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CASE STUDY AND APPLICATION

Uncertainties in scheduling and execution of trackwork in Sweden

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Abstract

Trackwork planning and scheduling are demanding because they require strategic foresight and must be completed well in advance. In Sweden, trackwork is performed by maintenance contracting companies during an operation period free from trains. In the contractors' practice, once the maintenance plan is authorised, some unexpected events might interrupt the plan's execution, leading to uncertainties. The purpose of this study is to identify and classify uncertainties and strategies applied to manage uncertainties in the contractors' everyday planning and scheduling of trackwork. This work presents semi-structured interviews with foremen and planners at railway maintenance contracting companies in Sweden. The main findings show that in trackwork planning and scheduling, contractors deal with two types of uncertainties: internal and external. We categorised uncertainties and strategies to deal with uncertainties and described them on tactical and operational levels. The majority of the revealed uncertainties led to trackwork rescheduling. Furthermore, we suggest that current strategies to manage uncertainties applied at contracting companies can be improved by revising organisational design strategies for maintenance projects. This work increases the understanding and supports the management of uncertainties in trackwork planning and scheduling.

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1 Introduction

Planning and scheduling are key to efficient work execution for railway maintenance projects, as access to the tracks for maintenance purposes is limited. Continuous increases in train traffic have led to infrastructure deterioration and reduced the available time for trackwork. A large and growing body of literature has been focused on the selection of efficient maintenance strategies in the railway industry (Lautala and Pouryousef 2011; Stenström et al. 2016). Previous studies in railway maintenance have focused on issues such as trackwork optimisation (Forsgren et al. 2013; Lidén 2014) and trackwork scheduling (Higgins 1998; Budai-Balke 2009; Famurewa 2014; Mira et al. 2020; Lidén 2020). Although maintenance rescheduling expenses might represent up to a fifth of the overall maintenance expenditures (Tantardini et al. 2014), trackwork rescheduling and uncertainty management in railway projects are studied to a lesser extent than other aspects of railway maintenance (Lidén 2015).

Uncertainties in transport infrastructure projects have received attention in research. Project uncertainties are increasing the risks of disruptions that require an excessive amount of planning and re-planning (Kiefer et al. 2016; Ge et al. 2022). The analysis of the effects of uncertainties on project performance was of interest in the project management literature (Klakegg et al. 2010; Wied et al. 2021). Although many studies have focused on new investments in transport infrastructure, maintenance of existing facilities has not been explored to the same extent (Shou et al. 2021; Larsson and Larsson 2020). Nevertheless, the robust operation of transportation infrastructure requires regular maintenance. Many maintenance activities are organised as projects, even though they may be contracted and formally managed as more or less continuous activities (Ivina and Olsson 2020). In a previous study (Ivina et al. 2022), we discovered challenges in the contractual relationship between the infrastructure manager and maintenance contracting companies related to project uncertainties. Therefore, this paper aims to contribute to the understanding of uncertainty management in railway maintenance projects.

Project success in railway maintenance, as in other projects, depends on revealing and managing project uncertainties (Kutsch et al. 2015). Internal or external factors can cause uncertainties that affect project performance and increase project cost (Flyvbjerg et al. 2003; Perminova et al. 2008). Organisational design strategies for managing uncertainties can be analysed within the framework developed by Galbraith (1974). Uncertainty management in Swedish railway maintenance projects is the responsibility of maintenance contracting companies (Ivina et al. 2022). Therefore, this paper aims to identify and classify uncertainties and strategies to deal with uncertainties in the railway maintenance projects' planning and scheduling process. We focus on three main questions:

1. What are the uncertainties related to trackwork planning and scheduling highlighted by the maintenance contractors?
2. How can the uncertainties in trackwork planning and scheduling be classified?
3. What are the strategies applied by contractors to manage uncertainties?

This paper focuses on the trackwork planning and scheduling process in Swedish railway maintenance. It presents the results of semi-structured interviews with professionals from Swedish railway maintenance companies. The uncertainties thus revealed are analysed and classified within the framework of contingency theories formulated by Galbraith (1973).

2 Maintenance of railway infrastructure

2.1 Railway maintenance

According to the RailNetEurope (2017) definition, railway maintenance is an "activity aiming to maintain assets in good working order, prevent operational disturbance and/or uphold a given technical standard". Railway maintenance can be preventive or corrective (European Standard 2001). Preventive maintenance is undertaken regularly to reduce the probability of an item's failure. Preventive maintenance does not rely on last-minute repairs, and, therefore, comes with lower costs; at the same time, it reduces the risk of an unscheduled breakdown. In corrective maintenance, measures are taken after an infrastructure item's failure. Corrective maintenance in the case of failure tends to cost more, so project managers aim to increase the ratio of scheduled versus unscheduled work (Yile et al. 2008; Mostafa et al. 2015; Stenström et al. 2016).

As with other maintenance projects, railway maintenance is performed following five main steps: identify the work to be completed, create a plan for the upcoming works, schedule the planned work, execute the planned work, and complete the planned work. Maintenance planning means preparing a plan of the forthcoming works, managing resources and prioritising the repairs. Scheduling for maintenance involves allocating the plan and available resources, optimising the workload and managing human resources (Palmer 2013).

