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# Span of control in supervision of rail track work

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## Abstract

The supervision of engineering work on the railways has received relatively little examination despite being both safety-critical in its own right and having wider implications for the successful running of the railways. The present paper is concerned with understanding the factors that make different engineering works perceived as easier or harder to manage. We describe an approach building on notions of 'span of control', through which we developed the TOECAP inventory (Team, Organisation, Environment, Communication, Activity and Personal). This tool was validated through both interviews and questionnaires. As well as identifying the physical factors involved, the work also emphasised the importance of collaborative and attitudinal factors. We conclude by discussing limitations of the present work and future directions for development.

Keywords: Span of control, Rail Human Factors, Workload, Management Science.

# 1. Introduction

A major activity in operating a rail network is to inspect, maintain and upgrade its infrastructure as required, an activity that typically requires tightly controlling a stretch of line (establishing an 'engineering possession') while work is carried out. It is difficult to overstate the sheer scale of this work: between 2002 and 2008 Network Rail in the UK renewed rails on 1,614 km of track, sleepers on 4,468 km of track, ballast on 4,647 km of track and 2,627 switches and crossing units (Network Rail, 2011), with such figures predicted to rise in response to the demand for greater utilisation of the rail network for both passenger and freight journeys. Efficient and safe engineering possessions are therefore vital to the running of the railway and must be planned, managed and supervised as carefully as possible.

Research dealing with the workload in rail operations, and the development of tools to measure and predict it, has mainly concentrated on signalling and train driving (Mitchell et al., 2005; Pickup et al., 2005a; Pickup et al., 2005b; Pickup et al., 2005c; Wilson et al., 2001; Wilson et al., 2005). However, recent studies have identified concerns with the work stresses, pressures and load felt by staff involved in the planning, management and execution of engineering works (Ryan et al., 2007, Farrington-Darby et al., 2005), particularly important because the behaviour and performance of track workers can impact not only on their own safety but that of the whole network, drivers, staff and passengers alike (Wilson & Norris, 2006). While some research has focussed on various performance and safety aspects of rail engineering and maintenance (den Hertog et al., 2005; Golightly et al., 2013; Schock et al., 2010; Wilson et al., 2009) little has been done to directly examine  measuring and predicting the loads and stressors affecting track staff.

The work reported here identified and assessed the factors which impact upon the management of engineering possessions, and particularly on the Engineering Supervisor (ES). The methodology employed was based on the notion of 'span of control' which led to the identification of factors that could be rated in terms of their contribution to perceived difficulty in the management of engineering work. These factors was then used to develop an inventory tool called TOECAP (based upon and named for constituent top level factor groups of Team, Organisation, Environment, Communications, Activity, Personal) which was evaluated both qualitatively and quantitatively. The paper starts by describing how engineering possessions and rail maintenance occur in the UK, and then some background on span of control is explored. The methods used to develop TOECAP are described in the following section, and then those used to test its validity. Results are presented referring to the validity of TOECAP and the wider understanding the role of the Engineering Supervisor in rail possessions.

# 2. Background

## 2.1. Engineering possessions and worksites

When workers go out onto the railway they are required to do so under strictly controlled conditions. From small teams carrying out day-to-day maintenance of the track or routine inspections to large-scale renewals teams, this work has to be carefully planned and scheduled (Schock et al., 2010), often planned as *engineering possessions*, giving workers access to the track without the presence of passenger or freight traffic. Within a possession are worksites, within each worksite are located work groups, each work group usually being a gang of maintenance workers carrying out a specific task. A simple possession may be just a few hundred meters long, only

having one worksite and one work group carrying out a simple maintenance task, but a large complex possession could be several miles in length and include multiple worksites containing upwards of 50 work groups carrying out a vast array of different renewal and maintenance tasks. Possessions also vary widely in duration, with some spanning a few hours over night and others lasting several days.

Physically, within a standard possession on the British railway, workers are protected at both ends of the designated area by red signals and physical demarcations in the form of possession limit boards and often detonators, providing auditory warning should a vehicle move over them (see Figure 1).

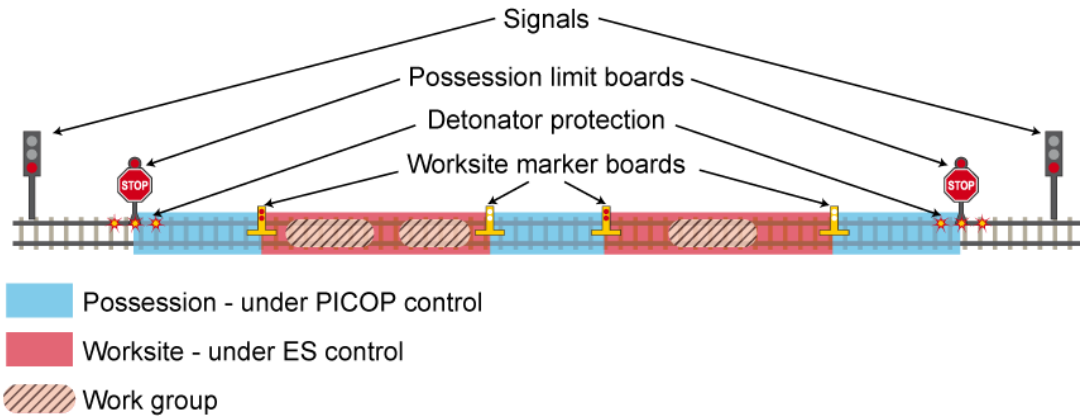


*Figure 1. A schematic diagram of the protection measures in a typical engineering possession.*

Whilst there are a variety of types of possession and protection, the key roles commonly involved are: Signaller, PICOP (Person In Charge Of Possession), Engineering Supervisor (ES) and COSS[1] (Controller of Site Safety). Figure 2 shows

[1] Subsequent to the completion of the present work, the role of the COSS is currently under review by Network Rail, see: https://www.safety.networkrail.co.uk/On-site-Solutions/Planning-and-Delivering-Safe-Work.

how this forms a hierarchical management structure and how those structures relate to the physical space of possession.

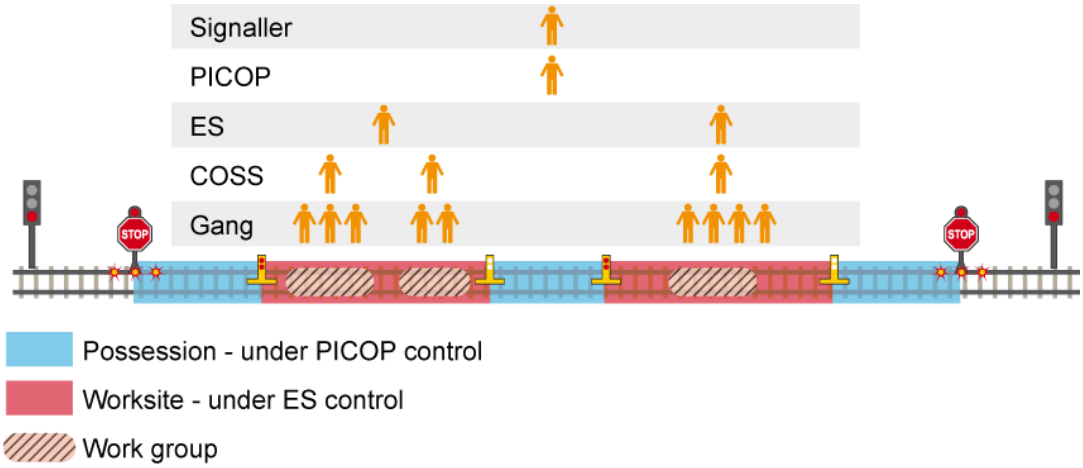


*Figure 2. The relationship between the physical space of possession and the hierarchical organisational structure of maintenance teams.*

The signaller for that area of track will confirm with the PICOP when the last train has left the possession area and when the relevant signals are red so the area is safe. At that point, the PICOP will arrange for the possession limit boards and protection to be placed. Once this is done the PICOP will confirm that the ESs can set up their worksites and begin the process of signing in COSSs, each of whom will be associated with a work group or machine and usually a gang of track workers. This is a simplified version of a standard maintenance possession and does not fully represent all the possible permutations but the tasks required of an ES are defined in the RSSB (Rail Safety and Standards Board) Rule Book - Handbook 12 (GE/RT8000/HB12), a brief synopsis being:

- Setting up the worksite, including contacting the PICOP to confirm exact positioning and limits of the worksite.
- Arranging the placement of marker boards at the end of the agreed worksite and confirming the completion of this with the PICOP.
- Briefing and signing-in the COSS for each work group and any individual working alone (IWA), agreeing what work they will be doing and where this work will take place.
- Confirming with the PICOP any arrangements for work and train movements around level crossings in the worksite.
- Authorising train movements within the worksite and recording the details of that movement.
- Liaising with the PICOP to organise train and plant movements in and out of the worksite.
- Giving up the worksite at the end of the possession ensuring the track is fit for the passage of trains.

