Institute of Transport Economics
Norwegian Centre for Transport Research

Quality Assurance of the New Swedish Public Emergency Network, Rakel G2

Report of June 30th 2023

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Short summary

In this investigation report, we quality assure the new Swedish "public protection and disaster relief" (PPDR) network project, Rakel Second Generation (Rakel G2). Rakel G2 is planned as a hybrid network, where a state-owned core network is connected to one or more commercial mobile networks through a so-called "multi-operator core network" (MOCN) solution. The new 5G-based network will provide ordinary data services including video in addition to push-to-talk and messages. Key users will include ambulance services, fire services, sea rescue services and the police. Our mandate is to conduct an evaluation of the planned infrastructure project, applying adapted methodologies from the Norwegian quality assurance scheme for large national government investment projects. The quality assurance includes a project cost analysis, uncertainty analyses, quality assurance of the project preparations and analyses of impacts external to the infrastructure.

Kort sammanfattning

I den här undersökande rapporten så har vi kvalitetsgranskat projektet för det nya svenska räddningstjänsts- och katastrofskyddsnätverket (PPDR-nätverket) Rakel generation två (Rakel G2). Rakel G2 planeras som ett hybridnätverk där ett statligt ägt kärnnät är sammankopplat till en eller flera kommersiella mobila nätverk genom ett så kallat multi-operatörs kärnnät (multi-operator core network, MOCN). Det nya 5G baserade nätverket kommer tillhandahålla datatjänster, inklusive video i tillägg till push-to-talk (PTT) och meddelande-tjänster. Nyckelanvändare kommer att vara ambulans, brandförsvar, sjöräddningstjänst och polis. Vårt uppdrag är att utföra en ex-ante utvärdering av beslutsunderlag för nästa fas i infrastrukturprojektet, genom antagna metoder från det norska kvalitets¬granskningssystemet för stora statliga upphandlingar. Kvalitetsgranskningen inkluderar analys av projektkostnad och en osäker-hetsanalys samt kvalitetsgranskning av projekt-förberedelserna och även en analys av effekter externa till infrastrukturen.

Preface

In this project, we have quality assured the infrastructure project for the new Swedish public emergency network, known as Rakel Second Generation (Rakel G2). This has been an interesting assignment, which we have undertaken with considerable humility and effort.

Our mandate has been to conduct an evaluation of the infrastructure project prior to its execution, applying adapted methodologies from the Norwegian quality assurance scheme for large national government investment projects.

The Swedish Transport Administration (Trafikverket, TrV) and the Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och beredskap, MSB) have been responsible for the quality assurance assignment with Svenska kraftnät (i.e. the Swedish electricity transmission system operator) as a third involved governmental agency. Anders Björklund at MSB and Jonas Lindh at TrV have been joint project principals for the project.

The project has been carried out by Institute of Transport Economics, Analysys Mason and Dovre Group. Rasmus Bøgh Holmen at Institute of Transport Economics has been project leader, while Harald Wium Lie and Inge Mossige have helped to coordinate the project members from Analysys Mason's Oslo office and Dovre Group, respectively. Other project members have been Guri Natalie Jordbakke, Jostein Tvedt and Sunniva Frislid Meyer from Institute of Transport Economics, Amund Kvalbein and Lars Juvik from Analysys Mason's Oslo office, and Anders Ågotnes and Espen Sørlie from Dovre Group.

The English parts of the report have been proof-read by Anna Herzog at Anna Herzog Ywc, who also translated subappendix B.2 to English from Norwegian. Christopher Ryder, Jacob Renning og Jacob Sjödahl at Analysys Mason's office in Lund has translated the summary to Swedish from English. Kjell Werner Johansen at Institute of Transport Economics has been quality assurer for the report. In addition, Trude Kvalsvik and Bjørn Grimsrud at Institute of Transport Economics have prepared and provided feedback on the final report, respectively.

Throughout our investigation, several informants outside the project have provided input to the quality assurance through interviews. In addition, the project organization – especially project principals Anders Björklund and Jonas Lindh – have provided essential background information and insights throughout the quality assurance project, while keeping a professional distance to the investigation.

We thank all informants contributing to the information foundation of this investigation for their contributions. We also thank the contact persons at MSB, TrV and Svenska kraftnät for very good cooperation throughout the project.

Beyond potential errors in the knowledge input provided by the project principals, we take full responsibility for all potential errors and mistakes in the report.

