Appendix A

Fieldwork: Design Activity in the Workplace

A.1 Arrival story: a narrative

An ‘arrival story’ of entering the field to study design is documented below, to give a flavour of the workplace and to expose the nature of collecting material in naturalistic research. It is important to make the issues involved in data collection clear, so that the fieldwork can be evaluated in a manner appropriate to the methods used.

“As I stepped into the hallway to enter the office I could hear the sound of stamping feet, and several voices raised, swearing together, accompanied by a loud guffawed laugh. Clearly this was going to be a different experience to the lab and office based work that I had so far observed. A clod of mud shot across the room, narrowly missing me; the office erupted into laughter. A desk was prepared for me (books and papers on a rickety table were roughly forced to one side), and I was introduced to the group (“This is John: he’s a tosser” - what did this mean? Was there really such a craft or profession?).

Over the next few hours, I had to amass a huge quantity of information. Knowledge was rapidly imparted, using terminology that I had little experience of, relating to problems and work that I knew nothing about. Over the next few days, things became clearer; I grew to know the engineers who I had spoken to on that first day, and met the foremen and gangers who organised the physical side of the work. I toured the site and learned something of the process of construction, about pouring concrete and erecting scaffolding. Most importantly, I learned something of the processes of how they organised themselves to turn the abstract designs into structures. What had initially appeared to be a mass of “blooming, buzzing confusion” (James, 1890) began to take on an order that, without living with, and becoming involved with, appeared chaotic and inconsistent. It was not that engineers and other workers operated in a highly structured environment, but that they had learned to operate in conditions of disorder, organising pathways for information and using methods of communication that could cope with the noise and complexity of the site.”

A.2 Temporary works design

A.2.1 Entering the field

The intention of the study was to understand the work of design in engineering practice, so the study had to track the major phases that became apparent as the ethnographically informed fieldwork unfolded. This resulted in work being carried out at three sites at a construction company and at a single site with a building engineering group (Appendix B). The rationale of the thesis is to examine the process of design, rather than a pre-specified set of designers at a single site, so the distributed nature of the fieldwork, although unconventional[1], was not inappropriate. Within the construction company, the three sites included, the construction site itself, the production support teams that provided technical and material assistance to the construction teams, and lastly the temporary works designers, who developed the temporary structures involved in construction. The consulting engineering group study was conducted on a single site, although meeting were held in other locations. The four groups were studied over a period of eleven months although the studies were necessarily of limited duration. On each occasion, follow up studies, involving a review of the reports written about the fieldwork, were conducted to investigate how the participants viewed the research; their comments were incorporated into the studies and contributed to an improved understanding of work, in addition to being an external control on the validity (specifically, the 'face validity') of the research.

One of the greatest problems in doing fieldwork lies in entering the workplace. Gaining access to a site is an extraordinarily complex and time consuming activity. Negotiations of the value of the study to the observed ORGANISATION are a major part of gaining access, and how this is done can affect the study, even before the fieldwork begins. In this particular set of workplace studies, sponsors appeared in the form of the CICC project industrial partners, who were interested in discovering a 'human factors' perspective on the design and construction process. These sponsors made contacts with employees in their ORGANISATIONS (in general, managers) who were interested in the perspectives of an independent examination of communications within their companies.

In the workplace studies documented in the thesis, it was impossible to participate as a 'participant observer', due to the skilled nature of the work (to which I had no background) and because a number of studies were required across a range of

[1] Traditionally, ethnographers tend to spend large amounts of time at a single site, or with the same people; the reason for this is that they are trying to understand the perspectives of individuals. In this case however, the emphasis is not the individuals, but on the processes that bind a distributed *group* of individuals into a problem solving unit.

ORGANISATIONAL boundaries. The role of the ethnographer was therefore defined early on in the workplace studies as a consultant, and I was associated with the management perspective and as a 'communications expert'. In addition, I was labelled as a computer scientist and technologist, neither of which I wanted to apply to me. Being seen as a management 'stooge' would not be conducive to the open and free access to team processes - in the construction site I was humorously referred to as 'the spy' by one of the foremen, and this was something that had to be disavowed early on in fieldwork. Similarly, as a 'communications expert', I did not want informants to answer questions on, and make available, only 'communications relevant' information, nor did I want to seen as a technologist, who only required information relating to computers. On entering each work site, it was important to carefully make these issues clear to all of the people that I came into contact with.

A.2.2 Background to the study

The background details to the fieldwork, including the participants to the design process, their roles and procedures they follow, must be made explicit before data from the fieldwork on the design process can be discussed. This contextual information will allow the reader to get a feel for what the design workers are trying to achieve and the resources that are available to them, in terms of the participants, their relationships to one another and the setting. Whilst construction work is partly dependent upon (UK) legislation and accepted civil engineering practices and particular contractual details, some generalisations can be made from the data outside of the fieldwork. Bearing this in mind, the study was not intended as an ORGANISATIONALLY independent (i.e. cross cultural) examination of civil engineering in the construction industry, but as a particular instance of design within a real world setting.

The field study of the construction company (known as ConsCo) involved examining the work of civil engineers and construction workers. Fieldwork was performed in three locations, tracking the design process through the structure of ConsCo. One project was studied, involving a £75 million road building scheme. The 'client' (funding body) of the project was the Highways Agency, reporting to the Department of Transport, who set the initial specifications of the design. The engineering detail and project management was contracted out from the Highways Agency to an engineering company, whilst the construction work, known as 'civil engineering' was contracted out to ConsCo.

For the purposes of the study, the unit of examination comprises of all of the parties involved in the design activity - the functional design system. The activity involved the participation of three distributed units working for ConsCo. Several other

ORGANISATIONS also participated in this activity. It is important to note that the *activity* is the determinant of the boundaries of the design system, and not the artificial ORGANISATIONAL groupings. A description of the project, the teams involved and the resources available to the project are documented below, setting the context for the more detailed fieldwork described in the cycle of design.

A.2.3 The construction site

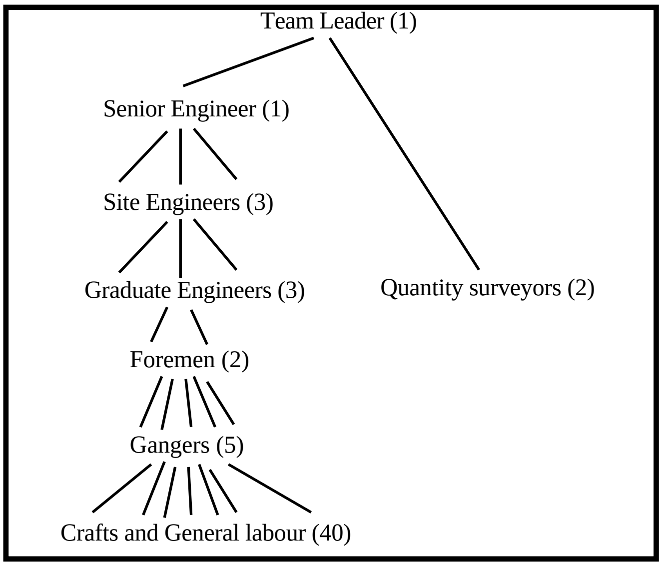
Goals, relationships and resources

The construction work on-site was performed by a team of engineers and labourers, aided by quantity surveyors. The task of the team involved building a new section of road through marshland, part of which included a multi-span bridge. The primary goal for the team was therefore to construct the given designs as cost effectively as possible, conforming to the drawings, within the safety requirements, legislation, industry standards and other stakeholder requirements (most notably, those set by an environmental agency, and a railway operator, over whose tracks the bridge crossed). A photograph of the bridge deck under construction can be seen in fig. A.1, which shows an engineer (right of picture) examining steelwork, surrounded by steel fixers attaching the concrete reinforcing 'rebar'. Scaffolding supporting the bridge deck can be seen to the right and centre of the photograph.

fig. A.1. Bridge surface prior to concrete pour.

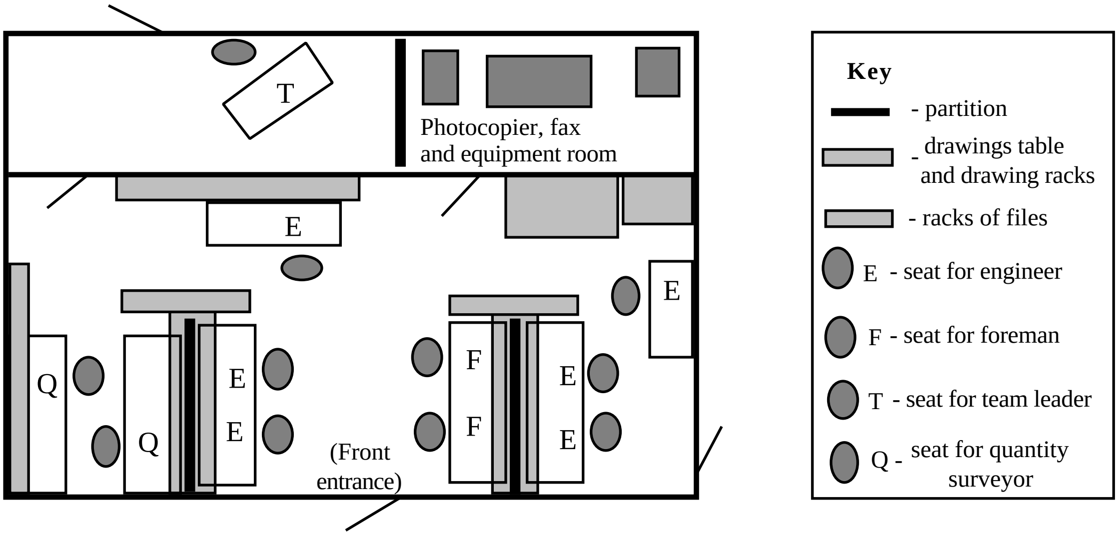
The construction team was located in a satellite office around a quarter of an hour drive away from the main site office, where the construction management and other construction teams operated from. Communication links with this main site were described as poor because of the distances involved. The construction team included a hierarchy (ordered in seniority) of team leader, seven engineers (one senior, three site, and three graduate engineers), two foremen (senior work supervisors), five gangers (junior supervisors), the craftsmen and general labour, varying around forty in number (see fig. A.2.). Two quantity surveyors, similar in rank to the graduate engineers reported directly to the team leader. This hierarchy was important to the distribution, of labour in the group, because it determined the responsibilities and roles that individuals undertook. It also provides an insight into how work was delegated 'downstream' through the team, and how knowledge about site conditions was propagated 'upstream' from the site.

fig. A.2. Hierarchy of seniority in the construction team.