The Rule Book also states that to perform in the role, the individual must hold a valid ES certificate of competence. This means that any track worker can perform the ES role provided they have been certified (and that certification is up-to-date). In summary, the ES role in any given specific setting is dependent on a number of factors, including the type of activity occurring, the size of the worksite and complexity of the track, the amount and type of machinery being used and the duration of the work (Ryan et al., 2007).

Management of engineering works are challenging for myriad reasons (see Golightly et al., 2013). Arrangements can be complex and include a range of issues subsidiary to the actual track work (e.g., checking and maintaining electrical isolation

and site access). Management of engineering works are of sustained complexity throughout their life cycle, from initial planning, through to short-term replanning when underway through to managing safe hand-back of the line. Thus, there is a requirement for a way of structuring the understanding the complexities of work of this type.

## 2.2. Span of control

Span of control has also been referred to as span of command, span of management, span of responsibility and span of authority, but generally equates to the extent of supervisory capability (Meyer, 2008). Early investigations into span of control (e.g., Graicunas, 1937) sought an optimal management structure/strategy that would lead to the highest level of control and coordination over subordinates with initial estimates being behaviourally based in terms of the typical memory or attention span of a manager. Various simple metrics and ratios were developed to quantify the relationship between the number of employees and managers or between the number of size of teams and the manager's available time. However, as this research agenda developed it became widely recognised that the 'optimum span of control' would not have one value defined by the unchanging human characteristics of managers but rather would vary with the nature of the activities and types of employees being managed (Kootz, O'Donnel & Weilhrich, 1980).

Span of control appears to have declined somewhat as a topic of research interest in management studies proper, most probably because of a general move to 'collapsing' management structures to make them more 'horizontal' rather than seeking out optimal ways to structure hierarchies. In recent years however there has been something of a resurgence of interest in the concept in specific domains such as

healthcare, possibly because these are areas where formerly procedure-based work has given way to far more diverse types of activity as healthcare technology has developed, professions like nursing have become more recognised as diverse and skilled and managerial restructuring has also placed pressures on pre-existing structures (e.g., Cathcart, et al., 2004; Doran et al., 2004; McCutcheon et al., 2009; Meyer, 2008; New, 2009; Wong et al., 2009)

The modern way to view Span of control is therefore not in terms of trying to design the 'perfect organisation' once and for all, but in using the concept to understand under which circumstances work is easier and harder to manage and to answer questions concerning the nature of a managerial role, what kinds of support are required, how many lines of report a manager can handle and how much time a manager can spend on supervision (Meyer, 2008). It may be the case for example that a team that can be easily managed in normal circumstances may become far more challenging to oversee when moved to a different site, given different tasks to do or perhaps working under unusual forms of disruption. Therefore, given the nature of rail maintenance as described earlier and its diverse nature, we took the view the concept could also be useful, if tailored somewhat, to the rail domain.

The starting assumption for our work was that the factors impacting performance for an Engineering Supervisor might be broadly mapped to those that are shown to affect span of control during army operations (Wenzel & Christ, 1993, Ford et al., 1998). Both scenarios of work involve teams working in a planned, goal-directed manner outdoors. The framework developed by Wenzel & Christ (1993) was therefore used as an initial template for the TOECAP inventory. There are six factors that Wenzel & Christ (1993) suggest influence span of control: Tradition (in this instance referring to organisational conventions), Environmental Uncertainty,

Technology, Subordinate's Task Characteristics, Leadership Behaviour and Leader's Workload, though with the caveat that these factors are not "*exhaustive nor mutually exclusive"*(p.887). Meyer (2008), reviewing span of control concepts in the healthcare literature, identified a list of factors believed to contribute to span of control in the healthcare field. These factors are split into six categories, namely: Region (inc. local policies, cultures and structures), Organization (inc. size, stage of development, degree of decentralisation of support services), Manager (inc. leadership skills, scope of role, experience), Work Group (inc. delivery model, team size, distance/location, task interdependence) , Employee (education, experience, stability) and Healthcare Consumers (acuity, care, complexity). Given the fundamental differences between the fields of study, Meyer's (2008) list bears striking similarities to that of Wenzel & Christ's (1993), albeit there are slightly different groupings of sub-factors. Both are concerned with the organisation, the individual leaders and their teams, and the features specific to the environment of work.

# 3. Investigating factors for span of control in the rail maintenance domain

The approach taken was to first investigate key constructs in span of control in managing possessions and worksites. We began with initial familiarisation interviews and then progressed through to more focused Subject Matter Expert interviews and the administration of a questionnaire to verify the inventory.

## 3.1 Development of Initial Rail Factors

In order to gain an initial understanding of the ES role, four formal interviews (two initial familiarisation meetings and two validation follow-ups) supplemented with less

formal open discussions held with members of the Network Rail Ergonomics Team where two of the authors were 'embedded' throughout the data collection phase. Following this, an interview with a senior maintenance manager at Network Rail, who had recently investigated a serious on-track incident, was conducted. The knowledge gained from these familiarisation interviews, as well as reviews of incident reports and existing literature in this area, were used to adapt the factors proposed by Ford et al. (1998) into a set of Initial Rail Factors. The only initial change in categories was to rename 'unit continuity' as 'team history' to fit better with the language of British industries. Then a list of factors specific to the role of ES was developed from these categories; this initial rail factors list can be seen in Figure 3. The intent of this phase was to build on the work of Ford et al. (1998) by taking their military-specific items and converting them into both more generic and railway-oriented items to use as a basis for discussion with a view to then adding detail specific to the ES role and the rail maintenance setting. This intermediate step was carried out as it has been our experience in past work that some effort towards domain-specific language counts for a lot in terms of engaging informants and persuading them of the relevance of the work.

| Wenzel & Christ (1993) | Ford et al. (1998) | "Initial Rail Factors" | TOECAP Factors |
|---|---|---|---|
| **n/a (no category)** | **External organisations**<br>· Military commands outside normal channels<br>· Government organisations<br>· Non-government organisations | **External organisations**<br>· Machine/train drivers<br>· Contractors<br>· Other NR Teams | **Team**<br>· Attitude of others in the worksite<br>· Respect amongst workers in the worksite<br>· Confidence the ES has in others in the worksite<br>· Familiarity amongst the workers in the worksite<br>· Pressure from others to perform |
| **Tradition** | **Unit continuity**<br>· Members experience with organisational structure<br>· Members experience with operation procedures | **Team history**<br>· Experience<br>· Familiarity amongst team | |

| | | | |
|---|---|---|---|
| | · Shared experience amongst team<br>· Experience with similar mission | | |
| | **Organisational structure**<br>· Number of units controlled<br>· Types of units<br>· Composition of units<br>· Structure of staff | **Organisational structure**<br>· Volume of communications<br>· Pressure from management<br>· Planning and briefing<br>· Size of teams<br>· Consistency of language | **Organisation**<br>· Quality of planning and briefings<br>· Quality of training, mentoring and assessment<br>· Performing other roles as well as ES (e.g., PICOP)<br>· Shift patterns<br>· Amount of paperwork required of the ES<br>· Changes to planning/access documents<br>· Accuracy and availability of track diagrams |
| **Environmental uncertainty** | **Complexity of environment**<br>· Mission, enemy terrain, troop and time factors<br>· Ambiguities<br>· Constraints | **Environment**<br>· Day/Night<br>· Weather and temperature | **Environment**<br>· Physical length of the worksite<br>· Number of rail lines in the worksite<br>· Number of level crossings in the worksite<br>· Other features of the worksite (e.g., tunnels)<br>· Weather conditions<br>· Quality of light available (e.g., day/night or lamps) |
| **Technology** | **Technology**<br>· Communications equipment<br>· Tactical command and control systems | **Technology**<br>· Communications<br>· Equipment and machinery | **Communications**<br>· Clarity of communications to and from the ES<br>· Communication technology availability<br>· Amount of unnecessary communications<br>· Consistency of language used (e.g., use of head-codes) |
| **Subordinate's task characteristics** | **Task characteristics**<br>· Mission essential tasks<br>· Amount of coordination between units<br>· Specialised knowledge required | **Task characteristics**<br>· Time span<br>· Size of worksite<br>· Type of tasks<br>· Number of tasks<br>· Complexity of tasks<br>· Level of protection<br>· Number of train movements | **Activity**<br>· Type of activity/activities in worksite<br>· Number of different activities in worksite<br>· Amount of vehicle movement within/through worksite (including trains, machines etc.) |

| | | | |
|---|---|---|---|
| | | | · Train movement on open lines near worksite<br>· Number of COSSs in worksite<br>· Time pressure during the possession<br>· Total time span of the possession<br>· Extra work emerging during the possession (e.g., broken rail discovered, access work)<br>· Total number of people in the worksite |
| **Leadership behaviour**<br><br>**Leader's workload** | **Individual characteristics**<br>· Commanders training and experience<br>· Training and experience of subordinate officers<br>Quality of staff<br>· Leader traits of commander and subordinates | **Individual characteristics**<br>· Experience<br>· Leadership skills | **Personal**<br>· Number of years the ES has worked in the role (or in related roles)<br>· How frequently the ES performs the role<br>· Local knowledge the ES holds of the worksite<br>· Communications skills of the ES<br>· Attitude of the ES |