Oslo, July 2023
Institute of Transport Economics

Bjørne Grimsrud Managing Director	Kjell Werner Johansen Deputy Managing Director

Contents

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ENGLISH **Summary**

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In this investigation report, we quality assure the new Swedish "public protection and disaster relief" (PPDR) network project, Rakel Second Generation (Rakel G2). Rakel G2 is planned as a hybrid network, where a state-owned core network is connected to one or more commercial mobile networks through a so-called "multi-operator core network" (MOCN) solution. The new 5G-based network will provide ordinary data services including video in addition to push-to-talk and messages. Key users will include ambulance services, fire services, sea rescue services and the police. Our mandate is to conduct an evaluation of the planned infrastructure project, applying adapted methodologies from the Norwegian quality assurance scheme for large national government investment projects. The quality assurance includes a project cost analysis, uncertainty analyses, quality assurance of the project preparations and analyses of impacts external to the infrastructure.

In many countries, the legacy emergency networks are approaching the last leg of their useful life. Swedish authorities will replace the current network system (Rakel First Generation, Rakel G1) network with a new public protection and disaster relief (PPDR) network, which in the government assignment is referred to as Rakel Second Generation (Rakel G2). While the existing Rakel G1 network builds on Tetra-technology and primarily offers Mission Critical (MC) push-to-talk and messaging, Rakel G2 will provide additional mobile data services including video and internet of things (IoT) services for a broader PPDR service portfolio. New services create new possibilities for usage and collaboration within and between user organizations.

Rakel G2 is planned as a hybrid network for mobile electronic communication, where a dedicated and state-owned network with 5G radio access in the 700 MHz band will provide the core network. The hybrid solution is intended to create flexibility, where commercial and government infrastructure for radio access complement each other in terms of coverage, capacity and robustness. The core network will be connected to one or more commercial mobile communication networks through a so-called multi-operator core network (MOCN) solution. Key users will include ambulance services, fire services, sea rescue services and the police.

The government assignments have been delegated to the Swedish Transport Administration (Trafikverket, TrV), the Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och beredskap, MSB) and Svenska kraftnät (i.e. the Swedish electricity transmission system operator). According to MSB and TrV, Rakel G2 ultimately concern authorities tasked with ensuring society's safety and security and that citizens have the right conditions to do so (Myndigheten för sammässskydd och beredskap and Trafikverket 2021b). During 2023, decision documents will be delivered to the Swedish government for continued establishment of Rakel G2.

Unlike the Swedish government, the Norwegian government has developed a scheme for quality assurance of large national government investment projects. In this investigation report, the Institute of Transport Economics, Dovre Group and Analysys Mason have been hired to conduct quality assurance of the Rakel G2 project in line with the requirements of the Norwegian quality assurance scheme. This scheme requires quality assurance at two stages. The first stage quality assurance (KS1) is carried out prior to requesting the Government to approve the selection of project concept. The second stage quality assurance (KS2) is carried out prior to asking the Government and the Parliament to approve the project's investment budget.

To the extent earlier investigations on Rakel G2 have been carried out, they have not followed the Norwegian quality assurance process. Furthermore, the Swedish investigation requirements differs from the Norwegian, so the project preparations have to some extent been carried out in another order and with somewhat different priorities than in the Norwegian scheme. Consequently, this quality assurance investigation entails elements recognized as both early stage (KS1) and late stage (KS2) quality assurance in the Norwegian scheme.

Furthermore, Swedish governmental agencies do not face the same investigation requirements as set by the Norwegian scheme, leaving them with a less stringent project preparation process and more flexibility in governance. Still, an important premise for the QA investigation has been to follow the methodologies applied in Norway with some adaptions to the status of the Swedish project preparation. The Swedish project is now approaching parliamentary approvement.

Another central premise for this quality assurance is that the concept choice has already been made. This means that the dedicated public protection and disaster relief (PPDR) network with a MOCN solution and the specified MC services is only evaluated against a reference scenario. In this reference scenario, Rakel G1 is gradually replaced with uncoordinated use of commercial electronic communication services in commercial networks. Other concepts, inter alia concerning different extents of utilization of commercial networks and other requirements to MC services, are not considered.

Moreover, our assignment has been to quality assure the preparations of the project which will realize the new Rakel G2 network. Using methodology from the Norwegian quality assurance scheme for large national government investment projects, we conducted four main analyses, each dedicated a chapter in our investigation report:

- **A project cost analysis**, where we have reviewed and evaluated the project's own base estimate for lifetime project costs, established an updated base estimate, compared this to the internal project estimate and considered funding options

- **Uncertainty analyses**, including a cost uncertainty analysis of the QA-team's updated base estimate for lifetime cost and a quality assurance of the project's own method and process for uncertainty analyses on costs and the time schedule
- **Quality assurance of the project preparations**, including key features such as project frames, management and control basis, and strategies and organization
- **Analyses of impacts external to the infrastructure** project, including analyses on direct user impacts, gross user costs, indirect impacts, tax distortions and distributional impacts. Here, the chosen project concept is compared to a reference scenario, where the existing PPDR Network (Rakel First Generation, Rakel G1) is gradually replaced by commercial mobile services in an uncoordinated way.