The office was used by the engineers and senior construction personnel, and was laid out in an open plan style (see fig A.3.). The diagram demonstrates how the team personnel could be made aware of each other within this confined space, and shows how they had access to design artefacts (the drawings and files) that could be used as resources for performing their work.

fig. A.3. Layout of construction team office



One of the graduate engineers had an office on the site itself, and only visited the main office in the mornings and evenings. The labourers worked on the site ten minutes away along a half mile stretch of poorly maintained haul road, accessible only by foot or four wheel drive transport (available to the foreman). This distance meant that communication between the construction workers and the satellite office was complicated by spatial fragmentation.

The construction process

The design for the original structures of the road was predetermined for the construction team, and was generated by an external ORGANISATION, known as 'the Project Engineer'. The Project Engineer produced design drawings detailing the structure of the 'permanent works' - the finished road and bridge. These showed the final structure of the built design, including the materials to be used, placement of the steel reinforcement, location of the supporting piles and the tolerances that would have to be used. The permanent works drawings set the precise specifications for construction. 'The resident engineer' (or RE) was the representative on site of the Project Engineer; they were employed by the client to oversee the construction of the design. The team had copies of the drawings that it was either working on, or would soon be working on, sent by a document control office at the central ConsCo office on the site.

The project's drawings held most of the design information used to direct the team's activities. The 'drawings' included two forms of representation relating to the road and bridge being built. One set of drawings, the permanent works drawings, were the designs created by the Project Engineer. The other drawings were created by ConsCo, and known as temporary works (T/W) drawings - structures removed following the completion of the permanent construction. These T/W drawings detailed how the structure of the original designs was to be put together: the supports to be used, the placing of concrete moulds, the location of the haul roads to supply the site, and so on. Once the form of the temporary works for construction has been designed, the work of construction could begin. During the fieldwork, the 'temporary works' drawings were the most frequently consulted representations used by the team. Building these temporary structures formed the most time consuming aspect of construction work. Once the temporary works structures had been erected, the permanent structures could be built, involving the placement of steel reinforcement and pouring of concrete. These tasks, whilst requiring a high level of precision, did not did not comprise of a great deal of effort, which was directed at the design, construction and removal of temporary works structures.

An explicit description of the construction process was available to the construction team, known as the 'Contract Quality Plan'. This document described what standard operating procedures to undertake at any given point in the process; in reality, it was hard to find anyone who had read it, and it was several months out of date. As a consequence, knowledge about the team process was localised in the individuals who had responsibility for the particular tasks. Only the team leader and senior engineer had an overview of the responsibilities and tasks performed by the rest of the team. In general, workers were only partially aware of the responsibilities of others, although this was not important to them, because they were aware of the procedures relating to their own work.

Accountability and Responsibility

In order to begin the steel work, concrete pours and other general work that make up construction, resources had to be put to work, in terms of labour, plant and materials. The organisation of this work was generally undertaken by the site engineers, and to a lesser extent the graduate engineers. Much of construction work was demand led, and work could only occur when the site had been prepared: materials or other resources might have to be ordered or cancelled at the last minute because the site was prepared earlier or later than expected. The use of different materials in the permanent structures could change the project's specifications and such changes would need to be checked with the RE. Changes to the materials used in temporary works structures meant that these designs had to be checked by the senior team engineer or by off-site temporary works designers.

To demonstrate that the work was being conducted as contracted, the team had to communicate with the RE, and get them to sign a form agreeing to this. This form was used to prove that the construction work has been completed to an appropriate quality level, and avoiding disagreements at a more costly to change, later stage.

Alongside the work of construction, the costs of the work had to be controlled; the team's quantity surveyors performed this accounting task through the production of reports on the team's projected and actual costs to demonstrate that work was being conducted cost effectively, and according to plan. The quantity surveyors therefore had to be aware of the work that the team was doing and understand the materials, processes and importance of the work being done.

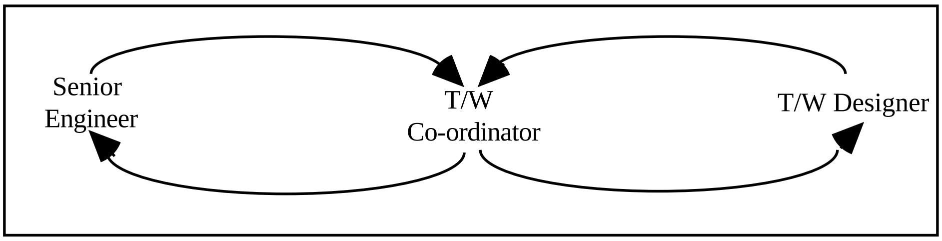
A.2.4 Temporary works co-ordination

Temporary works co-ordination was managed by the production support (PS) team. The PS team did not operate as a single problem solving unit; rather they acted as an extension of the construction teams, able to organise their activities at a level that the teams themselves did not have the time or experience for, and providing this service for several construction teams on the site.

Three members of the team were involved in the work relating to the construction team studied. These three were co-located in an open plan office in the middle of the main site office (distant to the construction team). Along one side of the room ran a corridor that people entering the site office would have to walk along. This was a deliberate arrangement, intended to increase their contact with passers by. On a weekly basis, either the construction teams visited the main offices and met the production support team members, or vice versa, with a member of the production support team going on site.

The main function of the production support team was to manage communication on the site for the groups involved in the construction process. This usually involved chairing meetings with external ORGANISATIONS, or acting as a proxy for the team when the team members could not be physically present. Their experience with the design of the temporary works structures and the construction work on the site allowed them to understand the problems that the teams faced, whilst leaving them detached from the construction work itself, and in a position to see arising problem situations from both perspectives.

The critical member of the production support team for the fieldwork was involved in co-ordinating the design of temporary works: the temporary works co-ordinator (known as the TWC). The TWC mediated communication between teams and the designers of temporary works: this involved passing the team's requirements on to the temporary works designers or proprietary designers (both remote from the site) and managing communications between the problem holders (the team) and the problem solvers (the external designers) until the designs were completed. The TWC maintained a single route for all temporary works design related information to pass through, thus allowing rescheduling and change to be performed more easily than by the various individuals working on other aspects of design and construction. The work of the TWC entailed them being constantly updated on the current state of the site, and acting as a conduit for filtering and passing on information between the remote groups:



Two other members of the production support team were located in the same room as the TWC. One of these was involved in planning, involving scheduling and programme management. This work involved producing scheduling information, such as weekly work schedules, and critical path analyses that were used to direct the team's behaviour in the long term (over three months). Their explicit function was to provide detailed scheduling advice to teams and to help them interpret what this planning would entail in terms of activities. The work also involved analysis of the construction team's progress reports to see how their ongoing activities matched the work schedule. The other member of the PS team was involved in temporary materials co-ordination**.** This involved the ordering and maintenance of temporary works equipment (such as scaffolding, concrete moulds and other falsework and formwork) on site, including both in-house and off-hire equipment. The close proximity of these two other people enabled the TWC to be made aware of other temporary works related activities being undertaken at any time.

A.2.5 The temporary works design team

The temporary works design team provided a design service for the many construction sites that ConsCo was involved with. The main ConsCo engineering office where the temporary works design team worked was a quiet, open plan room, with the engineers working almost silently at their desks in an atmosphere similar to that of a library, and there was relatively little interpersonal communication. Books and other reference materials covered the walls, and the TWDs spent much of their time reading these. The procedures that the temporary works designers were expected to follow were described in a document: the 'Planning and Temporary Works Handbook'. These procedures explicitly set out the relationships between the parties to temporary works design, their responsibilities and proscribed methods of work.

However, it was rarely used and was several years out of date, bearing only a passing resemblance to the activities observed. The main engineering office was distant to the construction site, located about an hour and a half away by car, across London. To communicate with the site, the temporary works design team had fax machines, telephone links, and were able to visit their assigned sites on a two weekly basis.

The construction team collaborated with the temporary works designers when they required designs for temporary works, including items such as falsework, formwork, cofferdams, retaining walls, access roads and bridges, temporary foundations, road diversions and demolition. These temporary works features were not specified in the original designs or drawings created by the Project Engineer, which only detailed the designs for permanent structures. The temporary works generated were required to conform to the safety and quality requirements specified in the CDM (Construction [design and management]) regulations and also to meet the demands specified in the project contract. In addition, the work had to be performed as quickly and as cheaply as possible, to which there may be a contradiction - designs that are quick or cheap to build can be expensive or slow to design, the reverse of which can also be true.

A.2.6 Other stakeholders to the process

The resident engineer was employed to ascertain that the constructions were proceeding to the designs and according to the quality standards in the contract between the client and tender company (ConsCo). This workload was split up into spatial areas supervised by ‘the assistant section RE’. The assistant section RE had a ‘man on the ground’ checking standards and watching the work as it was being performed - known as the ‘clerk of works’. At some stages in the design, construction teams required the services of subcontractors, who performed specialist activities that the team had less expertise in. ConsCo had to inform the RE whenever subcontractors were used; when subcontractors further subcontract with another party, they had to also gain the approval of ConsCo and the RE.

Materials suppliers were involved in the construction process, providing equipment and plant. The materials that were most important to the temporary works process were the ‘formwork’ and ‘falsework’ for holding up and moulding the concrete structures. If supplies were unavailable or too expensive, the temporary works designs had to be changed. The suppliers of some specialist materials were also involved in producing designs for work involving their materials, because of their skills and experience in using the products. This might involve particular layouts and configurations of the temporary works materials. These ‘supplier designs’ might also affect other designs in unexpected ways, because they could change access routes, or require work to be done in a specified order, and possibly affecting the critical path of the project. The teams therefore had to maintain close contact with these suppliers to check that their designs were compatible with existing plans.

Several other stakeholders had a voice in the construction process, and whose approval was required work to proceed. These included an environmental agency, who were required to check up on any watercourse pollution that the site might cause to the surrounding marshland, and a railway operating ORGANISATION, the owners of the railway line over whose tracks the bridge was being built. The railway operators had a particular concern that material would fall from the bridge onto the trains passing below. Each of these had an important say in how the construction process was undertaken.

A.3 Phases of activity in temporary works design

The six phases in the 'cycle of design' are elaborated on in the particular context of work arising out of the work on the bridge deck of the road building project, alongside examples of problems faced and behaviour observed during fieldwork.

Whilst the phases were seen to be discrete (i.e. they were discriminated at an abstract level), the reality of the situation was that these units were not completely distinct. The reason for this was that the same agents could be involved in several of the phases, and that whilst much of the information relevant to the sequential processes of design described was in the form of controlled documentation, a large proportion of the information relating to the design was retained in the form of mental representations held by these agents. This mentally encoded knowledge about the design was *phase independent* and could be applied in more than one phase.

An important point to note was that whilst the official, formal process of design and construction activity was regulated, an informal, socially based design activity took place in parallel to the official account. This formed an unregulated, mediating activity through which communication that was not proscribed in the official engineering process could take place. Informal, ad hoc, channels of communication were important to the design process because the idealised ORGANISATIONAL procedures could be too inflexible to adapt to the complex and non-standard situations of the real world setting.

