like the pre-cast concrete elements, chemical substances, demands to equipment and training of staff. Turning to the site, safety prevention is an issue of management, involvement of the entire organization, site lay out, logistics, equipment, training, coordination and communication as well as personal protective equipment. The appropriation of the taxonomy used here is a slight simplification in

terms of levels and coverage of each as well as the way it is used. The basic thinking is to develop a taxonomy, which can be used to develop prevention and it takes point of departure in a specific building site including elements outside the site (in time and space). Therefore the following four levels proposed are:

- Damages and losses
- Unanticipated events
- Reasons behind
- Reasons relating to management, design and supply chain.

Note that external factors are not included and that the first three levels relate directly to the building site, whereas the fourth relates to decisive frame setting layers of management, design and supply chain. The elements looked at under "reasons behind" are reasons attached to technology, organization (including operational management) and use of products at the site, including local procurement. The fourth level/areas are reasons relating to management, design and supply chain. These relates to the companies with employees on the particular site or those delivering equipment, building material or other to the site. Note that procurement in relation to major investments in machinery, equipment and building materials is considered as part of the fourth level, since these issues relate to construction firms rather than the building site.

THE METRO IN COPENHAGEN

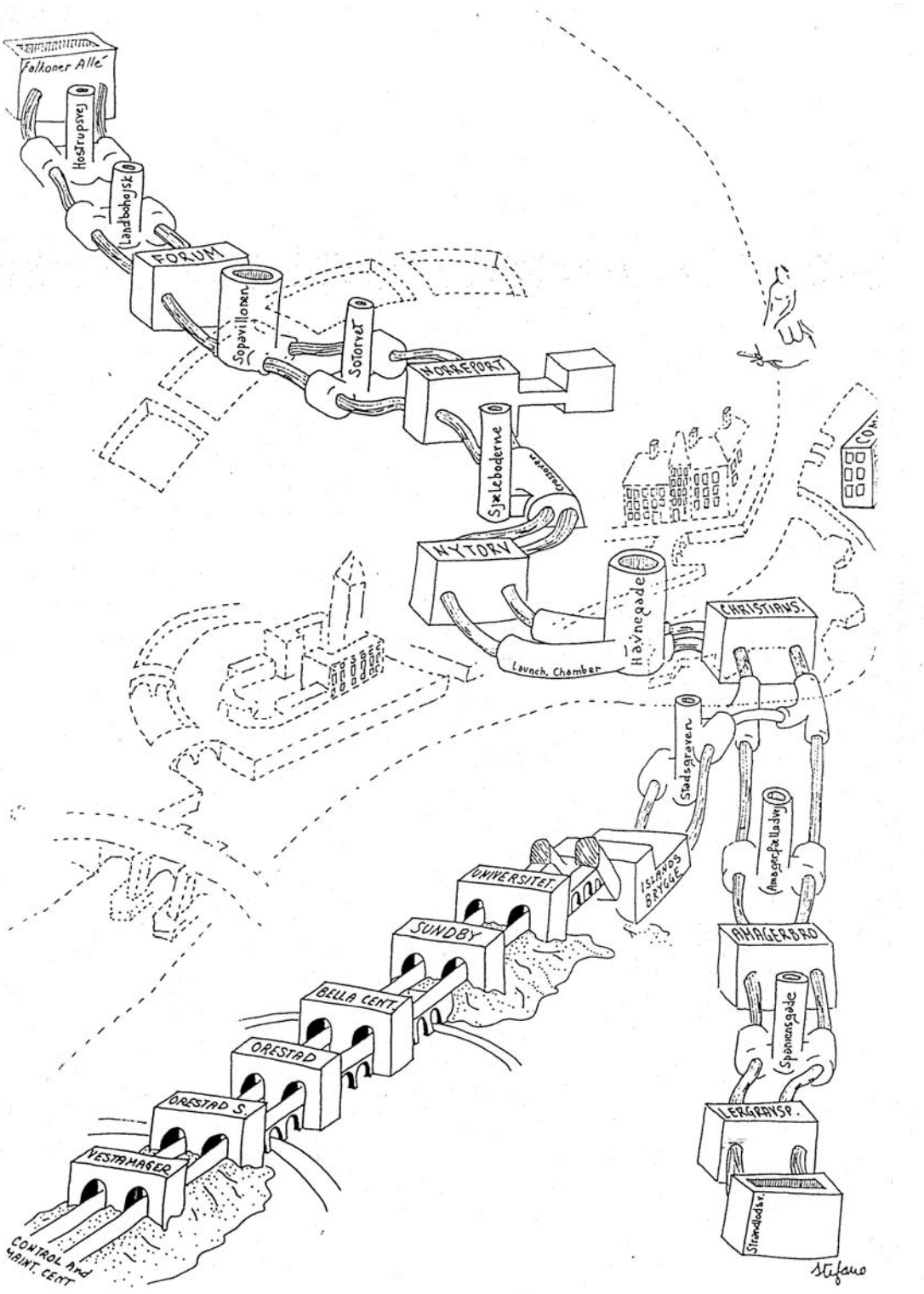
The metro in Copenhagen is designed to overcome some of the city's major traffic problems and link a new area for urban development to the centre. The first phase of the Copenhagen Metro commenced in 1993 and was inaugurated in October 2002. The client company "Ørestadsselskabet" was established as a shareholder company fully owned by two public parties; the Danish state and Copenhagen municipality. The design and contracting is carried out by a consortia encompassing Danish and international companies. The construction management is carried out by COWI A/S. The Metro has 13 stations, 9 emergency and ventilation shafts, approx. 32 km track located above ground and in tunnels. The Metro contractors had spent 11,5 million working hours from the beginning of 1997 to September 2002 and had 361 occupational accidents. An accident is defined as an injury to a person leading to absence for one day after the day of the event). The accident frequency N accidents/1,000,000 working hours was 31, which is less than the average of the industry having an accident frequency of 36-37. The next phases of the project are still ongoing.