Quality Assurance of Project Cost Estimates and Funding Options

Introduction to the Project Cost Analysis and Network Overview

This chapter documents the cost model received from MSB and TrV, and our work to review the model. This chapter also describes our proposed changes to the model based on benchmarking and seven expert interviews. We refer to the original model as the "Nova Model" and our revised model as the "Project Base Estimate" or "PBE", measured in Swedish 2024-krones.

The chapter also contains an overall description of the Rakel G2 mobile network and the elements that are included in the cost analysis. A mobile network consists of several elements as shown in Figure S.1.1, and the cost analysis is structured according to this figure.

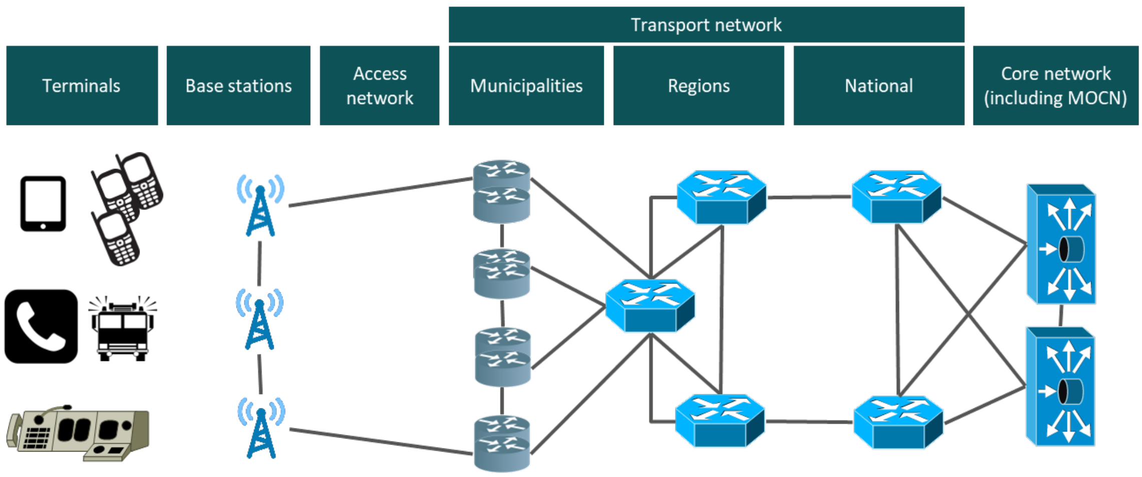


Figure S.1.1: System overview

The figure above shows the system diagram for a dedicated public protection and disaster relief (PPDR) network that we have used as a basis for the cost analysis.

Terminals and Control Rooms

Terminals are shown to the far left in Figure S.1.1. For most end users this means a handheld mobile phone, but it can also mean fixed terminals in vehicles and helicopters or connected sensors and actuators. In addition, there will be equipment in control rooms (such as SOS alarm centrals), where Rakel G2 terminals will be integrated with emergency software applications and public network connectivity. The Rakel organization will specify which types of terminals can be used in the G2 network, but the users are responsible for terminal purchase. Terminal costs are excluded from the cost analysis, while handling of terminals will be an important success factor for Rakel G2.

Base Stations

The terminals communicate with base stations. Rakel G2 plans for more than 7,000 base stations across Sweden, with an aim to provide national radio coverage also in some areas that are not covered by public networks today. The radio coverage will be established using 2x10 MHz of dedicated radio spectrum in the 700 MHz band. The 700 MHz band has good coverage properties with a potentially long range and high penetration of house walls and other obstacles. The data capacity available in this band is, however, limited. The plan is to add extra capacity to Rakel G2 through agreements with one or more commercial mobile network operators.

Access Network

In wired networks, it is common to define the access network as the connection between the end user and the nearest operator node. In mobile networks, we define the access network as the connection between the base station and the nearest aggregation point. Mobile access networks can be built in several ways. In commercial mobile networks, the access network often looks like a star network where one base station has one connection to an aggregation point.

In Rakel G2, the access network will often be built as a ring where each transmitting station has two access network connections. This means that a link failure does not have to mean that the transmitting station loses its connection to the rest of the network. Connections in the access network can be realized in the form of a point-to-point radio connection ("radio link"), a fiber network or even from satellite access. Over time, the proportion of fiber access will probably increase due to new service requirements associated with the new generations of mobile technology. Fiber networks usually have considerably higher capacity than radio links.