*Figure 3. The migration from Span of Control factors from Wenzel & Christ (1993) to Ford et al. (1998) through "Initial Rail Factors" and the final TOECAP factors.*

## 3.2 Development of the TOECAP inventory

To further develop the factor list, Network Rail and University of Nottingham Subject Matter Experts (SMEs hereafter) were consulted. Interviews took place in two stages, the first being two open interviews with Network Rail Ergonomics Team members discussing understanding of the human factors of rail maintenance and engineering and possible approaches to the measurement of span of control and task loading. The Initial Rail Factors list (see third column, Figure 3) was also discussed in detail, such that the list of factors was reviewed and edited and an interview structure for the research phase was developed.

The second stage of the Subject Matter Expert interviews acted as a pilot for the proposed interview structure, completed with two more SMEs chosen for their direct experience of the ES role. The interview started with open questions like *"What do you feel affects your performance as an ES?"* and *"When have you felt at your limit?"* (Full list given in Appendix A). Secondly, the respondents were shown the Initial Rail Factors list and asked to discuss each factor in turn and rate each on a summated scale of 1 to 5, 1 being low or no impact and 5 being high impact (Preece et al., 2007; Robson, 2011). The interviews were semi-structured and designed to be discursive (Schober & Conrad,1997), they led to significant alterations of the factors list.

Figure 3 shows the migration from Ford et al.'s (1998) categories to the final list of factors in the TOECAP inventory. The name TOECAP was derived from the initial letters of the six factor categories, Team, Organisation, Environment, Communication, Activity and Personal. The development process then can be understood as taking Ford et al.'s military domain-specific list, rendering it generic provide cues for discussion with the rail industry, and then using that input to re-specify in detail once more for the rail maintenance domain. Changes were generally made on the basis of fit with the distinctive features of the rail setting or effective operationalisation of concepts that would make the tool easier to use where an obvious or more specific indicator existed to replace a more generic idea. For example, it was felt that there were different types of experience that were relevant; how long a person had been an ES, how frequently they fulfilled that role (engineering managers may undertake a range of different roles across different projects and were not necessarily ESs on a regular basis despite having a long-standing qualification to do so) and specific experience as it applies to local

knowledge of a given line or area on the network. The latter is particularly important in the British railway system as it has had a long and complicated history leading to different lines sometimes having distinctive (and perhaps undocumented) practices or legacy engineering features. Similarly, issues of team experience/continuity became "familiarity amongst workers in the worksite" in recognition of the fact that while in the military setting, continuity is very much a feature of military organisation (e.g., regiment and unit tradition and organisation), in the rail setting teams are more likely to be reconstituted as required from the project to project. None the less, it would not be untypical for workers to have carried out prior projects with different subsets of their present team leading to a shared cultural and personal understanding throughout the team and thus the item was adjusted to better reflect the reality of the situation.

## 4. Initial validation of the TOECAP inventory

In order to validate and refine the TOECAP tool, ten expert participants were found by approaching maintenance managers within Network Rail; all were employed in one of four maintenance depots: Newport, Cardiff, Aber or Westbury. Each of the participants had been working on the railway for at least 7 years with the longest serving for 36 years and a mean of 19 years. All respondents held the required qualification to work as an ES but performed the role with varying regularity.

Each session involved asking the participant to complete the TOECAP inventory, rating the impact on ES performance of each item from 1 (lowest level of importance) to 5 (highest level of importance) followed by an interview (initially guided by the items in Appendix A) and a discussion of the factors. The intention was to assess the fit between scores given and how prominent these factors were in more

open discussion of the ES role. At the beginning of each session the participants were asked to read and sign a consent form as the interviews were to be recorded; one participant, whilst agreeing verbally to be interviewed, did not want to be recorded and so data collected from this interview are not included in the template analysis. The participant was happy to rate the TOECAP list and so these data were included. The interviews took the form described in Appendix A together with a guided discussion of the TOECAP inventory itself.

The interview recordings were transcribed and analysed for themes. As a list of factors had already been defined, we took an analytical approach known as 'template analysis', a method falling between content analysis and grounded theory (King, 1998). This approach allowed the researcher to code the data using the TOECAP list as a framework with a flexibility to add new codes if necessary. Examples are given in Table 1.

*Table 1. Examples of template analysis coding.*

| **Category** | **Factors** | **Example of coded chunk (Interviewee)** |
|---|---|---|
| Team | Team | "You need to delegate the roles" (001) |
| | Attitude of others in the worksite | "You can't make everybody happy. Someone's going to have an attitude" (004) |
| | Respect amongst the workers in the worksite | "It is important. Not taking people for granted" (007) |
| | Confidence the ES has in others in the worksite | "It's definitely easier when you know someone and what they're capable of" (006) |
| | Familiarity amongst the workers in the worksite | "It's better if you know who you're dealing with" |
| | Pressure from others to perform | "If it happened and someone didn't want to be there then it would be a big factor" (007) |
| Organisational | Organisational | "Switches were 5 inches shorter on delivery and I found out it was a bit of a mishap from our technical team" (001) |

| | | |
|---|---|---|
| | Quality of planning and briefings | "The planning stages are crucial, I suppose, to the smooth running of it." (005) |
| | Quality of training, mentoring and assessment for the ES role | "It's important to be trained at a high level too and not to cut corners" (001) |
| | Performing other roles as well as ES (e.g. PICOP) | "In my opinion, an ES should just do his ES duties and that's it" (004) |
| | Shift patterns | "Sometimes it's easier, I think, to work nights" (001) |
| | Amount of paperwork required | "ES is worse than PICOP with all the paperwork they have to do" (003) |
| | Changes to planning/access documents | "I could fill them all out and things could have changed when I come back in and I'd have to do it all again" (003) |
| | Accuracy and availability of track diagrams | "You need them, I wouldn't go too far without that." (008) |
| Environmental | Environment | "Yeah it's easier because you can gain access at certain locations." (001) |
| | Physical length of the worksite | "It is more difficult because it's the logistics, depending on the size of your worksite, everyone's got to come to you first and come back to you, you need to be available for those people" (009) |
| | Number of lines in the worksite | "If you've got a single line and its blocked and it's blocked there and there, that's quite simple" (010) |
| | Number of level crossings in the worksite | "There are more people to brief as it goes along . There's a different man at each one" (007) |
| | Other features in the worksite (e.g. tunnels, viaducts etc) | "One of the main things for us is the new axel counters" (006) |
| | Weather conditions | "Nobody likes working in the rain - it can cut visibility" (005) |
| | Quality of light available (e.g. daylight or lamps) | "I'd rather do it at night as long as it's well lit." (005) |
| Communication | Communication | "The phone doesn't stop ringing, you can't do anything else" (006) |
| | Clarity of communications to and from the ES | "Making it clear, people understand, repeat it back to you, it's very important" (004) |