The mechanisms used in the two ORGANISATIONS examined are analysed in the terms of distributed cognition, examining the inputs and outputs of each phase of the process and demonstrating the processes (formal and socially managed protocols), the context of the activity, and the representations used in the completion of each of the design and construction phases described in section 4.5.3.

A.3.1 Information gathering

This phase of activity arose out of the day to day management of construction activity. The information gathering phase of design was a continuous, ongoing process, involving searching out discrepancies between the inputs making up of the construction programme (incorporating the schedule, permanent works and temporary works drawings) and the state of the site itself.

Information relating to the state of the site was collected from the different groups of workers on the site, each using their different skills and experience to determine these discrepancies. Small problems relating to the construction materials would usually be noticed by the tradesmen, who would pass this information to the gangers, where it would precipitate upwards through the team hierarchy to the graduate engineers, who would either record the problem in the works record (this functioned as the site diary - the official record of activities on the site), or as in most cases, they would mention the problem to the site engineers who could determine an appropriate course of action.

Problems at a more global level would be determined by the engineers, based on their patrols around the site (known as 'site visits') where they would see how the activities that they had been previously assigned to manage (by the senior engineer) were progressing. Site visits also provided an opportunity for the engineers to engage in ad hoc encounters with the workers on the site which provided a source of information on any problems developing on the site. An example of a site visit is given below:

> In one site visit, a site engineer was taking a crane hire representative around the site, to discover what sort of crane they would require to place some beams onto the bridge underside - an awkward situation to reach.
>
> Standing under the bridge, the site engineer and the crane representative were joined by a foreman, and as they discussed the section, they pointed up at the bridge area that they were referring to. They deliberated over possible methods of access to the bridge and scaffolding, and other features that would have to be removed or reached over by the crane.
>
> Whilst involved in this discussion, the assistant section RE (the RE's representative on site) saw them and came over. They became embroiled in an (amicable) argument over the method used in a concrete pour on a section of the bridge adjacent to the area that they were standing on. It appeared that the Project Engineer had not specified in the drawings *how* the concrete was to be poured; the team's engineers had decided on a method that was not approved by the RE (although he could not legally enforce this due to the oversight). No answer was reached, but they agreed to continue the discussion at a more convenient time.

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Continuing from this area and leaving the assistant section RE, two gangers came over and mentioned that they'd seen the site engineer talking to the assistant section RE, and they wanted to complain about his intrusive way of examining their work, which was holding them up in completing a concrete pour. The engineer noted their arguments down in a notebook and agreed to discuss the matter with him when they next spoke.
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To obtain technical information on the state of the site, measurements of the current state of the site were taken by the graduate engineers using the theodolites and geodometers, which they would take out (called 'setting up') and do the 'chainage' (measuring the positions of the actual structures against the positions of the planned structures). This process was similar to that of plotting a course in the navigation process described by Hutchins (1988;1995a), where physical features of the world would be matched to a chart. Information collected on the location of structures would be noted onto tables of chainage and returned to the satellite office, where they would be matched to the drawings to see whether the structure was sited correctly, and the schedule could be signed off as a task completed.

Several artefacts were used on the site in information gathering. The schedule catalogued the order of actions to be performed: this was broken down into the contract programme, which detailed the work to be performed over the three year duration of the project. The contract programme was broken down into a representation delineating the teams expected activities over a three month period, known as the stage programme, and finally the weekly work schedule, which was generated by the team leader and senior engineer. This broke the activities described in the stage programme down into individual responsibilities for the gangers and foremen who supervised the labour.

The temporary and permanent works drawings were used to see what form the designed structures were to take and to determine the work involved in their construction. These drawings were used as diagrammatic representations that could be compared to the final built structures to see if they had been constructed correctly, as well as indicating what future work would have to be performed. One such situation was observed in a discussion between an engineer and a ganger who were discussing a conflict over the observed construction and the drawings:

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Ganger: 'You know that on the drawing?'

Graduate engineer: 'No.'

Ganger: <pulls out drawing onto desk> 'You see there?' <points at feature on drawing>.

Graduate engineer: 'That's the height of the parapet'.

Ganger: 'Aha! Yeah.'.

Graduate engineer: 'OK. So you start there...' (points at same feature of the drawing as the ganger)...'Ah...Err...'<mumbles>
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Ganger: ‘You see?’.

Graduate engineer: ‘Yeah.’

Ganger: ‘It comes square to the top level...’

Graduate engineer: ‘Just over the lighting column there...’<mumbles inaudibly>.

Ganger: ‘An that’s two metres there eh?’

Graduate engineer: ‘Yeah.’ <taps an area on the drawing with screwed up expression on his face>.

Ganger: ‘It’s only a metre to the top of the box’....‘Yeah, know what I mean?.

Graduate engineer: ‘OK...’

Ganger: ‘Do you wanna come up on the deck an’ have a look?’.

<They leave for the site soon afterwards>
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Here, the discussants use the drawing as a means of comparing the gangers expectations of what the temporary works structure should look like to reality on the site. The ganger has noticed a discrepancy in the match between the drawing and the his observations: ‘the parapet’ should be two metres from ‘the box’; it is, in fact, one metre. The drawing is used both as a means of gaining a better understanding of what the structure should look like, and as a means of communicating and discussing this with the engineer responsible for managing its construction. They then go on site to show the engineer the situation as it stands.

It was common for sketches and tables to be generated from the drawings because the drawings were often too large to take on site and over-complex for particular tasks. Re-representing the relevant information into a simplified media could enable simpler and more easily visualisable comparisons of data sets. An example is given below of how transforming a drawing onto a graph could aid understanding:

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A graduate engineer had spent several minutes poring over a drawing taking measurements of the gradient of the surface of the bridge (‘the deck’) onto a hand drawn table. These measurements were then transferred onto a sketch, but in a different format to that of the original drawing: whilst the original drawing had been an overview of the deck (viewed from overhead), the sketch was a section through the structure (viewed from the side). In addition, the axes on the sketch were chosen so that they exaggerated the gradient and made deviations and discrepancies in the data more easily visible: the horizontal axis was on a scale of 1:250, whilst the vertical scale was 1:10. The sketch was then taken onto the site and real measurements were annotated onto it as they were taken (see fig. A.4.).
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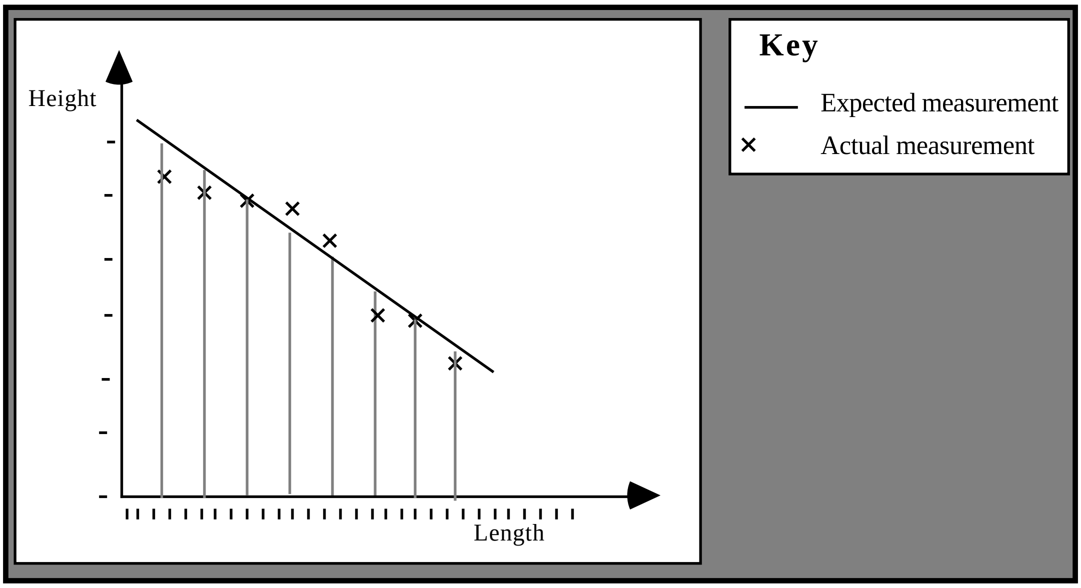
fig. A.4. Sketch of road gradient.



The sketch had been taken out into the field, and annotated so that the measurements taken with the geotechnical equipment could be annotated onto it. The sketch clearly demonstrates that the measured slope had a gradient that did not match the gradient on the drawing. The form of this representation clearly demonstrated this, as the difference was exaggerated through the differential scales on the axes.

The reason for this discrepancy was that a sub-contractor had driven the piles to incorrect tolerances, the discovery of which had important consequences on subsequent building activities because it limited the loading that could be placed on them.

The outputs of the information gathering phase were held informally in the heads of the engineers, foremen, gangers and labour as general information about the site. Other artefacts were used, including the officially sanctioned works records, as notes and memoranda on desks and in files, and as the ‘back of an envelope’ type sketches that the engineers took to represent spatial relationships between objects that were hard to describe in text. These sketches were rough, hand drawn, and captured selective information that was not immediately discernible or available from the official records of the construction process. These roughly created artefacts were often annotated with text and numbers over time, and were used as personal records or in conversations to demonstrate a concept to other people.

Each engineer would have many responsibilities, but only through bringing these together could an overall picture of the site and plans for future activities be generated. An overview of the project design requirements was performed by sorting this information into meaningful units so that problem specifications for temporary works could be set, and design requirements drawn up. This took place in the next phase of temporary works design - information collation.

A.3.2 Information collation

Information collation involved the transformation of knowledge (from the information gathering phase) about the state of the site into a representation of the problem that specified it in a way that could lead to a design solution. This involved organising the raw information obtained from the site into a form that could be used in problem solving. The process involved bringing together information about the site from a number of sources, and distributed over a range of personnel, into a coherent and organised form that related to a particular proposed design feature.

The inputs to the information collation phase of design incorporated the outputs of the information gathering activity. In practice this process involved communication between the different people on the site who held information about conditions on it, determining *what* information was related, and *how* it was related. Because designs had to be relevant to the conditions on the site, and so that they did not disrupt ongoing activities, many aspects of the site had to be considered. The information collation exercise therefore resulted in the collecting together of information that was represented in many different media, and held by several individuals. The information collation phase involved bringing together this apparently disorganised set of represented information into a unified structure, the output of which would form the basic problem specification forming the input of the next design phase (the generation of a structural design).