Transport Network

Figure S.1.1 shows how the access network connects to the core network sites. In Rakel G2, about 1,200 nodes (“kommun-siter” or municipal sites) will be established to connect the base stations to the transport network. Then, the transport network connects these nodes to central elements such as the core network and service platform.

Core Network and Service Platform

The core network consists of several elements that manage traffic and users. Rakel G2 is planned as a 5G network with a standalone 5G core network. Connected to the 5G core is a service platform responsible for service production. The Rakel G2 will deliver important PPDR services such as voice, group voice and messaging services. In addition, Rakel G2 will provide data services. Mobile data capacity will be increased through access to commercial networks using a multi-operator core network (MOCN) solution where users can connect to the Rakel G2 core network through a commercial radio access network. There are still uncertainties associated with the timeline and scope for the introduction of different services.

Summary of the Project Cost Analysis

The Nova Model is a detailed excel spreadsheet describing new investments, recurring costs, reinvestments and revenues. The model is developed by experts at MSB and TrV. In our analysis, we have restructured this model to achieve a clearer break-down of cost and revenue elements. Figure S.1.2 shows that the Nova Model estimates MSEK 9,100 for initial investments, MSEK 17,900 in recurring costs and MSEK 2,100 for reinvestments over a network lifetime of 17 years. This adds up to a total cost of MSEK 29,100. The Nova Model further estimates revenues of MSEK 16,300, so that the net cost is MSEK 12,800.

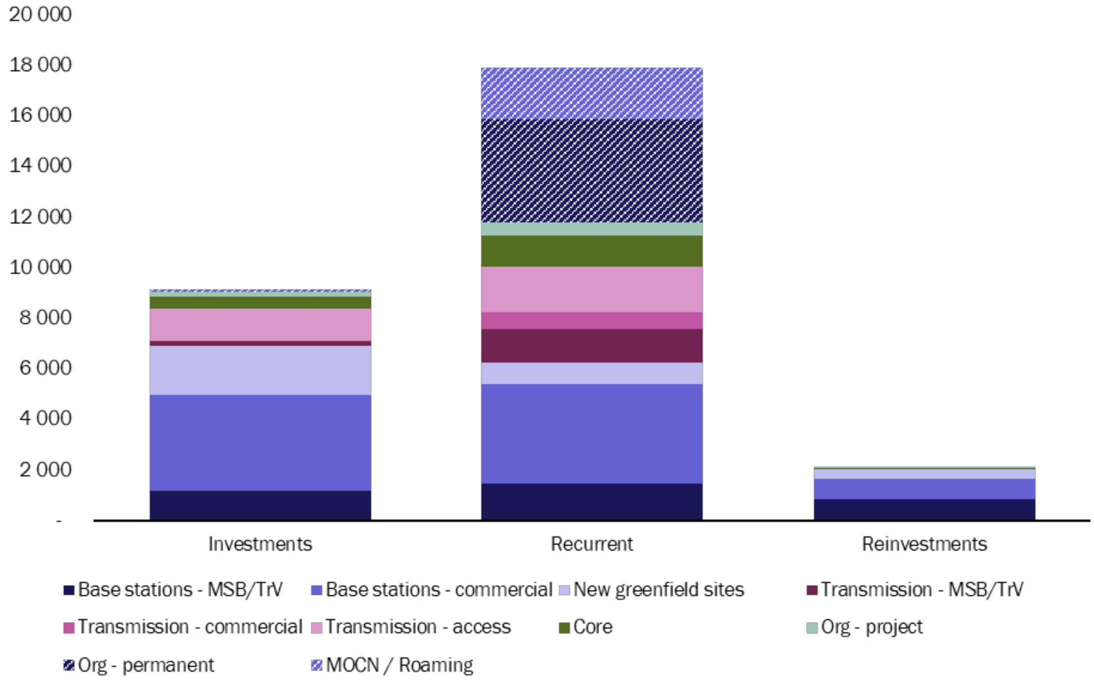


Figure S.1.2: Nova lifetime costs in MSEK

In our opinion, the Nova Model is detailed and thorough. The sources for most estimates have been documented, and cost drivers are explained and modelled in detail. There are, however, important uncertainties that remain and some adjustments that we believe should be made to the model. The most important adjustments are the following:

- Most cost estimates were collected in 2021 and 2022. Since then, inflation in Sweden has been high, and we believe the costs in Swedish 2024-krones will be higher than many of the Nova Model estimates.
- Over time, we assess that energy and construction costs will increase more than other prices. Note that we for energy prices have not included the most extreme price increase in the winter of 2022/2023. These are important cost elements in the Nova Model. We have adjusted the PBE to include an extra annual price increase of one percentage point for construction and two percentage points for energy (not accounting for the extreme energy prices in the winter of 2022/2023).
- The Nova Model does not account for real wage increases for permanent employees. Over time, we expect salaries to increase by 1.15 percentage points higher than inflation.