| | | |
|---|---|---|
| | Communication technology availability | "The communication is the worst thing, sometimes you've got areas where you've got no phone signals" (004) |
| | Amount of unnecessary communications during the possession | "There can be a large amount of unnecessary ones, especially if you're going to over-run and that can have a huge effect" (008) |
| | Consistency of language used (e.g. use of head-codes) | "It's important, most issues that arise are through communication problems" (009) |
| Activity | Activity | "If it's got to come out, it's got to come out" (001) |
| | Type of activity/activities in your worksite | "It depends on what you've got in the worksite and why you're in there" (004) |
| | Number of different activities in your worksite | "As an ES if you're on your own little job and you're on that site and it's not spread out over a long distance, it's very easy to do" (006) |
| | Amount of vehicle movement within/through your worksite | "You've got to be switched on about movements and that. You've got to think a bit more" (004) |
| | Train movement on open lines near the worksite | "Sometimes it takes a lot of time and effort to put a fence up when you're on a moving site." (001) |
| | Number of COSSs in the worksite | "More people to sign in, more people to brief, more people to check on" (007) |
| | Time pressure during the possession | "You don't want to overrun because people will want to know" (007) |
| | Total time span of the possession | "Obviously, the shorter possessions, you've got to be on the ball" (005) |
| | Extra work emerging during the possession | "If a weld goes wrong, for arguments sake, they've had a runout, that's beyond an ESs powers" (010) |
| | Total number of people in the worksite | "The more people the more work so there's generally a bit more pressure." (007) |
| Personal | Personal | "I enjoy a lot of the work out on the ground" (001) |
| | Number of years the ES has worked in the role | "Guys who've been around a long time aren't necessarily better than new ones" (004) |
| | How frequently the ES performs the role | "You just kept sitting the assessment in the line every 18 months but have not done it, |

| | | |
|---|---|---|
| | | that wouldn't be acceptable. You need some work experience" (009) |
| | Local knowledge the ES holds of his worksite | "It'd be pretty silly to be put in charge of a job when you don't know the track layout" (007) |
| | Communication skills of the ES | "Yeah, especially on the radio, over and out and all that" (003) |
| | Attitude of the ES | "You've got to have the correct attitude" (010) |
| Miscellaneous | Contractors (Non-NR staff) | "Contractors might phone and ask "where's the nearest place for this" and you know he hasn't been here before" (007) |
| | Fear of or pressure from senior management | "The ramifications, you know the come backs from it. People are on your back straight away" (005) |
| | Possessions not locally managed | "If NDS is taken from us and we have to go back to doing the PICOPing of our possessions. We'd be not to geared up for it then" (001) |

## 4.1. TOECAP factor rating results

The ratings given to each item are shown below in Figure 4, The highest rated factors were (in order): confidence the ES has in others in the worksite ($1^{st}$=), local knowledge of the worksite ($1^{st}$=), quality of planning and briefings ($3^{rd}$), communication skills of the ES ($4^{th}$), familiarity amongst workers ($5^{th}$=), clarity of communications ($5^{th}$=)

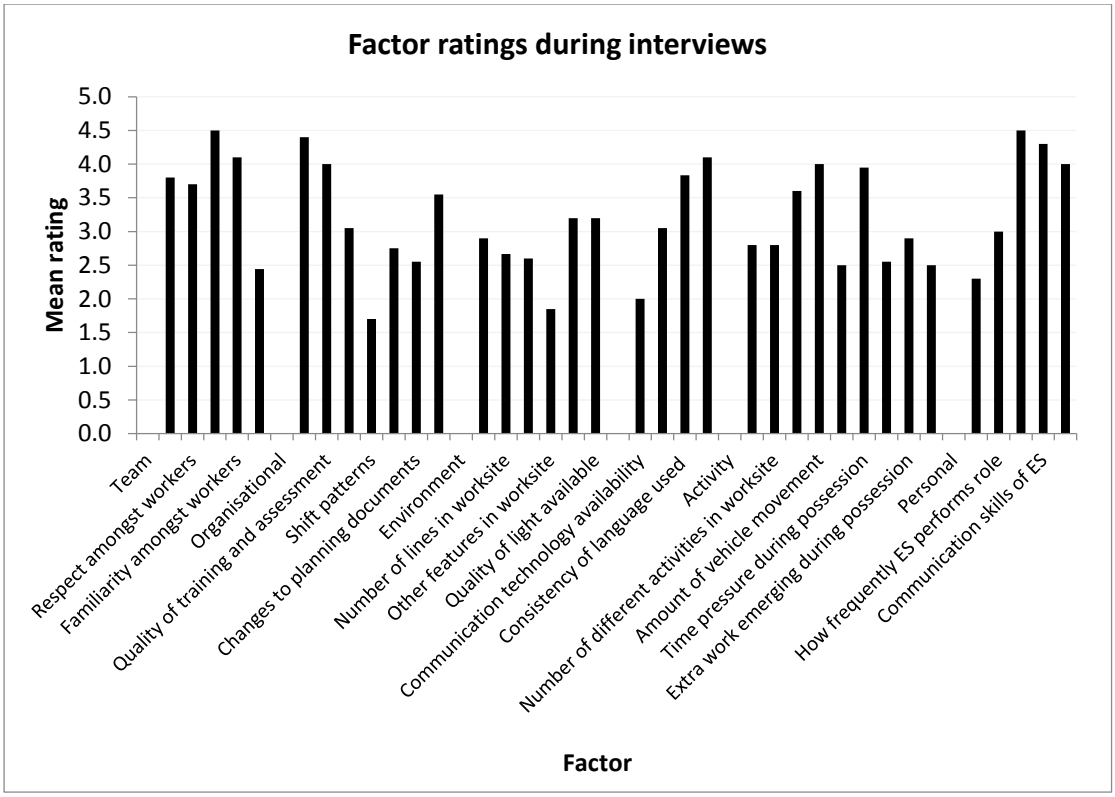


*Figure 4. Mean interview factor ratings from the interviews.*

## 4.2. TOECAP interview results

In the analysis of the transcripts, the researcher coded sentences and phrases (chunks) in which a factor was mentioned in association with participants' experience of the ES role, initially cued with the items in Appendix A. However, if a participant referred to a factor in a dismissive way, such as *"Taking on other roles isn't really a big deal"* (Interviewee 001), this chunk was not coded. In total 831 chunks were identified with 751 (90.3%) of those chucks falling within the original factors list. A further 46 chunks, while not relating directly to one of the original factors could be assigned to one of the categories. Just three other categories were added during the template analysis; contractors (non-Network Rail staff), managerial pressure, and possessions not locally managed. In total there were 34 chunks coded to these additional

categories. Figure 5 shows a bar chart of the number of interview chunks coded to each factor.

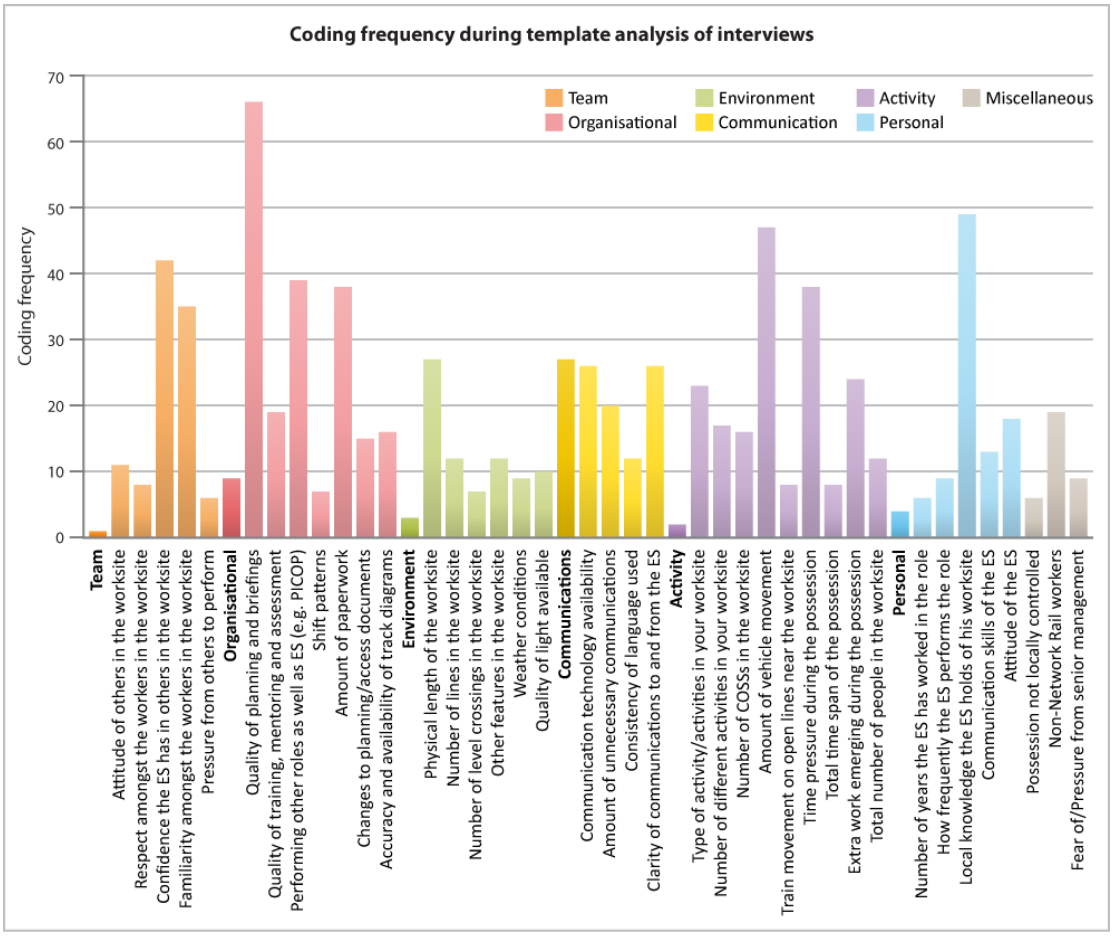


*Figure 5. Results of information chunks within factors from the interview template analysis.*

As can be seen in Figure 4, the factors with the highest frequency are (in order): quality of planning and briefings, local knowledge of the worksite, amount of vehicle movement, confidence in others in the worksite, taking on other roles as well as ES, amount of paperwork, time pressure during possession and familiarity amongst the team. These eight factors were the most commonly talked about and were discussed by all nine interviewees whose interviews were analysed.