Maintenance planning and scheduling are performed on three levels: strategic, tactical, and operational (Lidén 2015; Zidane et al. 2016; Ivina and Olsson 2020). The strategic level includes maintenance planning, dimensioning and contract design, and determining the responsibility of the client (see Table 1). According to Lidén (2015), the main problems on this level are splitting maintenance between the contract areas, relocating maintenance volumes, and restricting the available resources. The tactical level includes maintenance planning, scheduling, and rescheduling, as well as the routing of maintenance teams and vehicles. The main problems on this level are supporting a balance between traffic capacity impact and maintenance volumes, planning for operative restrictions, managing the efficient use of the available resources and responding to uncertainties by

Table 1 Maintenance planning and scheduling process on three levels

Levels	Time	Key documents (in Sweden)	Contractor involvement
Strategic	4 years–1 year	Contract	Low
Tactical	1 year–4 weeks	Trackwork plan and track utilisation plan	Medium
Operational	4 weeks–1 day	Daily graph	High

maintaining the flexibility of the plan. Finally, the operational level involves the maintenance project implementation. On this level, the planner must carry out final preparations, such as obtaining the necessary permits and documents, managing the workload, preparing detailed work timing and scheduling resources. On both operational and tactical levels, according to Lidén (2015), uncertainty is an issue, and the plan often has to be rescheduled.

Trackwork refers to maintenance or renewal activities performed on the railway track. According to existing regulations, trackwork has to be performed in a pre-booked time slot, referred to as ‘possession’, which is an operational arrangement that prohibits train movements during a period reserved for carrying out works in the area of maintenance (RailNetEurope 2017). Possession consists of overhead time and task time, where overhead time includes preparation and termination activities, while task time is the time for trackwork (European Standard 2001). According to Holmgren (2005), scheduling a possession which is too short (when only a part of trackwork can be performed within the assigned time) may lead to underperformed maintenance.

Most trackwork is planned and scheduled in the capacity planning process with a planning horizon of more than one year (Lidén 2014). When scheduling trackwork, it is essential to know how long the activity will take in terms of time on the track, and how long in advance the activity has to be planned. These are both primarily based on the experience of the technicians who are planning the trackwork. Moreover, trackwork must be scheduled for periods when there is less traffic on the tracks or when there is time available to access the tracks. Such periods can be predetermined by contracts which state the periods available for contractors to perform trackwork (Gruhs 2015).

Choosing the most suitable time to perform trackwork is a complicated task for the maintenance contractor (Forsgren et al. 2013; Lidén 2015, 2020). Higgins (1998), Lake et al. (2000), and Lake and Ferreira (2002) studied the complications of the weekly scheduling process at the last stages before the performance of track work. Lidén (2015) determined that work timing and resource scheduling are the main operational problems in maintenance planning. Contractors must apply for possession time in advance before they are able to enter the detailed process planning stage. This means that they must guess, based on experience, how long each of their planned activities may take. In the case of possession application rejection at the planning department, contractors must reschedule the trackwork and make a new application. The concern is a high rescheduling cost, as it depends on the complexity of the planned activity being rescheduled and the time until the rescheduled intervention (Tantardini et al. 2014).

One way to simplify the decision process is to apply digital solutions for maintenance planning and scheduling. Decision support in maintenance planning with machine learning and artificial intelligence comes under the umbrella term 'e-maintenance'. E-maintenance is a digital solution that refers to maintenance strategy, maintenance planning, maintenance type, or maintenance support (Muller et al. 2008; Karim 2008). This digital solution enhances maintenance efficiency and provides decision support in maintenance planning by linking maintenance processes with other expert systems (Kajko-Mattsson et al. 2011; Kour et al. 2014).

2.2 Swedish context

In Sweden, the Swedish Transport Administration (below referred to as the infrastructure manager) delegates the responsibility for performing preventive and corrective railway maintenance to contracting companies (Ivina et al. 2022). The companies are chosen in a tender process where the lowest bid price wins (Nyström 2008). The contractor company is responsible for performing all the required maintenance in the contract region and fulfilling all the requirements demanded by the contract. Currently, railway maintenance is delegated through 34 basic maintenance contracts to five major contracting companies (Trafikverket 2020).

In trackwork planning and scheduling, contractors rely on a variety of sources of information. Maintenance contracts and inspections are the primary sources. Inspections can be performed internally by a contractor company or externally by the infrastructure manager (this nuance is agreed upon before signing the maintenance contract). In both cases, the document (known as an 'inspection plan') contains schedules for all inspections and is under the constant supervision of the infrastructure manager (Trafikverket 2015a).

At present, there is an issue of information overload in the maintenance planning and scheduling process. The data is processed manually; therefore, decisions mainly depend on the contractor's experience, which creates discomfort for the maintenance companies. A variety of optimisation strategies and digital solutions have been developed to simplify information processing in order to produce the best possible decisions in maintenance (Higgins 1998; Peng et al. 2011; Bueno et al. 2019; Muller et al. 2008; Karim 2008). Although e-maintenance has proven to be a beneficial solution for efficient maintenance planning (Kajko-Mattsson et al. 2011), its adaptation has yet to overcome many challenges in Sweden. The challenges occur due to organisational design and human factors, such as a lack of strategic planning for digitalisation and the reluctance to change (Kans 2019).