The processes of information collation involved bringing together information relating to a particular design problem from the information gathering phase, and informed by this, producing a structured set of more explicitly specified knowledge that could be used as a means of specifying requirements for the development of new temporary works schemes. The information gathered by the construction team workers in the course of their involvement in the day to day running of the site in the information gathering phase was collected in a way that made sense to individuals who were using it on a day to day basis. The information was often represented in a media that was generated to aid the individual in their own activities, rather than as a component of a collaborative process for future design. Thus, scaffolders would carry sketchpads of scaffolding configurations; carpenters carried tables of woodwork measurements; and engineers carried various schedules, drawings, sketches, tables and notes, relating to work completed, work about to begin, and work underway. Some of this information was held mentally and these internal representations were not be directly accessible. To begin to collate this information into a unified state, the participants would have to communicate with each other to bring this privately held information into a publicly accessible arena.

Co-ordinating the information distributed between the participants was facilitated by the situated aspects of the construction activity, where the environment of the construction site and satellite office provided both resources and constraints to support this. The actual processes used by the participants to co-ordinate their understandings about design problems on the site, occurred through both direct and indirect communicative events. Direct communication involved activity that was primarily intended for communication, whilst indirect communication included activities that were not primarily communicative in their intent, although they had a secondary function as such.

Direct communication

Direct communication included reporting of events observed and of events that were expected. This took place in the weekly team meetings, but also in ad hoc meetings, and chance encounters, as people found themselves adjacent to a person who might need to know some information that they were party to. Team meetings were held at a specific time each week, chaired by the team leader, and all gangers, foremen, engineers and quantity surveyors were invited. An agenda was set (although not always followed) and all members of the team were invited to participate in saying what they had been doing, and whether there had been any problems on the site. At the end of the meeting the weekly work schedule would be handed out by the senior engineer, which the team were asked to comment upon.

A formal communication mechanism about activity on the site was the site record: at the end of each day, these were filled in by the engineers (on a pro-forma sheet), collected together, and filed, providing a common resource for all of the team to examine. In addition to acting as a resource for the team, copies were taken and passed to the main site office, where they were forwarded to the TWC and TWD, the resident engineer and the stakeholders affected. The site record provided a means of ‘covering the teams backs’, so they could not be accused of failing to notice design-critical information, an important consideration in a traditionally litigious industry.

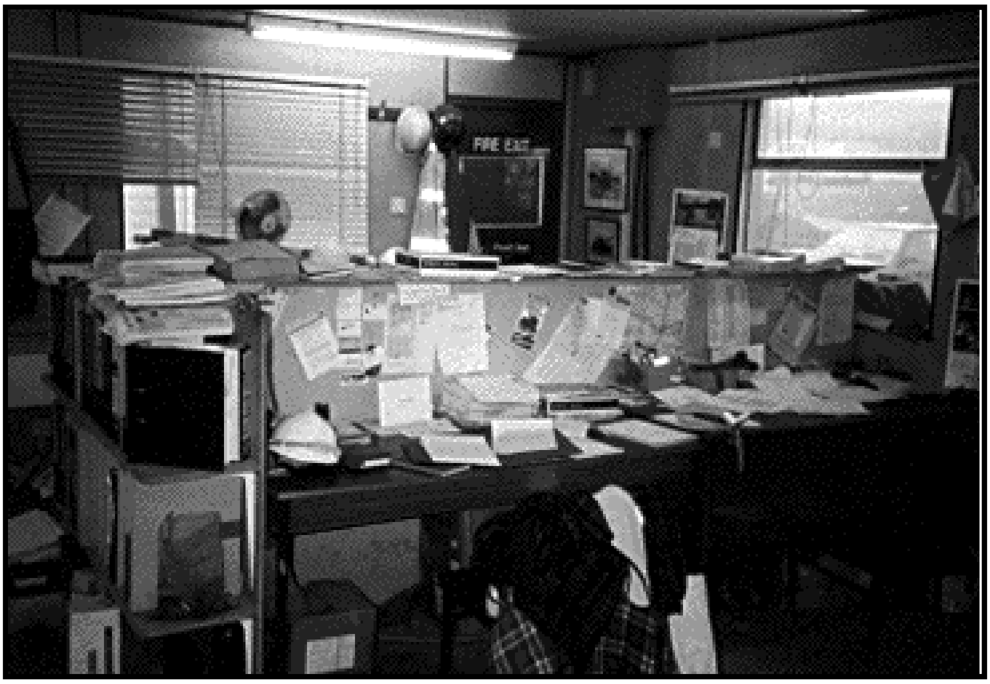
Another form of direct communication included the team members writing notes to each other, which tended to be used with single pieces of general information, or in asking simple questions; anything more complex would be left until a face-to-face meeting could be arranged. An example of this was observed in the sketch of gradients made in the information gathering phase: the graduate engineer left the sketch on the senior engineers desk, with a note attached to it explaining that he had found a discrepancy between the expected and actual gradient. It further commented that he was going to be away from his desk for the rest of the day, but informed the SE that he would be working at a particular location if he needed further information.

Indirect communication

In indirect communication, the context of the activity provided a mechanism for the transmission of information between people sharing that space. The physical structure of the satellite office allowed the behaviours of the construction team to be organised and to facilitate ad hoc communication, in a way that would not have always been possible under different environmental conditions.

The office was ‘open plan’, and the engineers and quantity surveyors therefore were able to see when other people were present, to speak to them without having to move from their desks, to overhear them on the telephone or when speaking to each other, and to see the information laid out on each others desks. There was a relaxed atmosphere to interactions, and when members of the team were not doing any work, they would engage in social conversations, or join conversations if something interested them[2]. These conversations almost always turned to work, and there was a constant stream of people coming into the office and asking for information. To demonstrate the resources available to communication, a photograph of the layout of the office is shown in fig. A.5.

fig. A.5. Photograph of construction team office.

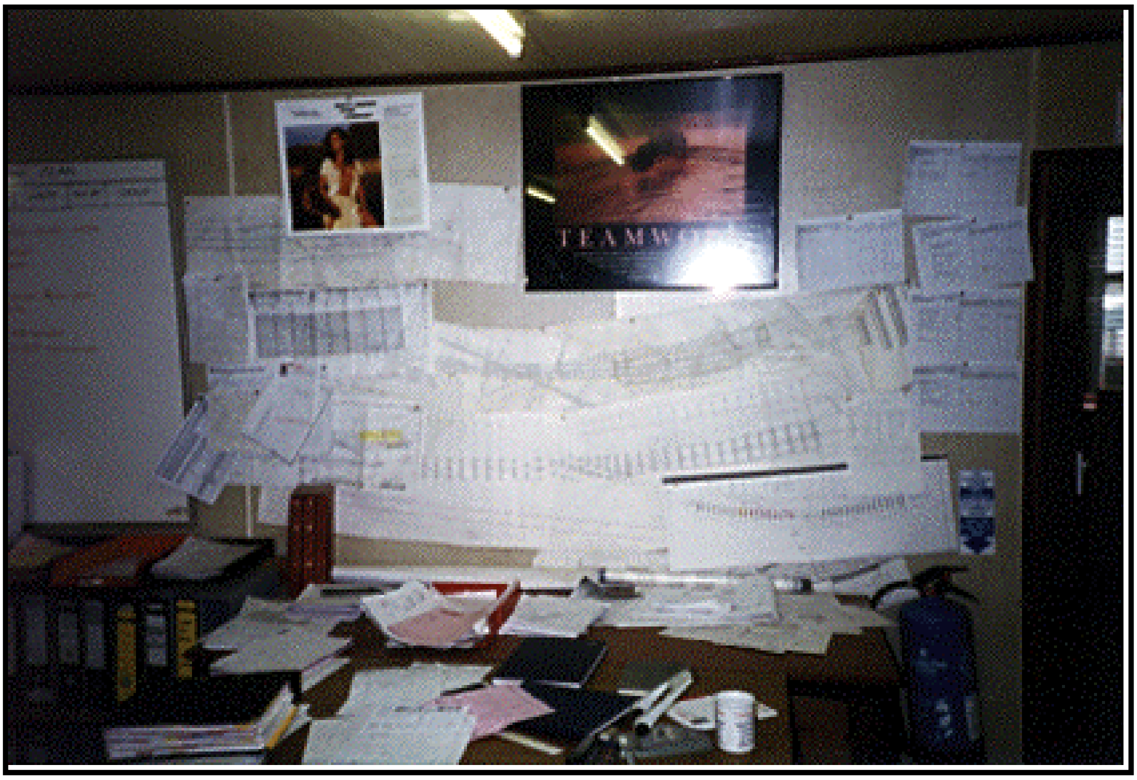


[2] These conversations were noticeably not joined by the labour or gangers, possibly due to social class boundaries, or due to a distinction between ‘the management’ and ‘the workers’. This was reinforced in the way that the labour force did not have desks in the office, spending their working hours on the site. This was a *hierarchical* barrier to communication, although at the same time it provided an information filter for the engineers, reducing the volume of material that they had to be sensitive to.

As can be observed, the workplace was covered with paper and other sources of information. Paper covered almost every surface, often several layers deep, and frequently referred to material was pinned up on the walls. When information was required from a person who was not physically present, this ‘desk litter’ could provide clues to their location, in the forms of the drawings and other representations on the desk, as well as the task that they were currently engaged in. Other artefacts also provided information about the whereabouts of people: if a person’s Wellington boots and hard hat were missing, they were probably out on site; if someone had a pair of muddy boots under their desk, it meant that they had been on the site and could be asked about the current work situation. Depending on the weather, it was even possible to see how long ago a person had been out on the site, for example from the wet or dried mud on boots, which could be useful if one of the team was trying to locate another individual out on the site. Other tools, such as the geodometer were also useful in this way - if they were missing from the office, then a graduate engineer would be out on site (in a predetermined location) and could be asked to run a favour by the more senior engineers. Even the window was used to see whether people’s cars were in the car park outside the office (seen through the window in fig. A.5.): if this was the case, then that person was highly likely to be somewhere on the site.

The walls of the office, and in particular the partitions, were covered in pinned up artefacts, including permanent and temporary works drawings, sketches, time-space scheduling charts, calculations, photographs, calendars, information tables, the addresses of suppliers and subcontractors and other information deemed relevant. The senior engineer had a particularly prominent pinboard on the wall in front of his desk (see Fig. 11.) Of particular note on this was a calendar with various dates highlighted and circled, including bank holidays, and a drawing showing the positions of piles with the areas that were completed highlighted in fluorescent pen. A plan view of the road that was intended to go over the piles was pinned above the piling drawing, with measurements to the same scale These three representations allowed direct comparisons to be made between calendar information, piling work and the location of the piling work. This linked resources, spatial information and planned activity for the tasks involved in piling. Present and recently completed weekly work schedules were also pinned up, some with comments annotated on them, as to when the work had been completed, or problems arising from their construction. Sketches and amended drawings were also pinned to the board.

fig. A.6. Photograph of drawings pinned to senior engineer's wall.