### 4.2.1. Quality of planning and briefing

With 66 references during the interview process, quality of planning and briefing is reported as the most frequently mentioned factor affecting performance for an ES. It was clear from the interviews that planning was seen as crucial to the safe and efficient running of engineering possessions:

> *"It's more the planning really, around the possession, actually doing the work is nothing really."*
>
> (Interviewee 001)

The workers place considerable trust in the planners that the work is feasible and all potential issues are considered. Eight interviewees suggested that the impact of one or more of the other listed factors is reduced for an ES when the planning is adequate. Four of the ESs also revealed that they often do their own additional planning prior to works beginning; from filling out some of the paperwork in advance to actually drawing out extra plans of the worksite. There was a consensus that current planning was adequate for possessions, although one interviewee suggested that the ES should be included more in local planning meetings.

Alongside planning, the quality of briefing received and given by the ES is important. Before work commences, the ES receives a briefing and in most cases will go on a site visit with a supervisor to discuss what work needs to be done. The ES is then responsible for briefing the other workers in the site.

### 4.2.2. Local knowledge of the worksite

The majority of the ESs interviewed had worked in the same area for several years and so felt they had a good understanding of their respective patches with some suggesting that they would find it difficult to perform as an ES in an area they did not know so well. It is clearly beneficial to have a site visit prior to starting work, particularly a day visit before night works. The local knowledge of the work group members is also important to the ES when, for example, the presence of new workers or visiting contractors potentially increases the level of vigilance required of the ES.

### 4.2.3. Vehicle movements in the worksite

The amount of vehicle movement depends on the number of vehicles, the types of vehicles and the tasks undertaken; all the interviewees felt that as vehicle movements through and within the worksite increased this added to the task load.

> *"I would have said road-railers are one of the biggest hazards. Trains are not too bad because, the thing is with a train, it doesn't slew about, it's in one line, you know where it's going to be."*
>
> (Interviewee 001)

The impact of vehicle movements is magnified on larger worksites, especially when the machines or vehicles are out of the ES's line of sight. Other factors link closely with the amount of vehicle movement, namely the volume of paperwork, the number of people in the worksite and the number of level crossings in the worksite.

### 4.2.4. Confidence in and familiarity with others in the worksite

Two closely related and important factors are the ESs' confidence in and professional familiarity with the men in their worksite. It is vital for an ES not only to trust those

they are working with but also to have an awareness of their individual capabilities. This is particularly important concerning the COSS in the worksite; the ES needs to be able to rely on the COSSs to control the people they're working with and also provide information, especially when the worksite is large.

> *"You're relying on the COSSs to give you information; where and what they're doing, are they near finished, are they on their way to the access point, are they clear? You have to know that all the time."*
> (Interviewee 001)

#### 4.2.5. Taking on other roles alongside ES

During maintenance tasks, any track worker with an ES certificate can perform the ES role but, on occasion, they may also be asked to perform another role in tandem such as PICOP or COSS. Opinions were split on this subject with some ESs believing that, especially for a small worksite, there are benefits with performing more than one role, such as a reduction in the amount of necessary communications. Others, however, feel that attention on the ES role must not be diluted by having other tasks to carry out.

#### 4.2.6. Time pressure during possession

Time pressure clearly makes the ES role more stressful, and this is often apparent in shorter (i.e. overnight) possessions. This pressure can be alleviated by good planning and organisation by the ES.

#### 4.2.7. Amount of paperwork

Filling in paperwork takes up a considerable portion of the ES's time. Some ESs consider that this is just part of the job while others feel there is far too much.

*"Yeah and the amount of paperwork they have to carry. To be honest with you, he needs a table and chair on the track!"*

(Interviewee 010)

Although the ESs are provided with weather protection for their paperwork, respondents suggested that bad weather added to the workload and stress associated with filling out paperwork.

## 4.3. Agreement between rating and interviews

We carried out a combination of collecting ratings of importance with interviews in order to attempt to triangulate between what respondents report as most important based on the items we developed and what they actually discuss most frequently in conversation about what characterises their work or makes it challenging. There is reasonable agreement as the most highly rated factors were also among the most frequently coded as being discussed in the interviews (namely local knowledge of the worksite, quality of planning and briefings and familiarity amongst workers). The exceptions were items related to communication specifically. However, during the interviews, communication was commonly discussed and as can be seen in Figure 5, it was the most common category coded (i.e. interviewees were well aware of *communication in general* as an important variable but their comments could not be matched to one of the more specific factors). The most likely explanation for this, taken from our interview corpus as a whole, was that although recognised as important in and of itself, communication was otherwise discussed in the context of other issues (e.g., communication as a part of the planning process or communication as aided by teams familiar with each other). In summary, although drawn from a limited sample of experts, there is a good level of agreement between the information

obtained from the interviews and the opinions reflected by the factor ratings suggesting that the TOECAP factors capture the major issues of concern to ESs. This suggests in turn that using the factors list as an interview structure or in questionnaire format should reveal useful information on the attitudes of ESs.

# 5. Deployment of the TOECAP questionnaire

In the next stage of development, we deployed the TOECAP factors in inventory form to a wider community of ESs who had not been part of the earlier stages of development. Questionnaire respondents were asked to rate each factor on the same 5-point scale as in the interviews. In the explanatory text at the beginning of the questionnaire, respondents were told that they could leave blank any factors they did not fully understand or that they felt were not relevant in their experience. Alongside the rating boxes for each factor a comments box allowed respondents to comment on any of the factors; an open comments area was also included at the end of the questionnaire.

## 5.1. Questionnaire results

In total, 22 responses were received, 15 from Network Rail employees and 7 from employees of a contractor. The respondents all work as ESs and have a mean of 15 years of experience on the railway (lowest 3.5 years, highest 33 years). The respondents represent a variety of jobs, from those who are an ES only to those who are possession planners or track section managers in addition.

