Safety efforts on large construction projects - the Copenhagen Metro.

By Ester Jensen, Consultant, Cand. Tech. Soc., COWI etj@cowi.dk and Christian Koch Associate professor, DTU ck@byg.dtu.dk

Abstract

Even though improvements have been achieved over the last years, occupational accidents at Danish construction sites continue to be a problem. An evaluation of the number of accidents occurring in the sector every year, also the Danish construction sector has been marked the last year by 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 organisation, site lay-out, logistics, equipment, training, coordination and communication as well as 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 in average. The paper analyses the experiences of the various activities and elements put in place, using taxonomy for the reasons behind the accidents and areas where to put prevention in place.

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 were also carried out. Induction systems and education. 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.

Introduction

Working with safety in construction is often said to confront what could be joined, being a tyranny of a single project, meaning that each new building is an isolated event, to and from which no experience nor learning flows in or out. In this paper, we address this myth, arguing that there might be circumstances that commence changing

the tyranny. Our context is the Copenhagen Metro project, a 7 years project so far and still ongoing. The Copenhagen Metro is the third in a row of major Danish construction works from 1990 to 2002. 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).

Moreover, these projects were been carried out in a context of increased public and regulatory interest in occupational accidents. The Danish Labour Inspection Service (Arbejdstilsynet) has set out vision including goals for preventive efforts on 7 selected tasks in 1994. The prevention of fatalities and prevention of severe accidents among young people are included in the 7 tasks. The general preventive efforts are supported in public as cost benefit analyses prove that occupational accidents are very costly to industry and to the general society. A recent analysis carried out by the Copenhagen School of Economics (Handelshøjskolen) in 2002 analysed the cost of accidents in different industries and found that even a minor accident in the construction industry could cause expenses for the contractor of 60,000 DKK. The Association of Construction Workers BAT has analysed the cost of occupational accidents and found that the companies must realize 18 times the immediate costs of an accident to regain the looses by the accident. (BAT Kartellet 2003).

This 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 the Copenhagen Metro and the orchestrated efforts are then described and analysed. The paper describes on this basis the various efforts carried out on 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, we evaluate the results and juxtapose with the development in construction in general.

Method

A theoretical frame is mobilised 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 contributions to this still continued developing issue (Koch 2002).

The case, the Copenhagen Metro is covered by one of the author's presence as safety engineer on the project for six years. The paper is based on these experiences gained in the employer's organisation mainly during the construction phase consisting of and including the following:

- Environmental policies system and dialogue with interested parties. (Ørestadsselskabet 1998).
- Design and purchasing (the other author'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 organisation).
- 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 one author's presence and employment at the Metro methodologically can be discussed. We contend that it is a condition of possibility since the presence at the Metro for such substantial time, also strongly enables the insight and understanding of the case.

Safety management and its implicit stationary bias

In recent reviews of safety research and practice (Hale & Hovden 1998, Kamp & Koch 1998), the area is characterised as having a bias towards large bureaucratic organisations with a tendency of keeping alive research and practice traditions along each other. Thus machine safety, behavioral cultural approaches and others co-exist in research and practice.

On the basis of empirical research, Kamp & Koch, 1998, argues that safety practices have developed into an orchestration of various methods. This can be seen as a parallel to the 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.

All these characteristics, whatever they discuss bureaucracy or a long term learning process, carry however 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 provide us with well-developed sets of methods and theories concerning where the efforts should be made. Jørgensen (2002) develops taxonomy, a systematic model for risk factors and processes behind occurred 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.

A second step is made in this paper by developing a tentative taxonomy for reasons behind accidents and risk areas in construction, based on Jørgensen (2002). 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 building context. This appropriation is due to specifics of the building sector as well as limits of the material used.

Temporary organisations as frame for safety management in the construction sector

In contrast to the stationary industry, building projects are temporary organisations, where design and production usually are separated and where a number of companies interact both in design and production. The safety organisations 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 organisation, site lay out, logistics, equipment, training, coordination and communication as well as personal protective equipment.

The appropriated taxonomy

The appropriation 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, organisation (including operational management) and use of products at the site, including local procurement.