The orchestration of preventive measures adopted on the Metro project includes:

- Environmental management system and dialogue with interested parties.
- Risk and working environment assessments established for construction activities before commencement of work operations.
- Audits and inspections. The contractors used the method of Model Work Places. (Danske Entreprenører SID 1998). Joint top management safety inspections.
- Induction and education.

Motivation, increased management efforts activated from the middle of the construction period, safety campaigns.

Copenhagen Metro Line phase 1,2A reception chambers for TBM, stations and ventilation/ emergency shafts.



Environmental management system and policies
Ørestadsselskabet set up an environmental management system (EMS), including working environment, for all phases from the design via tendering to signing of contract and construction.

The working environment policy for Ørestadsselskabet is to:

> *"Establish safe and sound work places and during the construction phase and to inform the public about the effort on the working environment"*.

The goals set out in the field of working environment were*:*

> *"Construction works will be executed without exposure of health risks. The working environment shall be of high standard and effective safety organizations are to be established to ensure that the demands from the client concerning working environment can be met. The effort on working environment is to be based on the principles of prevention." (Ørestadsselskabet, Copenhagen 1998).*

Dialogue with interested parties
The client decided to involve the interested parties in a mutual dialogue about the working environment. This was materialized by a reference group on working environment at the Metro. The group was compounded by the Danish Working Environment Service (Arbejdstilsynet), the General Workers' Union (SID), the Electricians Union, the contractors, the Working Environmental Service (Bedriftssundhedstjenesten). The construction management, represented by COWI chaired and reported the meetings in minutes. The group met every 3 months during the construction period. The 20th meeting was dedicated for to an overall evaluation of the working environmental efforts on the Metro. The experiences are expressed in the Review on working environment Metro, 1997-2002 (COWI 2002, Ørestadsselskabet 2002).

Design and purchasing
The operators' risk during the construction phases were identified in the design phase for the Metro project. The risks, and actions to meet the risks, were documented. Prior to purchasing of large equipment like the tunnel boring machine the Danish Working Environment Service and the client were consulted. Though actions of this nature generally were taken to eliminate risks already in the design phase, some examples occurred where safety precautions had not been sufficiently implemented into the design and purchasing phases (Ørestadsselskabet 2002). Requirements and employers expectations to contractors' working environment management were specified in the dialogue with the contractor shortly after signing of the contracts.

Assessment of risk and working environment
For the construction phases, the contractor was obliged to establish working environment assessments of work processes prior to commencement of each activity. As for identified safety problems, the contractor should add description of preventive measures to the assessment. The assessment would include exposure to:

- Dust
- Chemical substances
- Noise and vibrations
- Postures

- Risks of accidents

During the construction period, the Metro contractors have established approx. 600 assessments of risk and working environment prior to commencement of work.

The contractors used different methods to meet the contractual requirement for establishing working environment assessments: some modified existing systems for risk assessment that were well known to them from other projects. The system includes description of hazard, classification of risks such as likelihood, impact and risk exposure. Persons affected should be identified and normal and additional measures to meet the risk were described. Residual risk should be identified and described as well. Other contractors met the requirement of establishing working environment assessments by modifying already made Work Place Assessments (WPA) or establishing new WPAs.