Contractors are responsible for tactical and operational planning closer to the execution stage; they determine the time required for each activity and apply for possession. Since 2015, according to a new planning regime, contractors receive regular possessions (Trafikverket 2015b). These prearranged possessions, known as 'maintenance windows', are two to six hours long and are stated in the maintenance contract (Lidén 2015). Maintenance windows guarantee access to the railway track for performing essential maintenance during the contract period and are intended to increase the efficiency of scheduling for trackwork at contracting companies. The advantage of the maintenance window is that maintenance contractors can now obtain longer, less fragmented and more efficient track-access times for trackwork (Peterson et al. 2019).

Despite all the advantages of the new planning regime for contractors, they do not use maintenance windows to the extent that they should (Dyrssen and Göransdotter 2017). The issue is that some maintenance windows are too short for certain types of work (Trafikverket 2020). According to Lidén and Joborn (2016), having short maintenance windows forces the company to higher spendings, because maintenance cannot fit into one short maintenance window, it gets split into several possessions, causing an increase in overhead time (preparation, setup and termination) and cost.

All possession applications submitted a year in advance are documented in the railway maintenance plan. Each application goes through the planning department at the infrastructure manager, whose job is to balance the number of trains on the tracks with the amount of maintenance and investment work (Nilsson et al. 2015). All possible adjustments which are preferable from a production point of view, as well as entirely new works, are documented in the track utilisation plan, which is updated every week and contains a detailed description of capacity requirements (Trafikverket 2016, 2020). The final date for application to the track utilisation plan is four weeks before the production week, at which time contractors must deliver ready-made work plans and documents concerning safety (Trafikverket 2015b; Lidén and Joborn 2016). Later, contractors have a right to authorise unplanned possessions during the operation day, using a manual procedure called direct planning. This procedure is being discouraged as it lacks the support tools (Trafikverket 2020). However, according to Lidén (2014), direct planning happened 5–10 times a day at each traffic control centre (of which there are eight in Sweden).

3 Project uncertainty

There are two schools of thought with regard to definitions of uncertainty related to projects such as maintenance (Zhang 2011; Rolstadås et al. 2019). One set of definitions is inspired by Galbraith (1973) and focuses on uncertainty as a lack of information. The other school focuses on probabilities, or lack of knowledge about the probabilities of event occurrence, and the consequences if an uncertainty occurs (Smith and Edmonds 2006).

According to Galbraith (1974), uncertainty is related to the gap between the amount of information required to complete a task and the amount of information *available* within the organisation. Uncertainty can thus be related to the absence of information needed to make a decision at a certain point in time. Similarly, Ward and Chapman (2008) claim that uncertainty is, in a sense, a lack of certainty.

Uncertainty can be related to variability in relation to performance measures such as cost, duration, or quality.

The other school of thought is related to risk management, where risk is interpreted as a function of the probability of an event and the consequence of the event if it occurs (Rolstadås et al. 2019). Uncertainty can thus be related to the probability of an event, or the occurrence of an event by chance when the probability distribution is unknown. Smith and Edmonds (2006) refer to uncertainty as the possibility of an event, about which little is known except that it may happen.

Uncertainty is the reason for changes of plans, and the best way to keep up with activities is to update the plan quickly and regularly so that it remains efficient and up-to-date. Uncertainties affect project performance, as project risks originate from uncertainties. According to Galbraith (1974), uncertainty limits the ability of an organisation to make decisions in advance of a plan's execution. Studies show that uncertainties create pressure on project performance and cause stress for contractors (Haaskjold et al. 2020; Selviaridis and Norrman 2014). Although uncertainty is challenging to quantify, it can be assessed by subjective evaluation techniques (Raftery 1994).

Risk management is a continuous process of identifying, analysing and following up uncertainties which could lead to negative impacts on the project (Rolstadås et al. 2019). The first step in uncertainty management is the identification of uncertainties. The uncertainties must then be analysed and classified. If possible, uncertainties should be determined at the beginning of the contract, and be discussed by the contractor and the client (Perminova et al. 2008). According to Olsson (2008), a high degree of uncertainty is present at the beginning of a project, with uncertainty gradually decreasing as the available information increases. Change of plans or design has a growing cost as a project proceeds, and adjusting the project for new circumstances may violate all previous decisions taken in the project.

3.1 Classification of uncertainties

There are several different categorisations of uncertainties in the project management literature (see Rolstadås and Johansen 2008; Zheng and Carvalho 2016; Rolstadås et al. 2019). Uncertainties can be classified into technological, market, organisational and innovation categories (Zheng and Carvalho 2016). All these uncertainties can be *internal* or *external* to the project. Wideman (1992) differentiates between external unpredictable, external predictable, internal non-technical, technical and legal uncertainties. Rolstadås and Johansen (2008) distinguish between operational, tactical, strategic, and contextual uncertainties. We note that several categorisations of project uncertainty include a distinction between internal and external uncertainties, with external uncertainties sometimes being referred to as 'contextual'.

Uncertainties can arise from sources which are either internal or external to the project (Perminova et al. 2008). *External uncertainty* in the project is closely related to environmental (external) uncertainty, which represents uncertainty generated by factors outside a project's system boundaries (Karlsen 2011). *Internal uncertainty* (in Karlsen's 2011 interpretation this is called 'task uncertainty') relates to factors within project boundaries and, according to Olsson (2008), is related to operational uncertainty. However, contracts in both construction and maintenance are typically based on contractors assuming responsibility for conditions outside their control as *external* uncertainties. In contrast, the uncertainty that the contractor has accepted as a part of the contract can be considered *internal*.