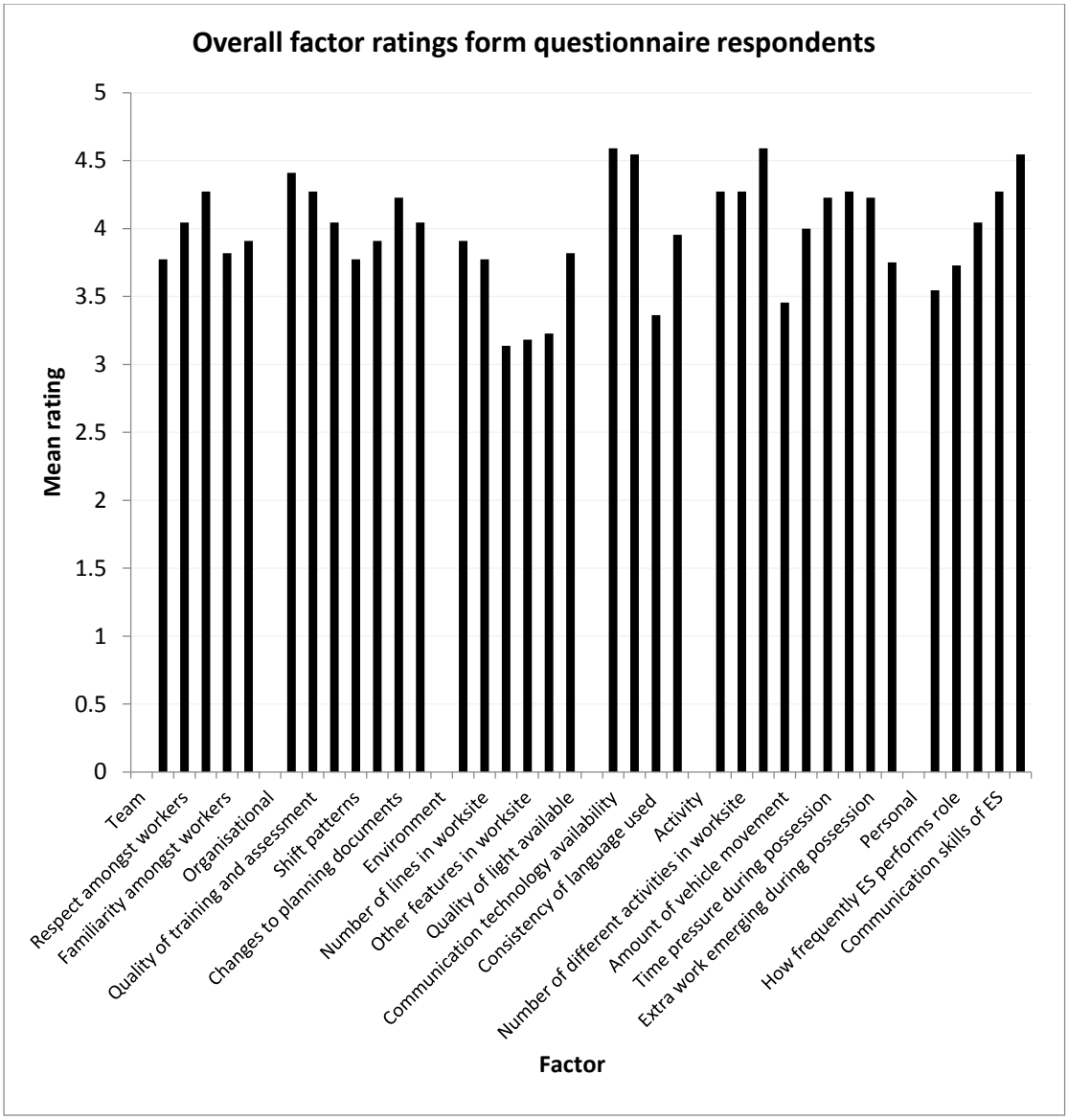


*Figure 6. Mean factor ratings from the questionnaire respondents*

From Figure 6, it can be seen that the respondents rated the number of COSSs in the worksite and the availability of communications technology as having the highest potential impact, and close behind are unnecessary communications and the attitude of the ES. Other factors that received high mean ratings were quality of planning and briefing, quality of training and mentoring, performing other roles, type of activity in the worksite, number of different activities in the worksite, confidence the ES has in others, communication skills of the ES and total time span of the possession.

### 5.1.1. Differences between NR employees and contractors

Time and personnel availability restrictions precluded a large enough sample to compare geographical locations, but it was possible to look at the difference between contractors and Network Rail employees on the TOECAP inventory. Figure 7 shows the mean factor ratings for each group.

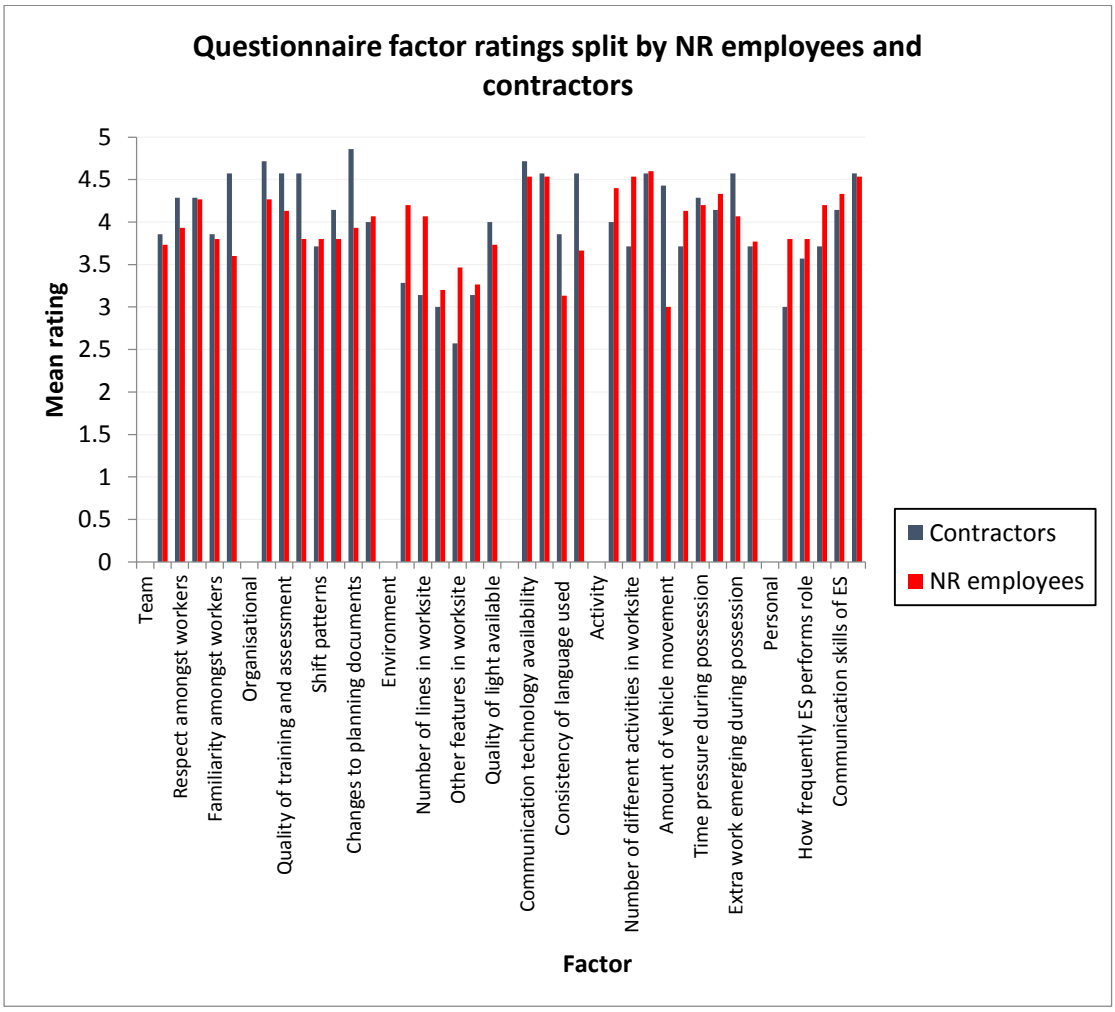


*Figure 7. Mean factor ratings split by NR employees and Contractors.*

Some of the mean ratings show considerable consistency in opinion between ESs regardless of their employer. However, there are some interesting discrepancies such

as the rating for changes to planning and access documents, which was the highest rated factor for contractors (mean of 4.9) but only received a mean rating of 3.9 by Network Rail employees. It is suspected that, when changes occur to planning and access documents, contractors might find out about them later than those ESs working within a Network Rail depot and they would have less time to reorganise their own plans for the possession.

There was also a discrepancy between the ratings for physical length of the worksite, considered very important by Network Rail staff ($\bar{x}$=4.5) but less so by contractors ($\bar{x}$ =3.3). More research needs to be done to find out why this is so but it may be because of differences in the type of work contractors usually get involved with compared to those employed full-time by Network Rail.

The largest difference was found in the mean rating for amount of vehicle movements, with Network Rail staff rating it much lower ($\bar{x}$=3.0) than contractors ($\bar{x}$ =4.4). Once again, the type of work carried out and thus the type of machines usually used by each party is the most likely explanation for this difference, particularly as part of the reason for hiring contractors is, in itself, to access specialist vehicles.

## 5.2. Questionnaire results compared to validation results

Multiple issues could have differently affected the responses from the questionnaires and the interviews. One noticeable difference is that the overall mean of all the factor ratings is higher from the questionnaires (4.0) than from the interviews (3.2). This could be because of the difference in presentation of the factors list; validation interview respondents were asked to discuss the potential of each item to impact performance before rating them, whereas for questionnaire respondents the list was sent out and presented without elaboration. There is also a possibility that the

presence of the researcher affected scoring in the validation phase (Hawthorne Effect). However, the most likely account is probably that the two groups differed as populations because their local circumstances. In this research, most of the interviewees work in South Wales and the majority of the questionnaires were returned from the East Midlands. Each area has different forms of electrification, train detection and other features of the track.. A much wider circulation of the questionnaire is therefore needed to get a balanced view across the country.

With those caveats in place, there were some interesting differences between the validation responses and those received from the more widely distributed questionnaire. For example, the largest discord between the two was the rating for the availability of communications technology; interviewee mean rating for this was just 2.0 whereas the questionnaire respondents rated it at a mean of 4.6. When this item was discussed with validation respondents, they noted a local issue with mobile phone reception: black spots and communications in tunnels were often mentioned, but respondents usually said that these issues were well known and caused no real problems.