Work Place Assessments
The requirement of establishing Work Place Assessments (WPA) for the construction industry was mandatory in Denmark from 1997. The process of establishing WPA-s has mainly involved the safety groups on the construction sites after commencement of the work. The effect of the WPAs has been evaluated by the contractors, and some find that the process of establishing WPAs have had a significant effect to the safety performance. An example is establishment of Travers crane under the deck to ease transportation of heavy reinforcement in the deep stations, which were a result of a WPA process (Ørestadsselskabet, 2002). The processes of establishing safety planning has created a constructive dialogue about safety and working environmental aspects of the work and has involved all management levels in the client's and contractors' organizations, whereas the process of establishing WPA have mainly involved the safety groups.

Audits and inspections
The working environmental system was audited and inspected both by the contractors' internal audits and inspections and the audits and inspections performed by the client, Ørestadsselskabet represented by the construction management. Almost all contractors used the inspection system for Model Building Estates (Danske Entreprenører, SID 1998) for their internal safety inspections on the Metro construction sites. The system was assessed by the contractors, which appreciated the effect of visualizing the safety effort. The system made it possible for everyone to see the logic. The client represented by the construction management, made frequent safety inspections on the construction sites. The inspections were generally attended by the contractors' safety group, the construction management's technical supervision for the area or process and the safety engineer and/or an environmental and quality resource person from the construction management. The construction management performed approximately 500 inspections of this character. The inspections involved site based problems identified by the inspections as well as safety items to be dealt with in the near future. The inspections were also a basis for the employers' appointment of candidates for safety prices in the joint safety campaign.

The project manager from the largest contractor COMET and the construction manager from Ørestadsselskabet performed joint safety inspections approximately every 8th week from the end of 1999 to the beginning of 2002. The management inspections lasted for one whole day and 4 to 8 sites were visited each time. Through the inspections, the top management was confronted with the safety problems on the

construction sites and at the same time sent clear signals to lower management following up on the safety issues was expected and appreciated from top management.

Induction and education
The two turn key contractors - Ansaldo and COMET - established induction programme for all persons working inside the areas where they were in charge of the safety coordination. More than 4,000 persons have attended the COMET induction. Approx. 2,000 persons have attended the Ansaldo instruction on work close to tracks and/or work in tunnels. The instructions for work close to track and in tunnels were part of a strict rail control system for assessment and coordination of activities near and on tracks. Special training for work in compressed air on the Tunnel Boring Machine, first aid, fire fighting, slinging of gear for elevation by crane, driving of locomotives etc. has been established by the contractors. All engineers from the construction management have undergone safety education of 1 week's duration (ØSS 2002). All site managers and site engineers in COMET have undergone safety education of 1 ½ day's duration in 1999.

Motivation, Safe Sites Campaign
As an effort to strengthen the accident-prevention work on the METRO, the client invited the contractors to participate in a joint campaign called "Safe Sites". All contractors agreed to the invitation and a campaign with the goal of having a lower accident rate than average for the construction industry was launched. The campaign made use of a number of tools such as: the logo, an ant (an insect which is known to be well organized and hard working below as well as above ground); flags placed on all construction sites; posters highlighting specific safety issues; introduction folders to the campaign; a news letter distributed in Danish and English languages (COWI 2002, Ørestadsselskabet 1999-2002). A "Safe Sites" competition between the work teams led by a foreman was established. The award was a T-shirt with the logo of the campaign, a diploma and a dinner. The winning team was portrayed in the newsletter. The runners up in the competition received a diploma. It was prestigious to win the award for the groups and the contractors, the safety groups, the unions and the authorities evaluated the effect of the campaign as positive (Ørestadsselskabet 2002).

DISCUSSION

The broad involvement of management and crew in the safety planning and follow up by establishing relevant safety precautions is considered to be very important for a successful execution of the risky operations during the construction. The relation between risks identified through working environment and risk assessments and occupational accident on the Metro has been analysed by Ørestadsselskabet (Ørestadsselskabet 2002) The analysis demonstrates that the project has escaped serious accidents in relation to the risky operations. This result has been achieved thanks to safety planning and follow-up on the planning by the contractors and the safety groups.

- Accidents avoided relate to typically critical works executed during construction of the Metro which escaped serious accidents:
- Collapse of soil during excavation of shafts, deep stations and tunnels
- Handling and placing of 1,000 pieces of reinforcement cages for secant piles. The cages were 10-15 m long and weighed approx. 10 tons each.
- Falls of persons from a height of 2 m and above.

- Handling of pre-fabricated elements for technical rooms and stairs in ventilation and rescue shafts.
- Collision and persons being run over by work trains during construction.
- Collision and persons being run over by trains during test and commissioning period.
- Poor air quality due to dust and alpha quartz during application NATM (New Austrian Tunnelling Method).
- Handling of big elements like escalators and ventilation units where space was restricted.
- Collapses of scaffolds and forms during construction.
- Fire and explosions.
- Work under pressure (diving with the tunnel boring machine).