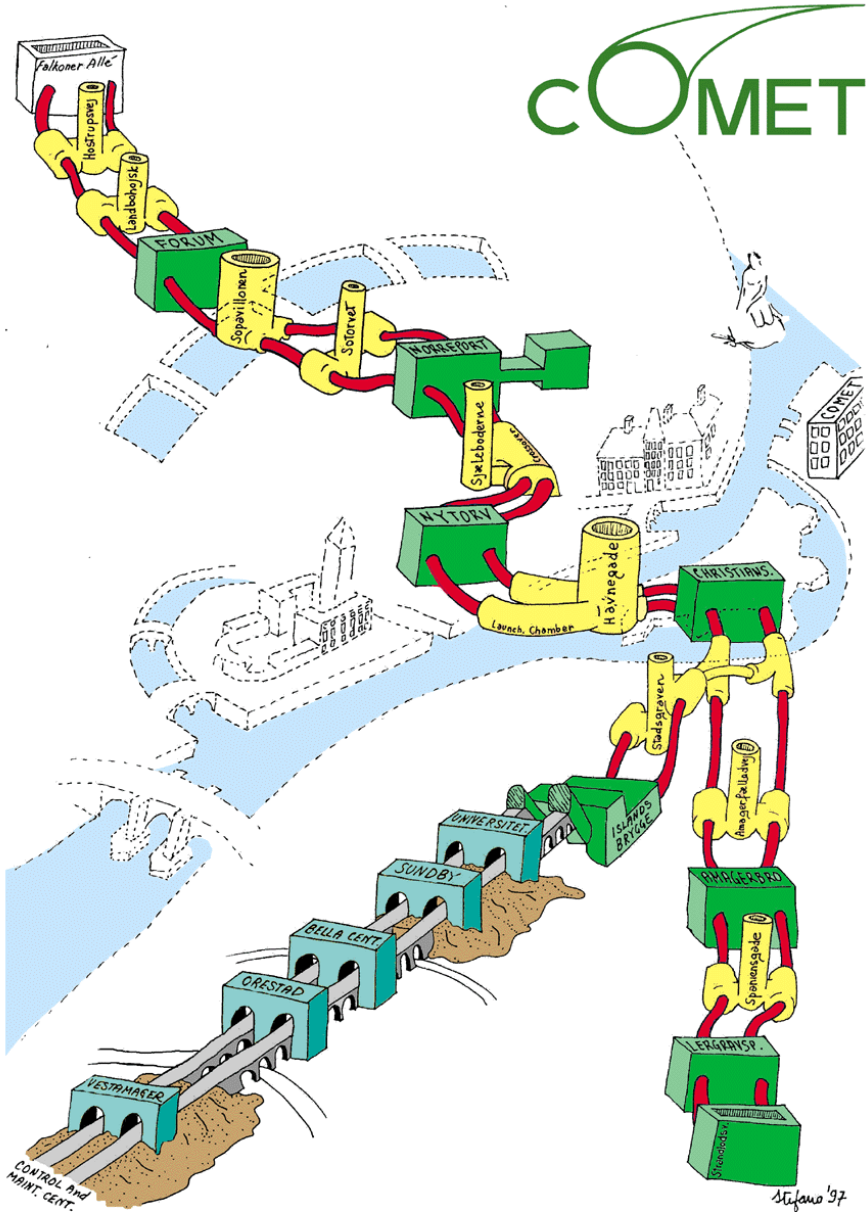
The fourth level/areas are reasons relating to management, design and supply chain. These relates to the companies with employees on the particular site or those delivering equipment, building material or other to the site. Please note that procurement in relation to major investments in machinery, equipment and building

materials is considered as part of the fourth level, since these issues relate to construction firms rather than the building site.

The Copenhagen Metro

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 figure below shows the route of the Metro. 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.

Environmental management system and policies

An environmental management system (EMS), including working environment, was set up by the client, Ørestadsselskabet 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
- Ergonomically conditions
- 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 which 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 (WPA)
The requirement of establishing Work Place Assessments for the construction industry was mandatory in Denmark from 1997. The process of establishing WPAs have 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' organisations, 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 who 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 approx. 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 were 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 to all persons who was supposed to work inside areas where they were in charge of the safety coordination. The COMET induction has been attended by more than 4,000 persons and the Ansaldo instruction about work close to tracks and or work in tunnels has been attended by approx. 2,000 persons. The instructions for work close to track and in tunnels were part of a strict train control 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 preventive 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 is an insect which is known to be well organized and hard working below as well as above ground surface, flags placed on all construction sites, posters highlighting specific safety issues, introduction folders to the campaign, news letter distributed in Danish and English languages (COWI 2002, Ørestadsselskabet 1999-2002). A "Safe Sites" competition between the work teams lead 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 effect of the campaign was evaluated positive by the contractors, the safety groups, the unions and the authorities (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 quarts during application NATM(New Austrian Tunnel 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		Less accidents reported Accidents avoided
Unanticipated events		
Reasons behind	Inspections Risk analysis	Learning

	Safety campaign	
Reasons relating to Management, design and supply chain	Contracting with design and specification company. Dialogues with interested parties	Safety design impaired Correction and modification of preventive efforts.

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.

Learning across three large DK- projects

The authors have assessed the broad orchestration of policies, involvement of interested parties and safety precautions, which have been implemented into the 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 organisations has not been described. It was however obvious that establishment and maintenance of safety precautions and safety coordination improved during the construction period as the organisations established formal and informal learning from the jobs. The learning from the recently finalised large construction works, the Great Belt Bridge and Øresundsforbindelsen has not been assessed, but the authors assume that experiences from these projects also have 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.

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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).

Handelshøjskolen, Price WaterhouseCoopers (2002): En undersøgelse af omkostninger i forbindelse med arbejdsulykker i udvalgte danske virksomheder Århus 2002. (The Århus School of Economics, Price WaterhouseCoopers, Investigation of cost from occupational accidents in selected Danish companies Århus 2002).

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.

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.