> *"We've got black spots down the Vale of Glamorgan, we use the back-to-back radios. It doesn't make it harder."*
>
> (Interviewee 005)

It is suspected therefore that the difference in geographical location could be a strong influence on the rating of this factor.

## 5.3. Results by category

The TOECAP inventory is structured around six categories: Team, Organisational, Environment, Communications, Activity and Personal. The mean scores given during

the interviews for the impact of factors in each of these categories can be seen in Figure 8.

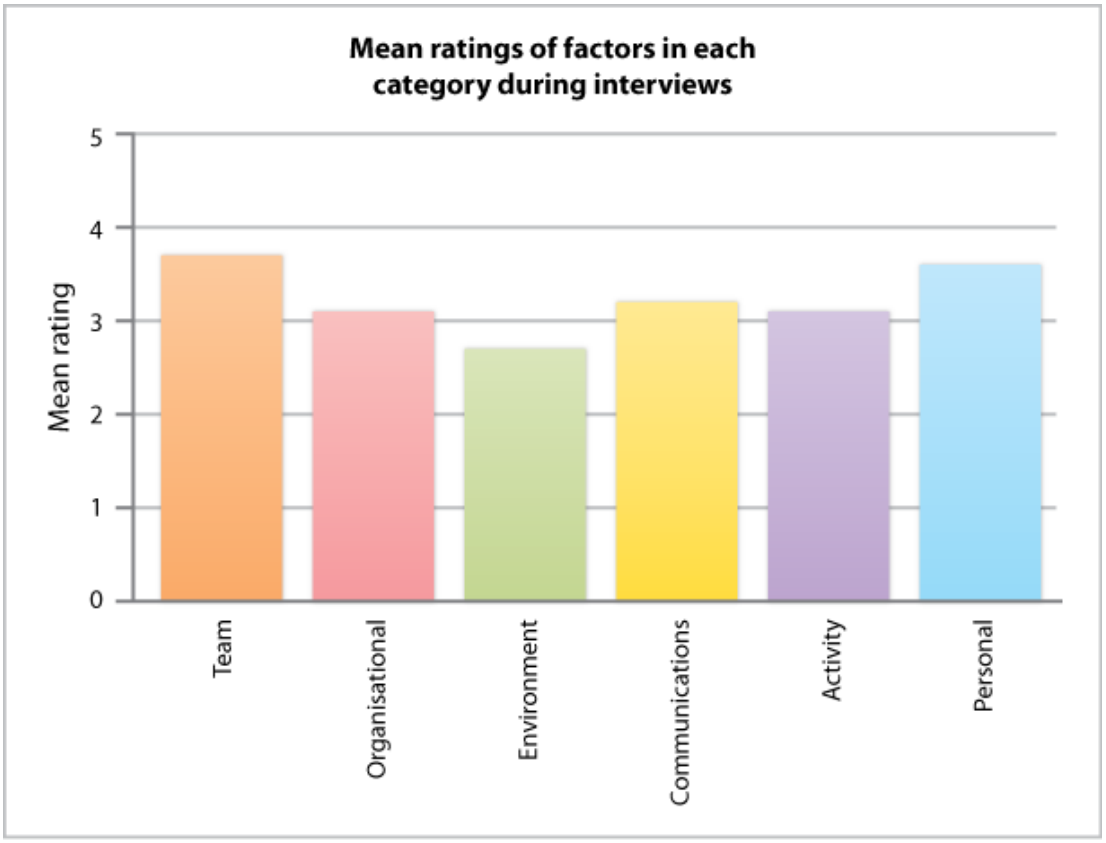


*Figure 8. Mean ratings of the factors in each category given during ES interviews.*

This shows that the factors associated with the physical environment are on average not considered to impact performance as much as others. It is the factors associated with the team surrounding the ES and the personal attributes of the ES that were rated as the most important. Figure 9 shows the comparable output from the TOECAP questionnaires.

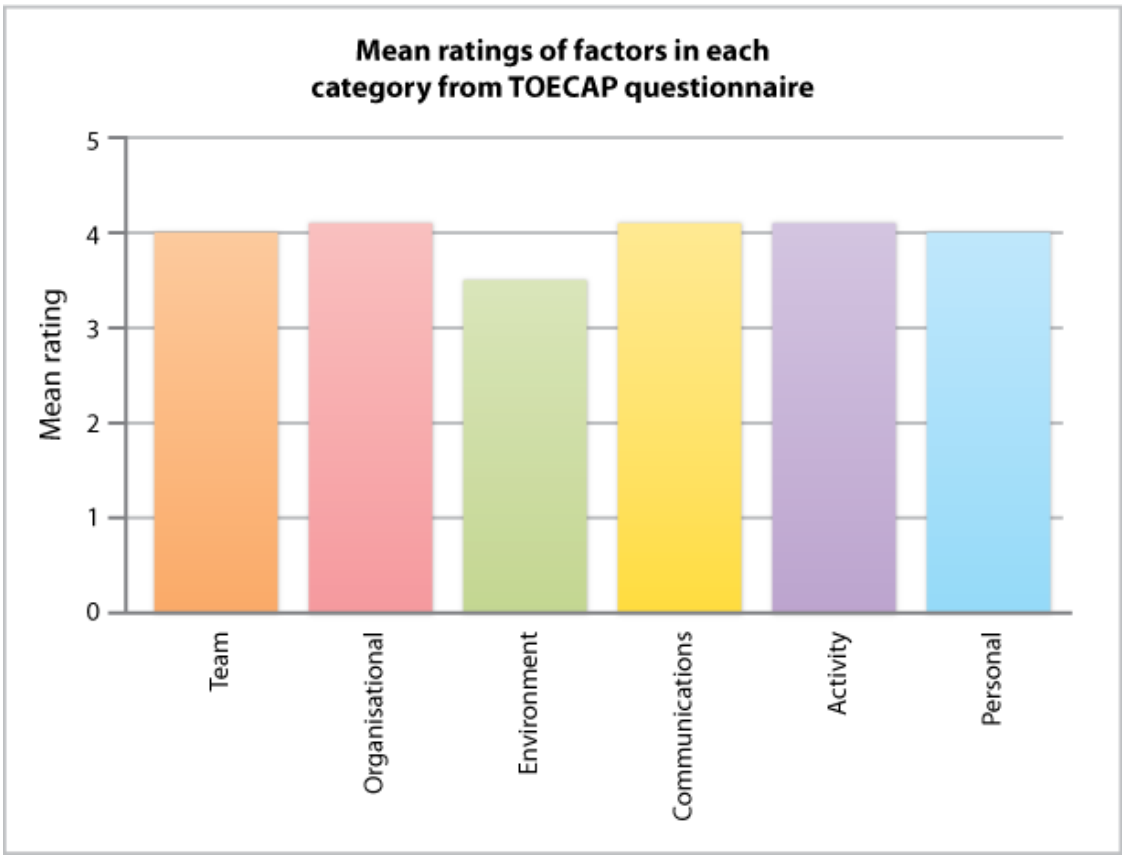


*Figure 9. Mean ratings of the factors in each category from the TOECAP questionnaire.*

Once again, the factors associated with the physical environment are rated slightly lower on average than the others. There are a number of possible explanations for this, for example, ESs may feel that the environment is difficult to change and simply an element of the role that they have learned to accept. However, the lower ratings for the physical environment could also be because questionnaire respondents had worked on the railway for nearly 15 years on average and their surroundings are very familiar to them. With a greater number of respondents it might be interesting to examine whether or not attitudes change as workers become more experienced.

# 6. Discussion

## 6.1. Further questionnaire development and deployment

The TOECAP questionnaire has provided useful data such that the study reported here can be viewed as a pilot exercise justifying a wider administration in the future, to ESs across Network Rail and contractors, and perhaps with small alterations to other supervisory employee groups on track. This will allow exploration of differences between ESs working in different areas of the country, on different projects, with varying levels of experience and working for a wider range of projects. The output from the questionnaire can be used to highlight the elements that targeted work groups consider impact their performance as an ES the most. The ratings could also be used to weight factors in future iterations of the tool.