Environmental (in this study attributed to *external*) uncertainty can be measured both objectively and subjectively. Milliken, in his (1987) review, mentioned discussions concerning the question whether uncertainty should be treated as a perceptual phenomenon or as a property of the organisational environment. In this paper, we follow the definition of uncertainty given by Milliken (1987), where uncertainty is a subjective measure, perceived by an individual as an inability to predict some upcoming event accurately.

3.2 Strategies to deal with uncertainties

The act of adapting to uncertainty invariably demands additional work from the organisation. According to Galbraith (1974), there is a clear relationship between uncertainty in the project and the amount of information that organisations have to process before making a decision. Milliken (1987) also states that organisations' strategic planning consumes more time and resources due to uncertainties. How well uncertainties are managed depends on a manager's experience of dealing with the same type of uncertainty previously (Perminova et al. 2008). Thompson (1967) discusses the concept of 'buffering': creating extra space between activities in order to allow adjustments to be made to the plan according to new circumstances.

As was mentioned previously, there are two schools of thought and definitions of uncertainty. One, inspired by Galbraith (1973), focuses on uncertainty as a lack of information, and the other is based on the probability of an event occurrence and the potential consequence of the event. The choice of definitions has implications for uncertainty management strategies. If a risk is seen as $R = P \times C$, where P is the probability of an undesirable event (uncertainty), and C is the consequence of the event if it happens, then risk-reducing strategies will involve either reducing the probability or the consequence of the event, or both. Note that this does not necessarily include information processing. When applying a definition based on Galbraith (1973), uncertainty can be visualised as shown in Fig. 1.

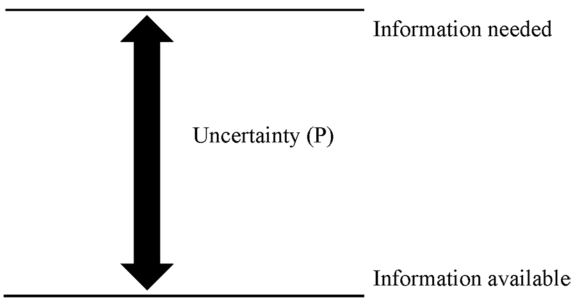

Fig. 1 Uncertainty as the difference between the information that ideally should be available in a decision situation and information available at that point in time

The organisational design approach to dealing with uncertainties is summarised as goal setting, hierarchy, rules and programmes. According to Galbraith (1973, 1974), there are two main strategies for reducing uncertainties related to organisational design (see Fig. 2). The first strategy is obtaining more information (Fig. 2a) and increasing organisational capacity to process information which includes communication with stakeholders (e.g. infrastructure managers or operators) and investigations of technical issues (such as condition monitoring). This strategy implies investment in vertical information systems and the creation of lateral relations to increase technical capability for data processing and decision making. The creation of lateral relationships means delegating a decision to the personnel who are most aware of the process, thereby moving the decision-making level further down the hierarchy.

The second strategy is to reduce the information that needs to be processed (see Fig. 2b); this includes creating 'slack' resources and self-contained tasks. The creation of slack resources is performed in order to reduce the amount of interdependence between subunits, for example by increasing the time available for completion of a task or by relaxing budget targets, while the creation of self-contained tasks involves grouping tasks, setting out a division of labour, and assigning tasks to teams. The second strategy improves the ability to preplan.

The main aim of these adaptations is to make the project resilient to new developments and unpredicted events. In other words, reducing vulnerability to events that occur during the project's final stages, from when plans are finalised until they are executed.

4 Interviews with contractors

4.1 Study outline

This paper addresses the complex process of trackwork planning and scheduling in Sweden. The subjective perception within the studied environment is the source of knowledge used in epistemological research and is essential in qualitative studies.

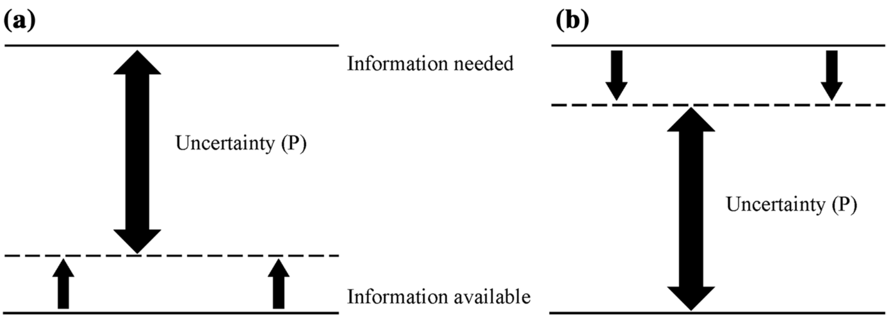

Fig. 2 Strategies to reduce uncertainty: **a** increasing available information; **b** reducing the need for information

Therefore, we use a qualitative research method to explore the maintenance contractors' perspectives on planning and scheduling complexity. We designed and conducted semi-structured interviews to better understand the key participants' experiences, attitudes, and perceptions. This approach usually involves a conversation between the researcher and the participant, which is led by a customisable interview procedure and reinforced by follow-up questions and comments (DeJonckheere and Vaughn 2019).