- On the revenue side, the expected launch of mobile broadband services has been delayed based on input from MSB and TrV. Also, the Nova pricing for mobile broadband is quite a bit higher than what we believe PPDR users[1] will be willing to pay. Therefore, we have reduced expected broadband revenues.
- The Nova Model plans for 143 Rakel G2 employees over time. In addition, there will be 63 additional employees in TrV's transport network divisions to handle Rakel G2. We believe it is possible to run Rakel G2 with 130 employees and have adjusted the PBE to reflect that.

We have also made a few minor adjustments related to model bugs and the cost of transmission equipment. In total, the changes increase the estimated net cost from MSEK 12,800 to MSEK 18,300 as shown in Figure S.1.3 as long as network lifetime is kept at 17 years.

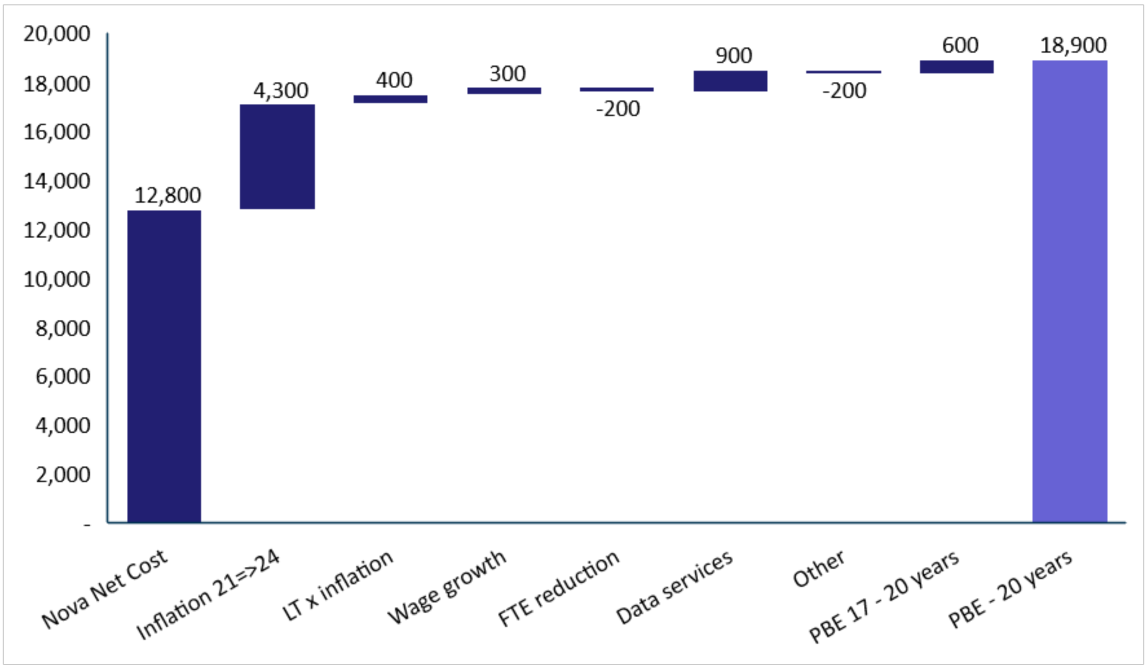


Figure S.1.3: Project Base Estimate in MSEK – changes in net cost

Most mobile networks have a longer lifetime than 17 years, and we believe a network lifetime of 20 years for Rakel G2 is reasonable. This increases the PBE net cost from MSEK 18,300 to MSEK 18,900 ("PBE – 20 years"), but the cost per year decreases from MSEK 1,076 (17 years lifetime) to MSEK 945 (20 years lifetime) as shown in Figure S.1.4 It is possible to extend the network lifetime even further, but this will likely require a higher level of reinvestments.

[1] PPDR: Public Protection and Disaster Relief. In Sweden often referred to as «Blåljus-etater» (directly translated – blue light agencies).