Use of the TOECAP inventory has identified differences in attitude between different individuals qualified to perform as an ES and the importance of understanding these; a particular example concerns differences in views between ESs employed by Network Rail and those supplied by contractors. Also highlighted is the variation in type of tasks required of the ES, and thus potential load, dependent on the nature of the track, the work to be carried out and extent of the possession. The railway infrastructure varies dramatically across the UK and this means that the work requirements during an engineering possession are different from place to place, especially in terms of setting up and giving back possession. For example, some areas of the country have electrification systems and others do not. Compared to non-electrified track, extra measures, taking more time, need to be carried out to make an electrified track safe for workers. Further, train detection systems vary from area to area; some have track circuits, others have axle counters, each with different requirements for resetting when the track is returned to the signaller's control. For

example, in order to reset some axle counters a sweep vehicle is required to move from one end of the possession to the other, meaning that time has to be built into the possession to allow for this. Further study of issues of both geographical area and the interactions of different groups (contractors and rail staff) would be questions worth probing with future iterations of the tool.

## 6.2. Further categorisation of TOECAP items

The TOECAP inventory is likely not to be a complete list of all factors impacting track staff performance but appears to include all of the most influential factors for the ES role as validated against expert interviews and discussions. Concepts such as workload and span of control can be conceptualised in different ways, from the presence of potentially loading factors imposed by the task and environment to the cognitive or physical demands and effects felt by the worker, and thus may be measured in a variety of ways. To make better use of the TOECAP inventory, each factor can be categorised into one of four groups (although several factors could fall into more than one category. The groups are described below and shown in Figure 10:

- Factors that are physically or controversially **quantifiable**: e.g. the physical length of the worksite (measured in miles). Values for these should already be available at the planning stage of the work and therefore easily used in assessment tools.
- Factors that can be **categorised**: e.g. type of activity in the worksite (vegetation clearance, replacing rails etc). These factors are easily defined but somewhat harder to quantify; however, more investigation of loads and felt

impacts could lead to some ordinal scaling for this type of factor, allowing their inclusion in a scoring-based assessment tool.

- Factors that need specialist investigation and **measurement**: e.g. for unnecessary communications recorded conversations during a possession could be analysed and used to reveal how much time unnecessary calls take up and how detrimental this is to the load on and performance of the ES). Factors such as this could then be incorporated into a tool or else used separately to make recommendations for improving the role of ES.
- Attitudinal factors. The remaining factors, such as confidence the ES has in others, fall into the category of being attitudinal. All could be assessed with subjective rating scale and combined with the measures of the other factor groups to assess (or possibly even predict) span of control and task loads during track possessions. Team factors in general fall under this category as they constitute interpersonal relationship issues that would be challenging to quantify in an uncontroversial manner.

| Quantifiable | Categorisable | Measurable | Micellaneous |
|---|---|---|---|
| Amount of paperwork | Performing other roles | Unnecessary communications | Attitude of others in worksite |
| Physical length of worksite | Changes to planning documents | Consistency of language used | Respect amongst workers |
| Number of lines in worksite | Availability of track diagrams | Clarity of communications | Confidence the ES in others |
| Number of level crossings | Shift patterns | Time pressure during possession | Familiarity amongst workers |
| Other features in worksite | Weather conditions | Extra work emerging during possession | Pressure from others to perform |
| Number of different | Quality of light | Communication skills | Quality of planning |

| | | | |
|---|---|---|---|
| activities in worksite | available | of ES | and briefings |
| Number of COSSs in worksite | Communication technology availability | | Quality of training and assessment |
| Amount of vehicle movement | Type of activity in worksite | | Attitude of ES |
| Train movement on open lines nearby | Local knowledge ES holds of worksite | | |
| Total time span of possession | | | |
| Total number of people in worksite | | | |
| Number of years worked in role | | | |
| How frequently ES performs role | | | |

**Key:**

| | |
|---|---|
| Team | Communications |
| | |
| Organisational | Activity |
| | |
| Environment | Personal |

*Figure 10. Factors list categorised by their potential style of measurement and assessment*

## 6.3 Relationship of TOECAP factors to Performance Shaping Factors

The present work began with the established notion of span of control and explored how it could be interpreted and made applicable to the specific setting of UK rail track maintenance and possessions. We note that the eventual outcome of this process

has been a set of factors at least in part broadly similar to those found in lists of Performance Shaping Factors (PSFs) commonly cited in the context of Human Reliability Analysis and used in the calculation of Human Error Probabilities. There are a wide range of PSFs available to the analyst depending on the method employed (e.g., THERP, Swain & Guttman, 1983; CREAM, Hollngael, 1998; HEART, Williams, 1988) and while a detailed review is outside the scope of the present paper, some sort of cognate of Team, Organisation, Environment, Communications, Activity and Personal (experience and attitudes) can be found to a greater or lesser extent in most lists of PSFs (see Bell & Holyroyd, 2009). This is perhaps not entirely surprising as indeed, most descriptions of the subject matter of Human Factors and Ergonomics itself would encompass these categories in some way or other (see, Wilson, 2005). The present work is distinct in that even in the outcome is on the surface similar, it began from a very different starting point with a different set of intentions (albeit that PSFs and span of control both ultimately converge on the core ergonomics question of what features of work affect that work and what should be done about them). The TOECAP factors are not intended to be used to calculate the probability of error in executing a given task but rather describes the overall scope of a specific managerial role (Engineering Supervisor in track work possessions). This specificity is demonstrated in the fact that many of the factors involved are either directly quantifiable or can at least be clearly categorised as the system of organisation is based on abstracting upward from the detail of the situation. Task-level factors are also not present, for example there is no consideration given to cognitive processes as such or (explicitly) the design or physical form of equipment, the factors are instead based on the scope and size of the engineering possession itself (the to-be-managed situation in other words). That said, this is to make a distinction between different

strands of development and traditions only and it would not be inappropriate to describe the TOECAP factors as a set of PSFs albeit ones that apply to a specific role at a specific level of abstraction (that which concerns the manager rather than the worker). The approach demonstrated here could be used to generate other domain specific PSFs particularly as they apply to managerial roles that are not necessarily well-addressed by task-based approaches from HRA that are intended for slightly different purposes primarily within the rubric of Probabilistic Safety Analysis. Conversely, it may also suggest that span of control itself might ultimately be reconceptualised not in terms of the number of subordinates as Graicunas (1937) originally suggested but rather in terms of a tolerable level of risk associated with the act of managing an activity. That the definition of what constitutes a tolerable risk may itself change across different situations presenting their own distinct characteristics might explain why the quantification of span of control remains such an elusive goal.

# 7. Conclusions

In this paper we have revisited the notion of span of control and applied it to the novel context of rail possession management. While an established idea within management science dating back nearly 80 years (i.e., Graicunas, 1937), arguably, the currency of the concept was damaged when it became apparent that it was unlikely that any simple universal principles would be identified to explain "how much management work is too much". In the present work we demonstrate the value of at least continuing to ask this question and that reasonable answers can be generated and factors identified, albeit through close investigation of a specific work domain and role (see also Meyer, 2008 for a similar investigation in nursing work). We also outline a process for the adaptation and development of rail engineering management specific span of control measures based on initial factors suggested by Ford et al., (1998) drawn from a military setting. This process could presumably be used in future to expand consideration of span of control in other work domains.

One view of the utility of taking a span of control approach to understanding work is that it offers a participant-centric framework for characterising a form of work beyond task analyses in terms of what actual workers feel is challenging. In the present study we found that a range of factors impact on the perception of management difficulty in possessions. These range from objectively observable variables concerning the physical layout of the worksite through to shift patterns and communication skills. Those factors are easily quantified could lend themselves to a future tool for predictive assessment of demands on ESs, this would be broadly similar to the approach taken in the ODEC (Operator Demand Evaluation Checklist) tool that is already used in assessing signaller workload in the UK (Pickup et al., 2010).

However, attitudinal and personal factors including communication abilities which are arguably amongst the hardest measure or anticipate *a priori* were actually amongst the most important in determining management difficulty terms of their ranking. This supports the emerging view in the industry of the importance of training and procedures for communication within rail (e.g., RSSB, 2012a, b) as has been already noted in other domains such as medicine (e.g., Fletcher et al., 2003) and aviation (e.g., Flin et al., 2003).

## Author note

The fourth author, John R. Wilson, is deceased.

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## Appendix A: Semi-structured interview

The aim of this research to identify and ultimately help mitigate stressing and loading factors associated with on track maintenance work. This will help reduce the chance of errors and improve the efficiency and safety of this work. This interview will help me understand the role of Engineering Supervisor and begin to identify those loading factors.

**Interviewee data**
Job Title
Duration in post
Route to post (through ranks, from other industry etc)

**Exploratory interview items**
1. What is like being an ES/PICOP?
2. How do you feel about the ES/PICOP role?
3. What aspects of the ES/PICOP role do you enjoy?
4. What have you felt at your limit?
5. What do you feel affects your performance the most?
6. What affects team/gang performance most?

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