Selection of interviewees was based on the concept of achieving a broad diversity of points of view. The qualitative sample size was based on an aim to reach thematic saturation, which means interviews were conducted until the systematic pattern in responses is defined (Simon 1966; DeJonckheere and Vaughn 2019). We interviewed two planners and seven foremen from the top three leading maintenance companies in Sweden involved in the trackwork planning and scheduling process. The 'snowballing' sampling method described by Harrell and Bradley (2009) helped to identify interviewees: foremen and planners suggested foremen from other contracts and regions for us to interview. Interviews with selected personnel were performed digitally between June 2020 and February 2021 and were each around one hour long. All participation was voluntary and anonymous.

All the questions in the interview guide were designed as open questions because these would result in more descriptive information being provided by the interviewee. The interview guide is attached (see Appendix A). At the beginning of each interview, funnel questions were used; this is known to be an effective questioning technique for the targeted discovery of specific information. As with a funnel, these questions begin broadly, with questions such as "What is your experience in the railway industry?" or "In which area is your contract?", before narrowing to a specific point, in our case questions like "What would you recommend should be improved in the current system?". Then, leading questions, such as "How do you plan the work on the tracks?" or "What are the main challenges in your planning?", were asked of the interviewee in order to acquire more specific information regarding their opinion on topics discussed in the paper.

4.2 Interviewees

Each maintenance contract has at least one foreman responsible for planning in each field of the technical area, such as track, signals, telecommunication, and electricity. Depending on the size of geographical coverage or the region's complexity, some contracts could have several foremen for each technical area and several planners. Not all contracts have a foreman responsible for telecommunication; therefore, that role was not addressed in this study.

The contractors interviewed have different areas of responsibility in the contract: planning and inspections, technical areas of track, electricity, and signals. Table 2 presents a summary of the interviewed contractors' profiles. Interviewees had different lengths of experience in the maintenance industry, ranging from two to 32 years. Both interviewed planners had previous experience of working in train operating

Table 2 Interviewees profile summary

Contractors	Experience in railway maintenance	Technical area	Region
Foreman 1	6 years	Track	West
Planner 2	2 years	Planning	South
Foreman 3	17 years	Inspections	North and South
Foreman 4	27 years	Inspections	East
Foreman 5	32 years	Electricity	South
Planner 6	16 years	Planning	East
Foreman 7	6 years	Electricity	Stockholm (East)
Foreman 8	11 years	Track	Stockholm (East)
Foreman 9	26 years	Signal	West

companies, which influenced their work strategies in the maintenance companies. The interviewees were working in different regions in Sweden.

4.3 Interview analysis

A thematic analysis at the latent level was conducted following the method described by Braun and Clarke (2006). Analysis at a latent level means that we examined underlying ideas in the semantic content of interviews. In the analysis, the focus was on revealing patterns in trackwork scheduling, which would be conceptually connected to project uncertainty. Recordings of conducted interviews were transcribed manually, producing a total of 90 pages of text.

The analysis was completed in five steps, as illustrated in Fig. 3. The first step was to code nine transcripts in a systematic way using the NVIVO software. In the second step, we organised and structured responses by grouping them into three initial themes: *planning and scheduling* of trackwork, *issues* in planning and scheduling, and *strategies* to deal with issues. Next, we focused on two of the themes, *issues* and *strategies* in planning and scheduling, related to the study research questions. The codes related to these two themes were reviewed again, which helped to determine patterns related to the uncertainty in the third step of the analysis (see Fig. 3). The fourth step was to group the codes that emerged into new themes. In the fifth step, these were classified as causes of uncertainties or as strategies.

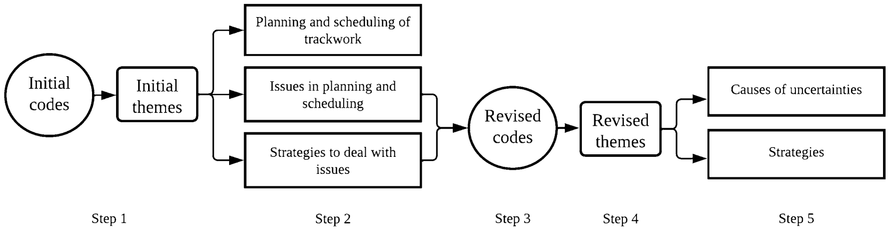

Fig. 3 Thematic analysis of the interviews in five steps

5 Classifying sources of uncertainty

We classify uncertainties as those which arise on *tactical* and *operational* trackwork scheduling levels caused by *internal* or *external* factors. We do not provide a classification of uncertainties on the strategic level because planning for maintenance on this level is the infrastructure manager's responsibility, and this study focuses on the contractors' perspective. Based on the classifications performed by Wideman (1992) and Perminova et al. (2008), internal causes of uncertainties are within the contractors' scope, while external uncertainties are caused by factors outside of the contractors' control.

5.1 External sources of uncertainty on a tactical level

One external cause of uncertainty on a tactical level is a practice of making changes to maintenance windows. Most of the interviewed contractors expressed a positive attitude towards maintenance windows, and some of them perceived maintenance windows as advanced assurance of time on the track. Others emphasise that changes regarding maintenance windows made the scheduling of trackwork more stressful. One contractor claimed that the maintenance windows guaranteed at the beginning of the contract period are not available for planning and booking later in the contract period. Sometimes contractors were promised maintenance windows of five hours when signing the contract, which were later reduced to three hours. Maintenance then becomes more expensive for the contractor company, as the same amount of work must be performed in a shorter period, and some trackwork has to be split into several shifts instead of being completed in one night. Breaking up trackwork leads to engaging more personnel and wasting time delivering and setting up equipment several times. To balance the lack of available maintenance windows, the infrastructure manager provides monetary compensation. Interestingly, not all the interviewed contractors used maintenance windows in their planning. According to the interviews, the usability of maintenance windows depends on the technical area of maintenance. Foremen in the track area used maintenance windows, while foremen in the electricity area ignored maintenance windows in their planning. One foreman also emphasised receiving information about maintenance windows for the upcoming year too late.