Over the period of the fieldwork, the content of the board was changed by the senior engineer, some artefacts being removed and replaced (such as the amended drawings and weekly work schedules), whilst the content of others changed, such as the drawing of the piles, so that after each successful concrete pour, as piles were covered over, the pile locations were filled in with fluorescent ink to demonstrate the changes. These commonly accessible artefacts provided a simple visual representation of the state of the construction site (to those who could read the representation), and which could be directly compared to the project schedules.

One of the ways that knowledge was passed around the group was through asking questions; this might be a direct question to a particular person, or a general question, shouted out so that anyone in the room with the answer might answer. These questions usually were simple, and once the answer was given, the conversation was terminated. Spoken communication was conducted from the desks, allowing all of the participants in the room to be aware of developments, or allowing them to contribute to the discussion. When the senior or site engineers wanted to speak to the graduate engineers, they would stand up and chat over the tops of the partitions, providing a visual and auditory focus of attention in the room. This allowed people to work whilst keeping an ear to the conversation, keeping abreast of developments, to ask questions, and to add to the discussion. An example of this is noted below:

```
Senior engineer: <goes over to graduate engineer at his desk> 'Have you got the delivery tickets for fifty two fifty six?' [the term relates to a particular set of substructure pile reference numbers].

Graduate Engineer: <mumbles. Begins to search through a file on his desk>.

Quantity surveyor: <sitting on desk opposite graduate engineer, and overhears conversation> 'I've got copies. I think I've got the ones you're looking for'.
```

In addition to these 'open' conversations, telephone conversations were carried out in loud voices; this was partly because the level of ambient noise in the room could be fairly high, but also because it allowed the others in the room to overhear (one side of) the conversation. One of the site engineers in particular would deliberately raise his voice whenever he was speaking about topics that he perceived to be particularly pertinent to the others, even standing up and waving his arms around to gain attention, or pointing to artefacts that were relevant to the discussion so that the others in the room might get an idea of the topic of conversation.

The participants in the information collation phase were centred in the satellite office, but in reality spent large components of the time on the site, with the more junior personnel spending almost all of their time outside, working on the site, whilst the more senior team members (and the quantity surveyors) were only away from their desks for a short time over the day. Contact between the dispersed team members with the site which was some distance from the satellite office was made possible through the use of a portable hand-held radio link, which allowed the engineers and gangers or foremen to communicate with each other (eight radios were shared by the team). These radios were kept on all of the time so that contact calls could be made. The background noise of the radios was also used as a means of indirectly monitoring general activity on the site.

The almost constant babble of the radios in the office meant that distant radio conversations could be attended to. This was possible because of one of the qualities of the radio as a medium of communication. The radios, unlike the telephone, were set to an open channel: all communication took place on a common wavelength, so that both sides of a communication could be overheard by non-participants with access to a radio. As with an open plan office, which allows overhearing, or 'surreptitious monitoring' of conversations, the radios had a similar function for spatially distributed individuals. This demonstrates how a communications technology can enhance task performance when it conforms with, and meets the requirements of work practice.

At various points in day, it was common practice for the foremen and engineers to gather in the office at lunch, the beginning, and end of the day to discuss any areas that they felt were important. This time sensitive co-location was important for the propagation of information between the team members, because at other times, it was difficult to predict where particular people would be; at this time however, they were likely to be present in the office.

The culmination of the information collation activity resulted in the generation by the senior engineer of a new document called the 'design brief' or the TW2 (the temporary works specification). According to the ORGANISATIONAL procedures, the TW2 should be presented ten to twenty days in advance of the date required, depending on the complexity of the design problem. The construction teams were encouraged to include in this suggestions for the design, and the materials that they proposed to use, some of which they might already have, and which might prove cheaper than buying in resources from off-site. The TW2 often included a sketch of the site to represent spatial relationships, taking information directly from the senior engineer's own site visits or understanding of the problem, or through the re-representation of a sketch generated by one of the other engineers (such as the problem of misplaced piles noted above). Once the TWC had studied the design brief and discussed it with the team, the TW2 would be sent to the main engineering office.

In addition to generating the TW2, a great deal more information about the expected design was held in the head of the senior engineer that he did not believe appropriate to put in the TW2 for various reasons, including time restrictions, relevance, or even office politics (such as him not wanting the true cost of the temporary works to be available to his own superiors).

A.3.3 Generation of Structural Designs

Clarifying the design specifications

The initial inputs to the structural design phase were the outputs of the information collation phase. However, because more participants become involved in to the design process in this phase, several new inputs must also be considered. These include general knowledge about the site known by the temporary works co-ordinator (TWC), generic knowledge about temporary works design processes and the permanent works designs known by the TWC and temporary works designer (TWD). The TWD also had access to previously created designs which could be re-used with little additional work on them. Additional inputs in the form of constraints on the temporary works design from agents external to ConsCo also have to be considered. These ranged from the resident engineer's knowledge about information relevant to the site, supplier knowledge about the performance of their materials, and other stakeholder knowledge (by the environmental agency and railway operator) about permissible designs. Constraints imposed by pre-existing documentation relating to legal responsibilities and national and international standards relevant to the construction and design process also have to be considered as an input to the process.

In the construction quality control documentation of the official ORGANISATIONAL procedures, the TW2 should be presented as a formal transition of a design representation to the TWC by the team's senior engineer. In practice, the TW2 was often little more than a few ideas sketched or jotted onto a scrap sheet of paper, because the senior engineer had little too time to perform the task, and often very little understanding of what information the TWD might require in the problem specification. Through discussions with the TWC, a detailed specification would be generated, containing information about the site conditions, the materials, labour and other resources available to construct the temporary works structure. Such meetings were usually booked on the telephone between the construction team's senior engineer and TWC, who would then sit down at the TWC's desk in the main site office, and pore over the permanent works drawings, the initial TW2 and several sheets of blank paper. As they discussed the problem, both tended to make sketches; often they elaborated on old sketches, jotting notes onto the sketch, and referring to features of the drawings by pointing at them. This could be seen in an example, where part of an interaction went as follows:

```
Senior engineer (SE): 'If you look here, there's a barrel run there' <points at sketch generated in the meeting of a section view through a design structure>

Temporary works co-ordinator (TWC): 'Yes I see'.

SE: 'So if we dig here...' <he holds one hand to the sketch and runs a finger on the other hand along a permanent works drawing (plan view) beside the sketch, indicating a line of reference>

TWC: 'No you can't do that because of drainage problems...' <pauses> '...No, no, I see now'.

SE: 'So if we cap these piles here...'  <indicates several points on the sketch>

TWC: 'Yeah. OK. Lets do that'.
```

The discussion also demonstrates how a common understanding of the problem was generated through cross-referencing different representational forms. Here, the senior engineer mediated the co-ordination of two representations on different artefacts by using his hands to demonstrate the spatial relationship between the drawing and the sketch, holding one hand to the relevant location on the sketch and the other, running along the permanent works drawing to indicate where the digging on the sketch (the section view) would have to be performed over the drawing (the plan view). This allowed the information on one representation to be mapped onto another to generate a third, processed representation.

The time spent on developing the TW2 was determined by the complexity of the design problem; this could range from a few minutes to several hours, and on occasions, involved multiple meetings. During meetings in the TWC's office, the other production support team members could overhear the discussions and occasionally provided information relating to the schedule and the availability of temporary works supplies (their specialist areas) that affected the design problem being discussed. When problems arose with deciding on the specifications or on the possible configurations of the design, the TWC would often break off the meeting to make a telephone call to someone who might know the answer, continuing the meeting when furnished with the necessary information.

The end result of the initial meeting or meetings between the TWC and senior engineer would result in the creation of a 'final TW2' by the TWC. The TW2 was intended to be a precise and consistent indication of the problem, discussed in terms of site specific information, the problem encountered, and the resources available. In theory, the TW2 should contain all of the information the temporary works designer would require to solve the problem situation. The TW2 would be filled onto an official form, appended with any sketches that were needed to unambiguously describe spatial relationships between objects, and copied, one copy sent to the TWD, one retained by the TWC, one by the construction team, and one sent to the project manager to add to the dayfile. The TW2 was therefore the first unified representation of the temporary works design problem.

Specification and structural design

The next stage in the structural design process involved the TWC contacting the temporary works designer (TWD) and passing on the TW2 to them. The task of the TWD was to transform the specified problem, made up of the conditions of the site and the resources available, into a design solution matching the requirements of the design brief. The work of the TWD involved reading the literature on standards, working on calculations, or drafting the drawings and sketches by hand on drafting tables. In addition to this, the TWD had to generate method statements of how the structure was to be erected, and risk assessments on the most dangerous aspects of the erecting the construction.

Often, the work of the TWD involved calculating the stresses placed on an existing structure to see if it was strong enough to cope with the expected loads (including an adequate safety factor). Occasionally, the TWD would simply be asked to approve whether a certain plan should be allowed to go ahead, although more frequently, they needed to enter into complex discussions with the construction team to coax out their requirements more clearly. The work involved in generating structural designs also involved checking that the new designs matched the requirements of the other stakeholders.

Co-ordinating the design of temporary works structures between the expectations of the team and the understanding of the design problems by the TWD was conducted by the TWC, who acted as a go-between, conducting a ‘diplomatic’ service between the construction team and the temporary works designer. The work of co-ordination by the TWC often entailed long telephone calls between the site and the TWD, including the faxing of tables, sketches and preliminary drawings (shrunk with a photocopier) to the TWD. This was intended to improve the design of the temporary works, matching them to the specifications set by the team - implicit and explicit.

The design brief (TW2) generally represented the problems faced in a sketch form. This was often annotated, and followed by a brief (text) explanation describing the problem, the resources available to solve the problem, the constraints on the possible activities that they could perform, and when the design would be required. Communications between the TWC and TWD following this initial contact generally took the form of annotated sketches faxed between the TWC and teams. The preliminary designs involved the generation of engineering drawings or sketches, drafted out by hand and sent to the TWC. Graphical representations were crucial to the work of the TWD because they were typically the form of information that they initially received on the design problem. They also used them to communicate with, as well as the media that they worked on. Sketches were important in communication, because of the difficulty in verbally and textually communicating spatial information, or the relationships between objects. However, a problem with faxing sketches was that the quality was extremely variable, and blurring occasionally obscured features that had to be clarified in a further exchange.

Whilst the role of the temporary works co-ordinator was to improve communications between the designer and the construction team by mediating between them, there were also disadvantages. One of these disadvantages was that the TWC became another obstacle through which communication had to move, with the potential of slowing down the process and filtering out possibly valuable design related information.