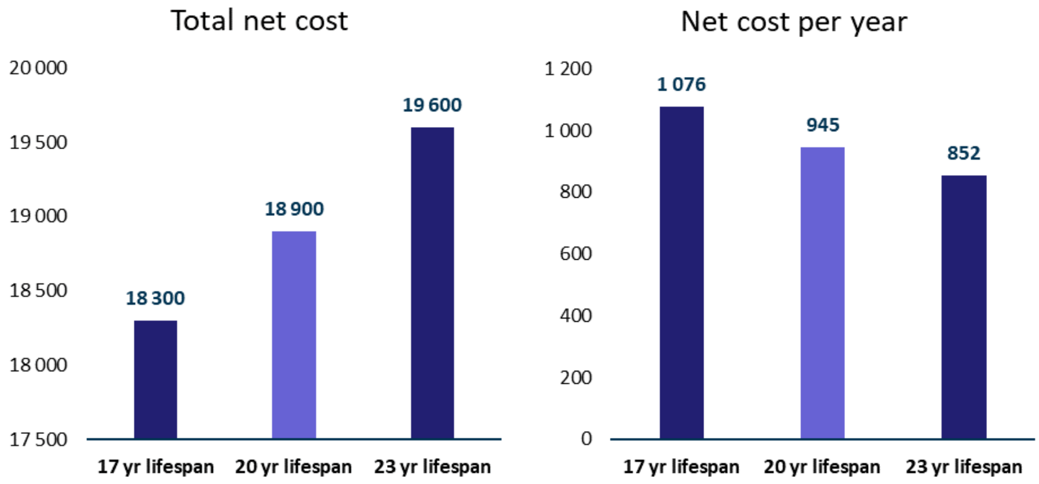


Figure S.1.4: Net project costs in MSEK in a) total (l.h.s.) and b) per year with different network lifetimes (r.h.s.)

We have not made any changes to costs associated with base stations ("sites") and the core network. Site costs are more than 50 percent of total costs in both the Nova Model and the PBE. A detailed radio plan is necessary to estimate the number of sites needed, and the cost per site varies significantly with the types of sites that are deployed. In particular, the cost estimates assume that base stations to a large extent can be placed in existing towers, owned either by Trafikverket or by commercial tower companies. We have discussed the estimates with several experienced Swedish network builders. They all underline the uncertainty associated with site deployment costs, but we are confident that there will to a large extent be space available on commercial towers. This is the most important driver for Nova site costs and we therefore assess that the Nova Model estimate is reasonable.

The situation is different with regard to Core network costs. These costs make up less than 10 percent of total costs, but important uncertainties with regards to functionality and design have made it difficult to assess the cost levels. Uncertainties are related to the complexity of seamlessly integrating the dedicated Nova radio network with commercial radio networks, and the development and timing of the Rakel G2 services. We have not made any changes to Core network costs in the PBE, but underline that these costs are uncertain and that they should be re-assessed at a later stage.

Figure S.1.5 shows the PBE estimated lifetime costs after all adjustments have been taken into account and we use a network lifetime of 20 years. The costs amount to MSEK 10,349, 25,478 and 2,399 for initial investments, recurring costs and reinvestment costs respectively. These are the costs which will be used as the base estimate in the cost uncertainty analysis.

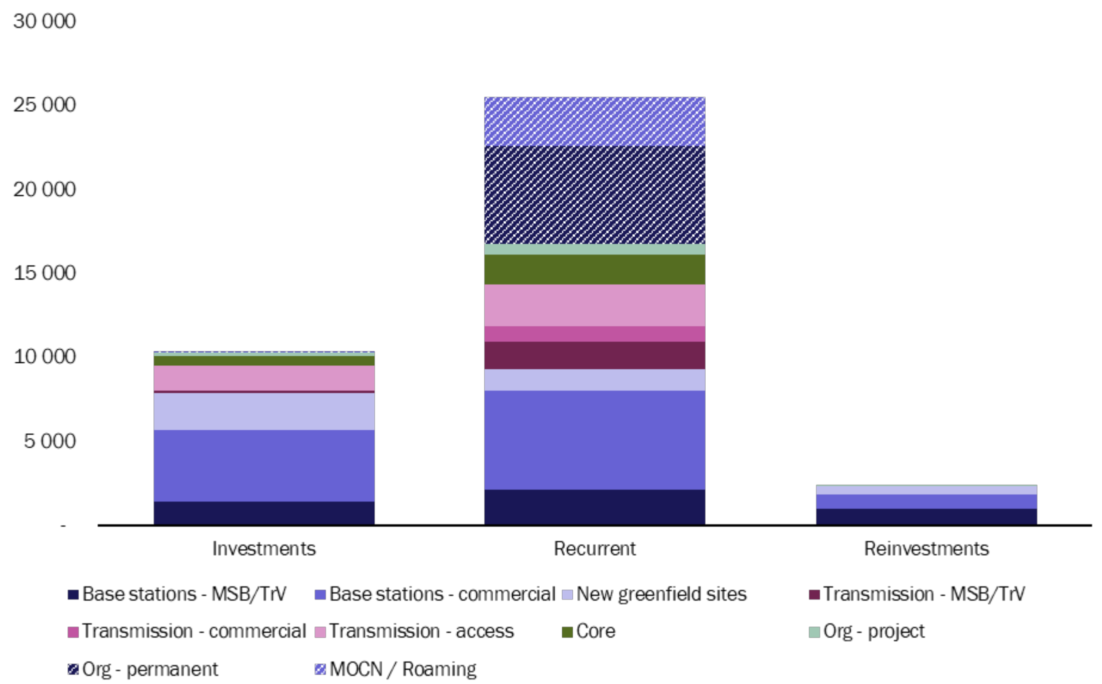


Figure S.1.5: Project Base Estimate in MSEK – Lifetime cost with 20 years lifetime