Another cause of external uncertainty on the tactical planning level is the rejection or modification of possession applications by the infrastructure manager's planning department. According to the interviews, to acquire possession one year in advance (i.e., to apply to the trackwork plan), one must deliver a detailed plan for the upcoming activity. Otherwise, the application would be rejected. However, the length of time required for some trackwork projects is difficult to predict. It also takes time to process an application for a possession, and sometimes contractors have to call and ask about the application status. Some interviewed foremen emphasised that application approval depends on a single person at the infrastructure manager who decides, which makes planning dependent on interpersonal relationships.

Concerns were expressed about not receiving the time which contractors requested in the possession application, and all interviewed contractors mentioned not having enough time on track for performing maintenance. Some interviewed foremen said that trackwork is given a low priority in decisions about capacity allocation: “We do not get exactly what we want all the time, but we understand that the infrastructure manager wants the trains to run, so we are a little flexible about that. But we do not get the time that we want; we always get less time than we want” (Foreman 7). Receiving approval for speed restrictions on track can also be challenging. Current regulations state that applications for possession with speed restriction must be sent to trackwork planners a year in advance. In some cases, contractors might need speed restriction on the double track for employees’ safety during the trackwork. Interviews revealed that some trackwork, even if it was assigned a high priority after inspection, must be postponed because speed restrictions are not approved.

5.2 Internal sources of uncertainty on a tactical level

The lack of preventive maintenance is one internal source of uncertainty on the tactical level. From the contractors’ perspective, the main reasons for not focusing on preventive maintenance are a lack of funding in the project and a lack of time on track. One of the interviewees claimed that in some cases, repeated maintenance work could have been avoided by replacing an infrastructure item, but this was not done due to a budget shortage. Most of the interviewed contractors mentioned not getting enough time on track to perform maintenance and inspections. These time constraints force contractors to prioritise corrective maintenance.

5.3 External sources of uncertainty on an operational level

One type of external uncertainty on the operational level refers to additional trackwork requests from the infrastructure manager. Sometimes these requests are received in the period shortly before the execution stage, or when the general planning on the contractors’ side is already complete. Moreover, one foreman interviewed stated that before closing an annual budget, the infrastructure manager ordered an extra work from the contractor, causing uncertainty in scheduling at the end of the year. Receiving additional trackwork requests creates uncertainty in planning in general, but especially when the requests are received shortly before trackwork execution.

Another external factor leading to uncertainty that shows up in the interviews is the cancellation of possessions. One contractor mentioned complications in trackwork execution related to weather conditions, which is an external factor leading to uncertainty. Much snow or rain can lead to infrastructure failure, which affects the trackwork plan. Some maintenance cannot be performed during cold or hot weather, and therefore must be planned for spring or autumn. All interviewees agreed that once the plan is complete, some events might interrupt plan execution. A sudden interruption of plans can be caused by a request to free the track with little notice.

Train dispatchers might contact technicians who have already started track work with a request to leave the track because a train must pass due to a failure on another track.

5.4 Internal sources of uncertainties on an operational level

One internal source of uncertainty that contractors mention is at the stage of crew scheduling and relates to both the cost of labour and the number of working hours. Maintenance windows are planned for nights when there is no traffic on the track. Interviewed contractors saw working at night as an issue because of not having sufficient time for trackwork and high labour cost. The problem is that technicians get paid for the complete workday of nine hours, but if the company is assigned only four hours during the night, the remaining five hours are difficult to plan efficiently. Therefore, the interviewed planners tried to schedule as much trackwork as they could during daytime or in the annually arranged maintenance weeks. However, maintenance windows are not long enough for some repairs, and so contractors must split these jobs into sections or request additional time for trackwork. Trackwork can also be cancelled at any time, by either party. In the interviews, some contractors mentioned the cancellation of the possession application due to a readjustment of the technicians' schedule, mistakes in planning, or broken equipment. In addition, technicians sometimes fall ill, which requires a search for replacement staff or the rescheduling of trackwork. According to one interviewee, the most sensitive part of planning is scheduling machine drivers and welders.

Inspection or infrastructure failure notifications are another internal source of uncertainty on an operational level. An inspection can notify the contractor about the need for urgent repair. This creates a feeling of instability in contractors' planning, and forces them to keep some spare time in their planning for urgent maintenance. All interviewed contractors mentioned infrastructure failures as a cause of interruptions to their planning and execution of work. Infrastructure failures have the highest priority and must be fixed immediately. Technicians must interrupt trackwork which has already been started and relocate to fix the infrastructure failure. Planned trackwork must be rescheduled or delayed, which in turn means that the trackwork schedule must be modified: "It is really hard if we plan eight weeks ahead and then the next week, we get a major fault we need to fix; we do not have enough manpower, so we must then work on the fault instead of performing the planned work." (Foreman 7).

6 Dealing with the uncertainties

We have also identified some strategies that contractors use to deal with the uncertainties listed above. These strategies also exist on both the tactical and operational levels, as outlined below.