The design work in this phase was highly organised and regulated: sketches and drawings were all given reference numbers and as they progressed from specification to verification, they underwent a rigorous process of checking and counter checking. At each stage of this process, the drawings were marked, either with a stamp (‘preliminary’, ‘for discussion’, ‘for inspection’, ‘for construction’), or with a signature to demonstrate that calculations on the aspects of safety tolerances for the drawings had been checked. Red ink was used on the stamp so that unauthorised copying would not result in ‘uncontrolled’ drawings (the duplication process resulting in all black copies) and meant that it was possible to tell which drawings were originals. This was important to the design processes, because amendments made to multiple copies of drawings were difficult to keep track of, and could potentially result in the construction of defective designs.

Stakeholder involvement

Temporary works design meetings, including the TWD, the TWC and the team leader, the site and senior team engineers were usually held on a two weekly bases to discuss the team’s response to the preliminary sketched out design ideas and drawings submitted by the TWD in response to the design brief. These meetings allowed the team members to make face-to-face contact with the TWD to match their understandings of the problem to the design solution reified in the drawing. In most meetings, heated exchanges were observed as the team challenged the TWDs understanding of the constraints imposed by the physical characteristics and available resources on the site. The TWC was required to act as a buffer in these cases due to the acrimonious and personal nature of some of these interactions, the construction team members complaining that the TWD has misunderstood their specifications, and the TWD claiming that he was not made aware of all aspects of the problem by the team in the design brief. Such meetings resulted in a set of minutes, detailing the comments made by the team and the TWD, written up by the TWC, and detailing the changes that needed to be made to the preliminary drawing, and additional information that the team had to make available to the TWD in order to make the required changes. These initial discussions would result in the creation of the second generation of (still preliminary) temporary works drawings. These were stamped with the words ‘for discussion’ and were not allowed to be used in construction.

Design meetings with the RE were held on a two weekly basis alternating with the temporary works design meeting. These involved the presentation of the drawings to the RE (those stamped ‘for discussion’). Occasionally, these meetings might result in the RE demanding changes to the drawings. Requests for redesign would involve a breakdown of the reasons for rejection, noted in the minutes and passed to the TWD. Meetings with the other stakeholders were also held on a monthly basis. The drawings also had to be ‘passed’ by the other stakeholders: the environmental agency was worried that chemicals would leak into the water table if certain construction techniques were not used, and they had the legal right to request change or even complete redesign of the temporary works drawings if there was a danger from pollution. The railway operating ORGANISATION was also worried that the temporary works over the railway lines would allow concrete or other materials to fall onto the lines causing an obstruction. The railway operator had ownership over the land affected and therefore had the right to demand changes in the temporary works designs if they felt that this was not being attended to. Following these consultations, and their resolution, alterations would be made to the drawings if necessary, and the would be stamped with ‘for inspection’.

In all cases of meetings, minutes would be taken by the TWC, placed in the project dayfile and circulated. All correspondence relating to the design from the construction team, the RE, suppliers, subcontractors and internal communications were also placed in the dayfile. The dayfile was forwarded to the TWD, so that they could become aware of the local circumstances surrounding the project. This was intended to make the agendas of the stakeholders more obvious to the designers who were physically distant from conditions on the site, so that implicit knowledge might be better understood by them.

The last part of the process through which the structural design drawings would have to pass involved a senior engineer who was independent from the design process. The independent engineer checked through the ‘for inspection’ drawings and calculations for accuracy and other potential difficulties. If no problems were discovered with them, the drawings were ‘signed-off’ with a signature on the drawing and passed on to the site document control office. The final output of the structural design phase in the design of temporary works was therefore a drawing, and marked with a ‘for construction’ stamp.

The final drawings were logged at the document control office, who entered them into the ‘drawing register’, a list of all drawings on the project. The document control office maintained the original copies of the drawings so that duplicates were not circulated. All of the drawings in current circulation to construction teams were noted, so that the people in possession a drawings could be contacted if amendments were made to them. Documentation relating to drawings amendments were held on computer, so that all of the correspondence from the dayfile relating to those drawings could be called up quickly[3].

The structural design phase therefore involved the collection of requirements from the construction team, the production of draft copies of a proposed design, checking that the requirements of the various parties involved were met, generating a final design for use in construction, and transmission of the drawing to the construction team.

[3] Although important in the design of the drawings, calculations were not generally sent out with the drawings to the site, because they were represented in the structure of the drawings themselves.

Whilst one person (the TWD) was involved physically transforming the temporary works problem into a design solution, the specifications and determination of constraints on the design itself was highly collaborative.

Other outputs from the structural design phase included ‘knowledge in the head’ of the team’s senior engineer about applying this information, derived through discussions with the TWC, TWD, RE and other stakeholders. This knowledge included information about the drawings that was not explicitly represented in the drawing, such as how best to lay the concrete: this could be done from side to side across the road, or lengthways, along the direction of the road, each of which had different loading characteristics. Other information was available in the method statements and risk analyses prepared by the TWD. These accompanied the drawings to the document control office and were logged onto the computer database so that they could be cross-referenced to the drawing. The method statements and risk analyses were distributed to the team with the drawings when requested.

A.3.4 Organisation of Site Activities

Once the temporary works drawings had been signed off and distributed, the construction team had to plan how they were to proceed with erecting the physical temporary works structures. The inputs to the process were essentially abstract representations of form, made up of lines representing structural forms. The T/W drawings were supported with material in the margins of the drawings summarising information about the design (such as amendments), and the method statements and risk assessments.

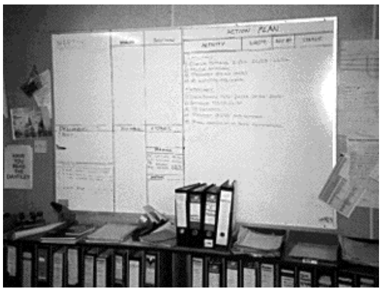
Other inputs to the phase consisted of the internalised knowledge of the senior engineer, along with the stage programme (the three monthly schedule of the team’s construction activities). This activity planning phase was not a trivial process of following instructions laid out by the TWD in the temporary works drawings, because construction resources had to be organised, including the ordering of materials and plant, breaking the drawings into activities that could be performed by the individual teams members, and determining the order of erecting the materials described in the drawings.

The organisation of the office was a major factor of how the engineers quantity surveyors and foremen interacted with one another, because it determined access to other people and the artefacts used in the co-ordination of work activities. Many of the activities that were planned had been performed before, and could simply be repeated, with minor alterations. When these activities had been performed by other people, this information was available either by asking other people in the office (it might even be volunteered by the person delegating the work), or through searching through the team's project filing archive. Project related information was contained in the many files scattered around the office and stored in files indexed by task and by date. Individuals also maintained their own files of activities that they had been involved with, which could provide information when they were not present in the office.

One of the mechanisms used by the senior engineer and team leader to allocate work and to inform the team members of planned site activities was through the use of a whiteboard (see photograph in fig. A.7.), on which several permanently marked out sections headings were written on it. The whiteboard provided a means of asynchronous, one to many, communication between the people in the office. Things written on the whiteboard allowed the workers in the office to see what the plans were and to write up comments on the board. In general it was written onto mostly by the team leader and senior engineer, and rarely by the others, who usually just read the details. Information on the board provided a means of making people aware of planning activities and things that had not yet occurred, and which might not be readily apparent from the other resources in the room, many of which only afforded awareness of things currently operating, or had already happened.

Meeting	Problem	Solution	Action Plan			
			Activity	Whom	Due By	Status
Deliveries	Bulk Material	Visitors				
Team Meetings		Training				
		Meetings				

fig. A.7. Photograph of whiteboard in construction team office.



The senior engineer initially worked alone on the drawings, allocating responsibilities amongst the site engineers, who in turn delegated tasks to the graduate engineers. It was important that certain tasks were completed in a particular order, so that for example, plant was moved before the bridge deck scaffolding was erected. If this was mis-engineered, large machinery could be trapped by the scaffolding until it was 'struck down' (removed by the scaffolders), resulting in increased hire costs, or delays to other areas of the construction. Attempts were made to determine the 'critical path' of the construction work, which involved planning the design areas that were central to completion of the project on schedule. Delays to these ‘critical’ areas would result in a slow-down of the construction work. Determining the critical path of the team’s activities was therefore seen as a vital component in the organisation of the team’s activity.

The physical state of the site, including the weather, soil structure, positions and form of the existing structures were a guiding feature on the possible ways that the resources could be organised to construct the temporary works. The context of the site therefore provided constraints to the types of operations that could be performed, limiting the possibilities for action. Organisational constraints also operated: for example, whilst the construction team worked on weekends, few subcontractors or suppliers did. This meant that activities requiring the participation of these groups had to occur on weekdays, and tasks had to be allocated so that some types of work did not fall onto weekends. The range of activities that could be planned was therefore limited, and whilst there might be many theoretical ways that structures might be erected, in practice, these were reduced by practical circumstances.

Information on the form of the structure derived from the drawings would be supplemented with information about when to build it from the stage programme. The stage programme was broken down into a weekly schedule by the senior engineer and team leader detailing the sequence of the activities to be performed by individuals. This schedule broke down the week ahead into activities, assigning responsibilities for actions to particular gangers and foremen. This was performed in advance of the team’s activities, but was regularly updated to incorporate changes arising from the delays and (occasional) activities performed ahead of schedule.

The weekly schedule was handed out and discussed with the team at the weekly team meetings, involving the team leader, engineers, quantity surveyors, foremen and gangers. These team meetings would begin with the team leader updating the team on how they were performing against the schedule on a long range forecast. Photocopies of this information would be handed around, and the team would be asked for comments and suggestions on improving performance. Foremen and gangers often made suggestions about how to allocate the labour to best perform the tasks assigned, and how problems with obtaining plant and materials might slow down construction. Alternatives were discussed and these noted by the team leader and senior engineer in their personal logbooks. Amended weekly schedules would be placed on people’s desks when suggestions were taken up and changes made.

Artefacts used in organising the activities on the site included sketches and tables, which were used to transform information from the drawings into simpler representations. The simpler representations were specific to particular forms of use, such as tables of locations on where to erect the temporary works materials. These were also shown to other people to help describe what was required more clearly than could be done using language or by showing them the original drawing. An example of this was the sketches used in erecting scaffolding which were handed out to the scaffolders by the engineers. These sketches showed only the positions of the scaffolding and the ways in which the struts were to be joined together; they did not carry information about loading weights or their eventual function, which was not important to the scaffolders. Another property of different representational forms was that they allowed a time dimension to be incorporated into the representation, such as tables of when work was to be performed, or more simply, through omission, in sketches that did not include design information that would be required at a later date.