Summary and Introduction for the Uncertainty Analyses

Introduction to the Uncertainty Analyses

As the Swedish government does not have a fixed scheme for quality assurance of large national government investment projects, the quality assurance (QA) of the Rakel G2 project is based on the requirements for QA of large public projects in Norway, as established by the Norwegian Ministry of Finance. One of the key requirements in such Norwegian QA processes is to undertake an independent uncertainty analysis of the project's investment cost estimate, prior to presentation of the project to the Norwegian government and parliament for investment decision.

This chapter describes the method and analysis results of the independent uncertainty analysis carried out by the QA team of the Rakel G2 base cost estimate, which includes the base investment cost estimate and the base estimate of recurring costs for the operational phase of Rakel G2. These estimates are described in detail in the cost analysis of this investigation. We have also included a brief comparison of methods and results between our uncertainty analysis (UA) of the investment cost estimate and the UA of investment cost established by MSB and TrV in May 2022 (cf. Erdalen 2022).

The uncertainty analysis has mainly been undertaken through a workshop with all key members from the QA group. In the workshop, characteristics of the project have been reviewed relative to their risk potential, and an uncertainty register has been established through brainstorming and review of the uncertainties identified in the UA workshop held by MSB and TrV in May 2022. These uncertainties have been grouped into nine uncertainty drivers. Further, estimate accuracy uncertainties have been reviewed. Three-point estimates, P10 (ten percent probability of being within this cost frame), most likely (ML) and P90 (90 percent probability to be within the cost frame) have been established for each uncertainty element to quantify the uncertainties relative to each base estimate, before Dovre Group's stochastic analytical model (AnRisk) has been used to calculate the results of the uncertainty analysis.

The cost uncertainty analysis is based on an assumption of no delays in project sanction (2024), and no delays in yearly budget approvals. Extreme events (with marginal probability and large consequences), as well as major changes to concept or project premises, are excluded from the analysis. The uncertainty analysis is carried out early in the project preparation phase, with limited documentation available on the project preparations. Hence it is assumed that the project will provide documentation that project preparations are acceptable, with reference to the Norwegian Ministry of Finance's requirements (Finansdepartementet 2019; see also Direktoratet for økonomistyring 2021). The cost uncertainty analysis should be updated and finalized, after the project has completed its documentation on project preparations.

Both the QA team's uncertainty analysis and the MSB and TrV uncertainty analysis are based on the successive method developed by Steen Lichtenberg (2000). However, comparison between the two uncertainty analyses is challenging due to differences in methodology and timing between the analyses. The main difference between the analyses is related to the methodology for the analysis. As opposed to the QA team analysis, the MSB and TrV analysis is not based on a deterministic base estimate, but on an estimate reconciled in a group process.

Based on the results from the uncertainty analysis the QA-team has also made a recommendation on risk reducing measures for each of the defined uncertainty drivers of the project. The most important risk reducing measure at this project planning stage, as assessed by the QA team, is to develop a clearer high-level project design for the Nova project. Such a plan document should describe the services that will be offered in Rakel G2, the time and order in which these services will be introduced, and a realization plan for the services.

The Norwegian quality assurance scheme for major public investments does not entail mandatory requirements for conducting uncertainty analysis of project schedules across time. Yet, uncertainty related to the project implementation over time is most often considerable. An uncertainty analysis of the time schedule for Rakel G2 was also carried out by MSB and TrV and documented in a project internal investigation report by MSB and TrV (Erdalen et al. 2022).

At the end of our review of uncertainty aspects, we have included an analysis of the method and process for this schedule uncertainty analysis, a comparison with the method and process used by Dovre, member of the QA group, and our recommendations for MSB and TrV's next schedule uncertainty analysis (Erdalen et al. 2022). Lastly, we provide a brief comparison of the schedule in the Rakel G2 Planning and Preparation Report (by Myndigheten för samhällsskydd och beredskap and Trafikverket 2021b, made public March 2023) and the results of MSB and TrV's 2022 schedule uncertainty analysis.