One coping strategy on a tactical level that the interviewed contractors emphasised is communication. They say that they often communicate with the infrastructure manager, with others inside their own companies, and with other maintenance companies to reduce uncertainty. One planner mentioned keeping in contact with train operating companies and scheduling extra time in each trackwork application. Communication plays a significant role in dealing with uncertainties. For example, if one piece of work could not be split into two possessions, or contractors could not get speed restrictions, interviewed contractors discussed train cancellations in the area with the project manager at the infrastructure manager. Through the infrastructure manager, the contractor can meet with train operation companies and discuss the upcoming traffic. For the interviewed contractors, it is considered natural to maintain a good relationship with other maintenance companies. The technicians mainly know each other due to the workers' migration from company to company after a contract is over. Communication within the company is common; interviewed contractors had a weekly meeting with other personnel responsible for the contract and discussed how to optimise trackwork.

Another tactical approach to dealing with uncertainty is to reschedule. One interviewed planner mentioned booking both tracks for maintenance, which creates a safe environment for technicians while avoiding having to apply for a speed restriction. Another interviewed foreman mentioned booking longer possessions because infrastructure failures are frequent in some areas. For example, if one piece of work would take one week, the contractor booked two weeks. Extra time in the plan makes it more resilient in response to the notification of a sudden failure: "You need to have space in your planning for unexpected events" (Foreman 9).

On the operational level, the interviewed contractors mainly had to reschedule trackwork activities and keep spare resources to deal with the consequences of uncertainties in planning. Strategies like direct planning and habitually keeping some personnel ready to respond to an emergency at any time were mentioned. Direct planning was used quite often by all interviewed contractors as a backup plan for finishing jobs which had already been started, performing small repairs, finishing interrupted work or if the contractors missed the deadline for sending an application four weeks in advance.

7 Discussion

This paper addresses the reason for trackwork rescheduling: project uncertainty. We discuss uncertainties in the trackwork scheduling and planning on the tactical and operational levels. The current strategies to deal with uncertainties are analysed in Galbraith's (1973) framework and discussed below, together with potential strategies suggested by the framework.

7.1 Project uncertainty

Based on the interview results, we can argue that project uncertainty is present in basically all phases of trackwork projects, on operational and tactical levels. It is interesting to note that, according to Olsson (2008), a high degree of uncertainty usually gradually decreases toward the end of the project (in the case of maintenance

Table 3 Observed strategies to manage uncertainties in planning and scheduling of trackwork on tactical and operational levels

Strategy	Tactical level	Operational level
Reduce the need for information processing	Schedule extra time for maintenance activities Communication with train operators	24/7 response staff Direct planning
Increase the capacity for information processing	Rescheduling Communication with the infrastructure manager Communication with other maintenance companies and within the company	Rescheduling

Uncertainties	Tactical level		Operational level	
External	Changes to maintenance windows	Rejection or forced modification of applications	Request for additional work	Cancellation of possession
Internal	Lack of preventive maintenance		Staff or equipment unavailability	Inspection or infrastructure failure notification

Fig. 4 Internal and external uncertainties in railway maintenance planning and scheduling on the tactical and operational levels

projects, on the tactical level), while in maintenance, on both operational and tactical levels, uncertainties have a high impact on the plan throughout the project.

On the tactical level, external and internal uncertainties were addressed by trackwork rescheduling, scheduling for extra time and increased communication (see Table 3). Trackwork rescheduling was mentioned as a problem on tactical and operational levels previously in Lidén's (2015) study. On the tactical level (see Fig. 4), external uncertainties prevail; therefore, increased communication is a natural response by contractors to external uncertainty. Increased communication as a strategy for the management of uncertainties was mentioned by Galbraith (1973). The lack of preventive maintenance seems to be addressed by scheduling extra time for performing maintenance.

On the operational level, contractors deal with uncertainties by trackwork rescheduling, direct planning and creating an emergency response team. Rescheduling of trackwork on the operational level leads to economic loss for the contractor, as the rescheduling is a time and resource-consuming process (Tantardini et al. 2014). As shown in Fig. 4, decisions regarding rescheduling or trackwork are equally affected by external and internal factors. Direct planning is also a common strategy applied by contracting companies. The use of direct planning as a strategy can depend on how heavy train traffic is in the contract area. Therefore, direct planning is not the best option to rely on in maintenance planning. Finally, the emergency response team is a strategy for contractors to deal with infrastructure failures. It is a costly strategy, but necessary for all maintenance contracting companies.

7.2 Classification of strategies

First, we classified the strategies revealed in the interviews according to the organisational design strategy formulated by Galbraith (1974). Then, we aggregated them into two groups, reflecting those which apply to tactical and operational levels. Table 3 illustrates the classification.

Table 3 illustrates two alternative strategies: reducing the need for information, or increasing the information processing capacity. Reducing the need for information may mean that the projects, to a certain extent, isolate themselves from the context, and base planning and execution on predictability. For trackwork, this can mean insisting on track access as specified in the contracts, and that established plans are not subject to changes. To reduce the need for information processing on the tactical level, interviewed contractors applied strategies for scheduling extra time and communicating with train operators. Scheduling extra time for maintenance and applying for longer possessions is a natural adaptive response for not receiving enough approved time on the track. This adaptive behaviour was as well discussed by Pinto (2013), where the author calls it a 'defence mechanism' towards an artificial schedule compression by the principal project manager. On the operational level, contractors use direct planning and have 24/7 response teams.