For all of the construction activities planned, a detailed method statement had to be prepared describing the work procedures undertaken by the labour. This was performed by the site engineers for the features assigned to them by the senior engineer. In parallel to this, risk assessments of the dangers imposed by the method had to be generated. These determined where the work was potentially dangerous and was used to alter the method statements so that the risks would be minimised. For example, using ladders incurred a high risk of causing a fall as the ladder toppled; this could be minimised by either tying the top of the ladder to the structure, of by having another person manning the base of the ladder. These method statements and risk assessments were similar to those produced by the TWD, but were at a much lower level of detail (physical actions), whereas those generated by the TWD attended to more abstract levels of activity, such as designing structures minimising the need to climb ladders in the first place. The site engineers reported that the TWD's method and risk documents were used as a attention raising resource, because they showed where more work needed to be done. All method statements and risk assessments were filed for later use and legal reasons.

The outputs of the organisation of site activities phase resulted in the production of detailed instructions that would enable the co-ordination of resources necessary to build the temporary works structures. These included written (the weekly work schedule), sketched and verbal instructions of work to be performed by the labour. These were given to gangers and foremen in the team meetings and ad hoc meetings. Other forms of instruction re-represented information in the drawings into tables of measurement for construction (and subsequent checking), developed by the graduate and site engineers themselves from the drawings. Reminders of instructions about the procedures and other related information were written onto the whiteboard. The order of things which were to be performed, and by whom, were recorded on the weekly work schedule and distributed. The method statements produced by the site engineers were distributed to the gangers and foremen who would use them to direct the physical work of constructing the temporary works structures on the site during the construction phase.

A.3.5 Construction

The construction process took as its inputs the outputs from the previous section which was incorporated with the tradesmen, gangers and foremen's knowledge about general temporary works construction technique. The process was initiated by the graduate engineers, who took measurements with the geodometers and theodolites to ensure that the temporary works materials were placed in the correct locations; the foremen then took over and unless problems developed, the engineers were not involved in the construction phase from this point.

The initiation of subsequent activities was derived from the weekly work schedule, work being undertaken on the scheduled date (all else going to plan, which was not always the case). The engineer's and foremen's sketches and the method statements were used as guides in the erection of materials by the carpenters, who built the concrete moulds, and by the scaffolders, who erected the scaffolding towers around the bridge deck.

The foremen spent much of their time on the site visiting the areas of activity and making sure that the temporary works were being constructed according to the drawings. The gangers worked closely with the crafts people on the site and were able to manage the work on a moment-by-moment basis. The gangers and foremen used their radios so that they could ask each other questions, requisition materials, or locate people around the site. If problems developed on site, the gangers and foremen could radio the office to ask for assistance from engineers there, or they could drive their four wheel drive vehicles back to the office to engage in face-to-face meetings.

The distributed nature of the site made contacting individuals difficult. When people were not present to talk to directly, other media were used to communicate, either through the use of the radio link, through placing written notes, sketches, method statements or risk assessments on people's desks, or jotting notes onto the whiteboard. Messages were also left with people who were in the office for when the person came back. An example of how one such person-location was performed using a radio is shown below. Note how the participants recognise the problem and pre-empt a request for them to pass a message on:

```
Site engineer: <Radioing from site office to the site> '15 to 17. Come in.'

Foreman: 'What you want?'

Site engineer: 'Have you seen Florida Phil?'
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Foreman: 'Hello? Having trouble receiving you.'
Site engineer: <repeats slowly> 'Have you seen Florida Phil?'
Foreman: 'Nah mate. He was here earlier.'
Site engineer: 'OK then. See ya later.'
Foreman: 'I can get him to call you if I see him'
Site engineer: 'You do that. Ta mate.'
```

The outputs of the construction phase included the constructed temporary works structures, including features such as aerial walkways, concrete moulds, scaffolding for concrete mould supports and so on. To demonstrate that the work had been performed, the weekly work schedule was marked as 'completed' and handed to the senior engineer, who in turn informed the team leader. To make this more generally known by the team, the whiteboard was updated with this information.

A.3.6 Reporting

The reporting phase was essential to check that the designs had been implemented correctly, so that they were safe to use, and matched the contractual requirements of the client. This involved examining the built temporary works structures, and comparing them to the drawings. Various people and ORGANISATIONS were involved in this phase, and the work ranged from simple visual inspections of the work to precise measurements with geotechnical equipment. This redundancy of checking was important in ensuring that the design was constructed correctly - bridge failure, as well as being expensive to repair, could result in injury or death, and the penalties for such failure could be severe.

The team attempted to maintain strict controls on the construction of the temporary works because any discrepancies that were found after construction could result in remedial work having to be performed, which would be both costly and potentially damaging to ConsCo's reputation. The work performed by the team involved examining the temporary works structures being built and the methods used in constructing them. The engineers continuously checked work as it was being conducted, by taking measurements of the positions of the built structures (with geodometers and theodolites) and comparing these measurements to the expected dimensions of the temporary works designed forms. Rather than taking the complete sets of drawings onto the site, measurements were often taken from the drawings and turned into tables of figures which were easier to read and carry about on the site. Whilst the engineers were involved in this measuring process, they, along with the foremen, checked on the methods used by the crafts people, and compared these against the method statements prepared earlier. The gangers also used their prior experience of construction activities to check on the methods used.

In addition to the team themselves monitoring construction, the project contract between the resident engineer and ConsCo involved a formal aspect to the reporting process, in which the RE checked the structures to see that they had been constructed to the contractually specified level of quality. This was either performed by the clerk of works, who continuously patrolled the site, or by the assistant section RE who would be called on site to examine the more complex or critical aspects of work. As each structure was completed, the graduate engineers would have to ensure that a form was signed by the assistant section RE (known as 'clause 17s' and 'clause 38s'), agreeing that the work had been performed to the appropriate standard. This form was copied and sent to the RE, the site main office for inclusion into the dayfile; one copy was retained by the team.

Other ORGANISATIONS were also involved in checking operations on the site to ensure that the work did not disadvantageously impact upon their operational areas. The railway operating ORGANISATION needed to check that the structural work did not represent a hazard to their train services on the railway line, and the environmental ORGANISATION had to ensure that work did not result in environmental damage or pollution to the watercourses. In any instances of failure to follow previously agreed upon methods, they were able to demand a halt to work until the situation was resolved with a redesign or change to the construction process.

An example of such a problem observed in the fieldwork was observed that demonstrates the importance of following the designs, and where reporting on progress was a vital component of the construction work:

> On one occasion, the team's carpenters had run out of planks to build a supporting platform over the bridge. They did however, have thicker planks available. Rather than ask if these were usable, the craftsmen took the initiative, reasoning that the planks, being thicker, would be even safer than the originally designated materials, and they used these instead. However, this solution was not as simple as they had imagined: because the planks were thicker, they were also heavier, and placed a greater load on the structure. This was above its projected loading tolerance.
>
> When this was noticed in a routine check by staff from the railway operator, a formal complaint was made to the team leader, who decided to have the strain tolerances recalculated for the new materials. He communicated the complaint and the properties of the new material to the TWC; the TWC passed the problem on to the TWD, who calculated that the loading factor was dangerously high. This information was communicated back, and the structure had to taken down and rebuilt with different materials. This was heavily time-consuming, and because it fell across the critical path of the project, it delayed other aspects of the task and increased the overall expense of the construction work.

Whilst the drawings were used as the basis of activity, they were not usually compared directly with the built structures, except where the structure involved a simple visual comparison. Other representations than the drawings were used, including sketches and tables made by the engineers to take out onto site. These captured elements of the drawings, but meant that the whole drawing did not have to be taken with them because only the relevant information for a particular task was displayed on the artefact. An example of this can be seen in fig. A.5, where a graph of gradients was used so that distance could be plotted against height. Non-graphical representations were also used in checking and reporting activities: the works records (site 'diaries') were written by the engineers to document changes to the construction requested by the resident engineer, and on the completion of work activities, or as requests for further information about the design from the site office. These works records formed a valuable source of information about the current state of the site to the senior site management. The site records were placed in the project dayfile, making the information available to all personnel involved with project. The site manager also forwarded the site records to the people that they affected in the project. Here, there is a 'chain of representations', propagating a representation from the site to other people who needed to be made aware of the state of the site, but were not in direct contact with the construction team.

The outputs of the reporting phase included the forms filled out and signed by the assistant section RE (clauses 17 and 38). Other outputs existed in the heads of the engineers, containing information of the state of the temporary works structures at a particular time and whether or not they were built according to the designs or had inconsistencies. The end product of the reporting process was a 'pass' or 'fail'. If the temporary works structure passed inspection, no further work would have to be performed, but if a fail was recorded, adjustments would have to be made to the structure. In the rare event of the discovery of major problems, failure would result in the design being resubmitted to the TWD, and the structural design, organisation of activity and reporting phases repeated.

An output that the team was intended to produce were 'as built' drawings, representing the structures that had been constructed. These were to note the actual configurations of the temporary works, noting in particular where differences to designed structures had occurred (a common feature of construction being that structures would be erected differently to the design, due to local conditions, materials available, or through minor error). These were intended be generated through taking measurements on the site and applying them to the original, 'for construction' drawing, rather than through creating a new drawing from scratch. However, no instances of preparing as built drawings were observed, the reason stated was that time limitations made the task impossible to perform, and that it was only for internal use within ConsCo (and was therefore an unnecessary procedure, because there were no legal or contractual obligations to do so). This meant that following the completion of the construction project, the only information that would exist about the process of construction would be the original drawings, the completed structure, the records available in the dayfile and knowledge about the construction by the personnel involved.

A.4 Features of the design process

A.4.1 Intra and inter-ORGANISATIONAL activity

Inter-ORGANISATIONAL activity in ConsCo was highly complex involving multiple people and laborious co-ordination activity. Design related activity was not limited to a single commercial entity and involved a number of stakeholder groups. This could be observed in the example described in A.3.6, involving the team's carpenters working with different plank sizes to those originally specified, so that other stakeholder bodies became involved. This demonstrates the importance of examining the *activity*, or high level task, as a unit of analysis, and not just the ORGANISATION. The interactions within, and between the ORGANISATIONS involved in the design of temporary works are shown in fig. A.8.

fig. A.8. Inter and intra-ORGANISATIONAL interactions.

(Insert file: <diagram of constrn process> here).

A.4.2 Bi-directional movement of representations

The permanent works defined in the engineering designs for the construction site were largely pre-determined at the beginning of the project in the drawings generation by the Project Engineer, and in the tender application put forward by ConsCo. These contained the specifications on scheduling and building processes. However, not all of the details were pre-specified, and some design details were left to be determined at a later time.

Whilst the construction work stemmed *from* the drawings and schedule, in reality, design and project planning were also performed by the team at many levels. These included suggestions for changes to the high level design concept in the materials and processes of temporary works erection, down to the implementation details that were left unspecified, and interpreted 'on the ground' by team members. In effect, whilst the flow of communication was planned as a one way channel from the Project Engineer, broken down into more manageable and simpler components towards the labour force and construction work itself, feedback about the site, in the form of various kinds of representation, also had to flow back *up* the chain of command, from the construction workers, to the team's engineers and back to the Project Engineer, via the RE. Whilst movement of representations downwards towards the construction team was well specified by ConsCo's official procedures, the design related information circulating around the problems and conditions on the ground was less well specified.