The table below shows the levels in taxonomy for reasons behind accidents, efforts and results in overcoming the reasons on the Copenhagen Metro.

Taxonomy level	Effort	Results
Damages and losses	Planning, safety precautions, motivation, training	Less accidents reported Accidents avoided
Unanticipated events	Near misses discussed at contractors safety meetings	Not documented, but expected to have effect
Reasons behind	Inspections Risk analysis Safety campaign	Learning

The authors believe that tools for establishment of safety precautions already in the design phases need to be implemented throughout the Construction industry. These tools are far too less developed at present stage.

CONCLUSION

The paper initially established an understanding of the need for an orchestrated effort and developed a taxonomy to map out efforts and results. The paper then assessed the broad orchestration of policies, involvement of interested parties and safety precautions, which have been implemented into the Copenhagen metro project. A row of important precautions have been described above, whereas others like inspections and initiatives established by the Danish Working Environment Service and the trade unions and the effect of the safety meeting and safety groups efforts are not described specifically. The effect of learning processes in the contractors and employers organizations has not been described or analysed here. It was however obvious that establishment and maintenance of safety precautions and safety coordination improved during the construction period as the organizations established formal and informal learning from the jobs. The learning from the recently finalized large infrastructure projects, the Great Belt Bridge and Øresundsforbindelsen has not been systematically assessed, but the authors assert that experiences from these projects have had an impact on the establishment of a safety culture, which managed to prevent serious accidents during the construction of the Metro. When evaluating prevention of poor working environment and risk minimizing it is known that the identification of risk and working environmental problems in the design phases is lacking behind compared to the ability of identifying risks and establishing preventive

measures for the processes on location. Tools for implementation of preventive efforts already in the design phase should be developed. The results from the Metro point out the need for an orchestrated effort. On the Metro, project learning and adjustment did occur due to the long running of the process. This is usually more realistic on large construction projects like the Metro. But such an effort has become more feasible due to recent capital concentration among contractors and civil engineers.

REFERENCES

Arbejdstilsynet (Danish Working Environment Service) (1994) På vej mod et renere arbejdsmiljø 2005 (On the route towards a cleaner working environment in year 2005).

Arbejdstilsynet (1995) Bygge og anlæg. Branchebilleder. Copenhagen.

A/S Øresundsforbindelsen (1997) Godt begyndt er halvt fuldendt. Midtvejsrapport for arbejdsmiljøindsatsen og arbejdsmiljøkampagnen på Øresundsprojektet København (1997) (Midt term evaluation of working environment efforts on Øresundsforbindelsen).

Bygge-Anlæg Trækartellet BAT (2003) Et godt arbejdsmiljø er en god investering. København. (Association of Building constructing and wood workers. A good working environment is a good investment).

COWI (2002) Copenhagen Metro Inauguration Seminar Proceedings of the Copenhagen Metro, 21-22 November 2002.

Danske Entreprenører-SID (1998) Introduktionsfolder til Mønsterarbejdsplads systemet (The Association of Danish Contractors and General Workers Union 1998, Introduction leaflet to the Model Construction Sites).

Hale A. R. og Hovden J.(1998.) Management and culture: The third age of safety. A review of approaches to organizational aspects and safety, health and environment. In. Feyer and Williamson (ed.) *Occupational injury. Risk, Prevention and Intervention.* London: Taylor and Francis.

Jensen E & Koch C (2003) Safety efforts on large construction projects- the Copenhagen Metro. *Proceedings 3. Nordic Conference - Construction Economics and Organization*. Lund

Jørgensen K (2002) En taxonomi for Arbejdsulykker. Rapport nr. R-031. BYG•DTU. Lyngby. (A taxonomy of Accidents).

Kamp A. & Koch C. (1998) Arbejdsulykker i dansk industri - nye strukturer, sikkerhedskultur eller ulykkesfugle? Arbejdsmiljøfonden. København.

Koch C.(2002) Accidents in Precast Concrete Element Assembly Work at Building Sites - an exploratory Investigation of Prevention Measures. Paper prepared for WorkingonSafety.Net, Inaugural conference, Helsingør.

Ørestadsselskabet (1998) Environmental Review, Copenhagen

Ørestadsselskabet (2002) Metro, Status over Arbejdsmiljø. Arbejdsmiljø og forebyggelse af arbejdsskader 1997-2002. (Review of working environment efforts on the Metro 1997-2002).

Ørestadsselskabet (1999-2002) Newsletter - Safe Sites Issue 1-10 Copenhagen.

Ørestadsselskabet (1999) All accidents can be avoided. Introduction leaflet to the Safe Sites Campaign.