The infrastructure manager introduced maintenance windows to make planning and scheduling less dependent on information processing at contractors' companies. The intended planning process, which the infrastructure manager regulates, implies locking the plan for trackwork four weeks before the operation day. According to this concept, maintenance windows would be fully utilised by contractors in their planning before the application deadline. Therefore, the maintenance windows concept can be seen as a strategy to reduce the need for information processing in the Galbraith (1974) framework (see Table 3). However, interviews in this study have shown, the application deadline is difficult for contractors to adhere to, due to uncertainties. At the same time, delivering the plan on time and using maintenance windows in planning would reduce uncertainty. Maintenance windows, if used correctly, would increase the certainty in contractors' planning.

At present, maintenance windows are not used to the full extent by contractors. The reasons for this are analysed in previous studies (Trafikverket 2020; Dyrssen and Göransdotter 2017) and in the current interview study. The size of maintenance windows and the arrangement of time patterns are inconvenient for use in scheduling trackwork. On the other hand, the maintenance windows do have great potential as a strategy to reduce uncertainty. Firstly, because they have already been implemented; secondly, because contractors may learn how to use maintenance windows to their advantage.

On the other hand, increasing information processing capacity can mean having resources and systems set up to manage a dynamic environment with continuously updated pre-requisites. There are indications that the planning process and contractor organisation is based on a strategy for reducing the need for information processing, while in reality these depend to a large extent on a greater need for information processing. This traps the planners between the two alternative strategies, with an expectation that they work as if there is a limited need for information processing, but without the capacity for managing the actual flow of information. To increase the capacity to process information on the tactical level, interviewed contractors focused on communication inside the company and communication with other maintenance companies. Contractors had to create a new resilient schedule on the operational level in response to sudden plan interruption.

According to Galbraith (1974), increasing information processing capacity on the organisational level includes using new technologies to the advantage of the planning process. E-maintenance is a concept that employs digital transformation in order to improve maintenance. In the Galbraith (1974) framework (see Table 3), e-maintenance serves as a strategy to reduce uncertainty. Recent technological developments which contractors did not mention in the interviews might represent solutions for existing problems. The interviewed contractors mainly complained about ineffective software and the need to search for the information used for planning in several different data sources which were not connected to each other.

The predictability of infrastructure failure is at the core of e-maintenance. Implementing e-maintenance in the railway field will improve the decision-making process and help to manage the consequences caused by uncertainties. With the support of e-maintenance, accurate and timely information will be available for contractors to make efficient maintenance plans.

8 Conclusions

The purpose of this study was to identify and classify uncertainties and strategies applied to manage uncertainties in contractors' everyday planning and scheduling of trackwork. We performed semi-structured interviews with railway maintenance contractors and revealed uncertainties in their planning. We categorised and analysed uncertainties and examined contractors' strategies to deal with uncertainties.

Defining and classifying uncertainties are the first steps towards managing them. This paper categorises uncertainties as internal or external, and on tactical or operational levels based on the project case of Swedish railway maintenance. The distinction which Galbraith (1973) makes between actions aimed at reducing the need for information processing, and actions that increase the capacity to process information, could also be applied.

Based on these categorisations, we described the strategies that the contractors applied in order to manage uncertainties. For example, strategies to reduce the need for information processing included creating different forms of slack in the system, such as scheduling extra time and maintaining 24/7 response teams. Strategies to increase the capacity to process information were focused on communication with the involved stakeholders.

This paper sees maintenance windows and e-maintenance as strategies to address uncertainties suggested by Galbraith (1973). We recommend increasing the use of maintenance windows, as it would reduce the need for information processing. The adaptation of e-maintenance in railway maintenance companies would increase the capacity for information processing. Once applied jointly, these strategies would improve the efficiency of railway maintenance planning and scheduling.

We found that the contingency theories of Galbraith (1973) could be applied in analyses of this type of project-based activity. We could also apply other project management concepts, especially risk and uncertainty management and project flexibility. Future studies will capture project uncertainties using a quantitative study, in which we will capture and analyse maintenance rescheduling and plan changes.

Appendix A. Interview guide

Background questions:

- For how long have you been working in the rail industry?
- What is your experience?
- What is your contract region?
- What are your responsibilities in the project?
- Tell me about track, electricity, signal and communication (BEST) areas and inspections.
- Do you have a planner in your contract?
- What type of foreman do you have in the contract and how many?

Planning:

- How do you plan the work on the tracks?
- Which information do you consider while planning for maintenance?
- Which data is crucial for maintenance?
- Which software do you use for planning?
- Do you encounter any problems related to the planning for maintenance?
- How do you apply for speed restriction or track closure?
- What do you do if you do not get the time on track for big works?
- How long before the work do you have the plan ready? Why?
- What can be improved in the planning process from your perspective?
- How do you plan for big works which demand speed restriction or track closure?
- When do you apply the track utilisation plan?

Plan realisation:

- How do you follow the plan?
- What are the problems related to plan realisation?
- How do you use direct planning? How do you record time applied in direct planning?
- How often do failures interrupt your planned works?

Possessions:

- What do you think about the given time scope for performing maintenance?
- How do you utilise maintenance windows?

- How satisfied are you with the maintenance windows allocation?
- How often is the application for possession rejected?
- How long before the planned work in the tracks begins, do you know which times you get?

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