Official procedures for the communication of information moving up the 'chain of command', from the implementors to the conceptual designers were arranged, involving meetings, but these were held relatively infrequently. Weekly internal team meetings were held, with other groups meeting on an even less regular basis (such as the inter-team, team-RE, team-environmental authority, and team-railway meetings). In addition to meetings, paper based forms were used to communicate construction problems around ConsCo and other ORGANISATIONS, and engineers were obliged to fill in 'works records', which were distributed with the dayfile. Most of these 'upward' communications were, however, informal, brief and opportunistically passed on using the resources closest to hand, on post-it notes, in telephone calls, or as verbal messages. It was the nature of these opportunistic communications that they were easily lost or misinterpreted: informants said that they forgot verbal messages; written notes were lost under other papers or passed on too late to be of use. Such communications were also potentially ambiguous: the informants noted that (indexical) terms such as 'it' or 'that' could be interpreted differently by conversationalists. Whilst these messages were quick to create, their information could be misused, demonstrating the fine line between the benefits of formality and the costs of an increased bureaucracy (Dahlbom and Mathiassen, 1993).

A.4.3 Patterns of communication

Whilst the flow of representations down the ORGANISATIONAL hierarchy, from the Project Engineer to the labour force, was relatively simple in terms of its structure, complications could occur which forced information to move back up the hierarchy. In order to solve problems that arose, agents had to first contact the person that they saw as appropriate and then communicate this to them, describing the salient features and why they were a problem. In a spatially dispersed team, such contact was hard to achieve. As a consequence, messages were often left with other team members to pass on, notes left on desks, radio requests sent out, or they might actively search out that person. Once contacted, the problem had to be described unambiguously. How this was done was dependent on the complexity of the problem, ranging from the sizes of planks to be used in concrete moulding, to more complex matters where the RE had requested information about the concrete loading on the bridge substructures. Depending on the circumstances - the complexity of the problem and the background knowledge of the participants - a few words might suffice; in other situations, a longer meeting, involving protracted speech and involving the use of artefacts - charts, graphs, schedules or drawings - might be required to resolve the situation.

Construction operations were co-ordinated by the constant stream of artefacts between the participants to the activity. The structure of the communications involved in co-ordination was partly made explicit in ConsCo's 'Construction Quality Plan' which specified how, or in what order, actions were to be performed. Not all of the events that occurred on the site could be predicted in this quality plan, and these had to be managed on a case by case basis, relying on the team members' experience of similar situations and what behaviour they believed to be appropriate in such situations. Many of these situations were not demanding, involving simple requests for information or confirmations of work performed. However, this difference in the two forms of information, ORGANISATIONALLY structured and those developed in an interactional, ongoing basis, is important in understanding how the design system processed the information it needed to perform work.

ORGANISATIONALLY structured communication of design representations typically involved artefacts being transmitted to and from the site office, in various forms, and to and from the RE. This involved the transfer of design documents from one party to another, using particular, pre-defined channels which determined who should make and receive the information. The permanent and temporary works drawings were particularly highly controlled to avoid the construction of out of date drawings, which would necessitate redesign of other parts of the project or demolition.

The socially mediated communications were harder to follow in the fieldwork because they did not usually persist in the environment for long as a permanent physical record. These typically were involved in co-ordinating the use of, and creation of, the ORGANISATIONALLY structured representations, involving spontaneous social interactions and the use of opportunistic resources, such as pen and paper ('back of an envelope') sketches, scribbled notes on scraps of paper, or verbal queries yelled out across the office.

A.4.4 Artefacts in the design process

The technologies for communication were numerous and diverse, including those explicitly recognised as communications technologies such as the telephone and fax, and those used as a means of communicating non-verbal information, such as the drawings and schedules. In addition to these methods of communication, the method statements, risk analyses, sketches, post-its, 'desk litter', speech (direct and overheard), the weekly work schedule, letters, works records (site instructions, site records and requests for information) and other paper based forms had to be completed in the course of work. All of these artefacts bore representations that could be communicated between the collaborating actors involved, allowing them to perform their own individual tasks as well as achieving the high level design goal.

The fieldwork demonstrates how the construction team stripped detail from the design artefacts, and added knowledge to these representations to create more succinct and modified representations. The new representations were better suited to their user's localised purposes. As these representations were propagated between people with different functions in the design process (determined by the division of labour), these artefacts assumed different purposes, and their representational status became altered. As representations were discarded or modified, their underlying informational content underwent change, and information processing occurred. At the end of a long chain of such transformations, the design representation had progressed from a definition of the problem into a solution for it.

A.4.5 The allocation of tasks

The organisation of activities in ConsCo was loosely knit, relying on a 'just in time' management ethos; in reality, informants said that this translated into a fire-fighting mentality, where design information was often described as being delivered 'just too late', leading to delays in the critical path and the project running over time. The remarkable feature of the building site however, was that it operated despite this general disorder and lack of forward planning. Long range forward planning was not always possible because it was often difficult to identify problems in advance, and because team members had little time with which to generate detailed activity plans. Most of the observed activities were arranged 'on the fly', emphasising the contingent nature of collaborative planning, and the ad hoc methods used to achieve this co-ordination. An example of one such situation observed is given:

```
<Scene: A site engineer is on the telephone, speaking to a remote person and discussing a concrete pour. Only this part of the telephone conversation could be monitored by the fieldworker>

Site engineer: <stands up and speaks loudly into telephone> 'So, what I'm asking is: should we put concrete into the tower?' <raises his head and looks at the senior engineer with raised eyebrows>

Senior engineer: 'Yes'.

<Site engineer, completes the telephone call, then lifts a radio to speak to a foreman to give the go ahead. A graduate engineer overhears this:>

Graduate engineer: <orients towards senior engineer> 'Do you have any spare...<pause>...can I have three cubic metres?'.

Senior engineer: <Pauses. Looks at ceiling. Pushes tongue into side of mouth. Pauses. Looks at graduate engineer> 'OK. Yeah.'

<Site engineer overhears this and radios through to the foreman to arrange it>.
```

In this observation, the potential to overhear telephone conversations (because of the open plan office space) is used by the site engineer as a means of asking the senior engineer if he can go ahead with construction. This was not pre-planned, but arose from a request for information arising from a distant third party. A graduate engineer, in turn, over hears this, and makes a request for materials, which was organised by the site engineer. None of this was prepared in advance, and the tasks were fluidly discussed and finalised as the participants were made aware of on-going activities around them, which they used to initiate and direct their own work.

Whilst allowing a high degree of autonomous freedom in behaviour, ConsCo operated within a central organisational framework that allowed the participants an understanding of the responsibilities and roles that each was expected to perform. Knowledge about how to operate within this framework was distributed across the Contract Quality Plan, the experience of the participants, and in the structure of the artefacts used in the construction process. These were often weaved together, where, for example, the quality plan would be used as a resource by an engineer who knew that under specific conditions, a particular procedure had to be followed. On following this procedure, an artefact would be created using the information from another artefact, whilst also drawing from their personal knowledge of the site. The structure of the created artefact would then determine how it would be used in the next stage in the design process - if it was paper based, it would have to be passed on physically, and would either require an accompanying letter explaining its purpose, or would be transmitted by hand. This was likely to result in conversation between the carrier of the representation and the recipient, explaining the reason for the document and might develop into a more general discussion covering other aspects of the construction work.

An example of this knowledge distribution occurred when a graduate engineer was asked to check on the particular characteristics of a concrete mould (known as "shuttering") by the clerk of works:

> According to the Contract Quality Plan, queries raised by the RE or their staff should involve recording the problem, finding the answer, and filling out a 'works record', which would be sent to the site office, placed in the dayfile, and a copy sent on to the RE.
>
> Accordingly, the graduate engineer filled out a works record form with the problem request and sketched a diagram of the concrete shuttering and the setting it was placed in. He telephoned <someone> off-site, and discovered that the information he needed about using the shuttering was in the advertising/promotional leaflet sent out by the shuttering company, and was held on file in the team office.
>
> The information was lying on one of the foremen's desks, who had been looking through it with an eye to ordering more materials. The engineer read off the technical details from a table on the leaflet and added this information to the form.
>
> The engineer then posted the works record to the site office for inclusion into the dayfile for circulation. As a works record, no accompanying information was required because the form of the document meant that it would always be processed in the same way. Due to the slow speed of the internal postal service, the engineer later went back on site, located the clerk of works and reported his findings personally.

In this case, knowledge distribution occurred over the participants involved (graduate engineer, unknown telephone informer, foreman, clerk of works, and RE), and artefacts (the work record, dayfile, sketch, leaflet). This involved the use of different channels of communication (spoken, postal, and telephoned), each with different qualities for the transmission of the information. The ORGANISATIONAL structure (in the Contract Quality Plan) determined who had responsibility for various features of work. However, the work itself was performed through social and contextual mechanisms, with the ORGANISATIONAL structure functioning as an (incomplete) resource for the allocation of work, rather than an absolute rule set.

A.5 Summary of Fieldwork

The design process was described as involving a cycle, incorporating data collection (an ongoing process), framing of the problem (through creating a set of specifications), solving the problem (in abstract terms), organising a means of activating the (abstract) solution, then implementing the design in a physical construction. Much of the work appeared to involve the setting of specifications and unearthing of constraints to discover the boundaries of the design space. The final phase of design appeared involved reporting on the outcome of the implementation (success or failure in matching the designed solution to the design problem, within the specifications and constraints), which was possible to utilise in the next cycle of design in the information gathering phase.

Work was distributed over the collaborating designers through a variety of means through which the task was decomposed. This involved the breakdown of the task into smaller and smaller sub-problems that could be resolved through simple design solutions, for example bracing beams with struts, to achieve an adequate load bearing strength. However, task decomposition necessitated bringing these component parts back together again in a coherent structure to meet the high level design specifications; for the example above, this might mean ensuring that these beams did not obstruct access to other areas of work.

The technical work performed by the engineering designers at both of the projects studied (see also Appendix B) involved similar patterns of activities. Both studies demonstrate how the physical environment and social organisation are major determinants of the actions performed in design. A central feature of design involved the use of artefacts of many kinds, in the use of drawings, but also other artefacts that represented non-spatial and more transitory forms of information.

The design artefacts were generated by re-representing information from the site, or from other artefacts themselves generated elsewhere in the design process. They included a number of different representational forms, including text and speech as well as diagrammatic and tabular forms.

Maintaining control over the processes of engineering design was an integral part of the engineering design process observed in the fieldwork. Control of the design artefacts was deemed to be of critical importance in this management of the design process. Only controlled representations were allowed an ‘official’ status in design work, although in practice the design workers predominantly used unregulated representations in the day to day operation of their work.