Main Results from the Uncertainty Analyses

The main results of the preliminary cost uncertainty analysis are shown in Table S.1.1. Values are given as MSEK with cost level 2024. Recurring costs (i.e., costs related to operations) are limited to 20 years' duration. Reinvestments exclude investment in significant technology improvements and new technology. Recall that terminals and other user costs are not included in the PBE nor in the analysis, as it concerns users and not the infrastructure costs.

*Table S.1.1: Uncertainty analysis results – preliminary. * Not comparable with sum of investments, recurring costs and reinvestments due to portfolio effects*

Parameter	Investments (MSEK)	Recurring costs (MSEK)	Reinvestments (MSEK)	Total (MSEK)
Base estimate	10,349	25,478	2,399	38,225
Contingency	1,467	242	143	1,853
Expected cost (P50)	11,816	25,720	2,542	40,078
Management reserve	2,502	3,467	1,110	4,440*
P85	14,318	29,187	3,652	44,518*
Relative contingency (%)	14%	1%	6%	5%
Relative standard deviation (%)	20%	13%	42%	11%

The uncertainty for (initial) **investment costs** is dominated by market uncertainty, site and transmission conditions and estimate accuracy uncertainty related to unit costs for equipment. The contingency of 14 percent to the PBE (for investments) and standard deviation of 20 percent of the expected cost are within the normal range for a project at this development stage.

The uncertainty for **recurring costs** is dominated by uncertainty related to the operating organization's capability for successfully undertaking the operation and supervision of the network, by estimate accuracy uncertainty related to the number of personnel needed for the operating organization, and by estimate accuracy related to unit costs for the operation scope, that is annual OPEX costs (operating expenditure, i.e., recurring cost for the operational phase). The overall contingency of 1 percent to the PBE (for recurring costs) indicates the base estimate is on a probable level. The QA group has identified the cost estimate for recurring costs based on documented and plausible reference data with low uncertainty. Further, most of the uncertainty elements are assessed with symmetric uncertainty spans. The aggregated uncertainty range represented by one standard deviation of 13 percent of the expected cost is somewhat low, but this must be seen in relation to the quality of the reference data.

The uncertainty for **reinvestment costs** is dominated by estimate accuracy uncertainty related to the percentage used to calculate reinvestment needs, by market uncertainty and by site and transmission conditions. The overall contingency of 6 percent to the PBE (for reinvestments) is low. Yet, it is mainly caused by reinvestments being far in the future, leading to many of the uncertainty elements being symmetrically quantified. The low contingency should also be seen in context with the very wide uncertainty span from the analysis, represented by one standard deviation of 42 percent of the expected cost. This is due to the fact that several uncertainty drivers are quantified with wide uncertainty spans, including the above-mentioned estimate accuracy uncertainty related to reinvestment needs.

Recurring costs amount to approximately two-thirds of the total costs, both in terms of PBE and in terms of expected costs. Accordingly, the analysis results for recurring costs have a profound impact on the overall contingency and relative standard deviation for the total project costs. The overall uncertainty in the project is dominated by uncertainty related to the organization and management, dominant for both the investment phase, the operation phase and for reinvestments. Further, the cost uncertainty is highly affected by market uncertainty and by estimate accuracy uncertainties for recurring costs.

We do not conduct an uncertainty analysis of the time schedule anchored in the project cost analysis, as we deem the affiliated documentation insufficient in our quality assurance of the project preparations. For the same reasons, we have not performed a quality assurance of the project's plans and durations, as no current sufficiently detailed schedule exists. Furthermore, the existing schedules from MSB and TrV's project report for planning and preparation of the further development and establishment of Rakel G2 (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021) was compared to the project internal uncertainty investigation in Erdalen et al. (2022). Both have been prepared in an early planning phase. Besides, both are at a very general level with a very limited number of activities, and where the logic and durations of the two existing schedules differ considerably.

Instead, we have carried out a comparative analysis of the method and process of MSB and TrV's schedule uncertainty analysis (Erdalen et al. 2022). As the analysis was done in the early planning phase, few strategies and details were in place. Except for general uncertainties, the study contains no documentation data used nor any description of the reasoning behind durations and uncertainty quantifications. Furthermore, the impact of general uncertainties is only shown for the total project duration and not allocated to the relevant activities and cost their effects. Thus, there is a high likelihood for overlaps in quantifications of activity uncertainties and quantification of general uncertainties. By the same token, MSB and TrV's project internal report breaks down the project into seven high level activities only, leaving subactivities and their dependencies undefined and untreated. In addition, limited identification of a network of processes and dependencies, long activity durations could give a wrong analysis result (ibid.).

Based on our concerns and our impression of changed planning assumptions since May 2022 (when MSB and TrV's internal uncertainty investigation was carried out), we support the Nova project's plans for a new uncertainty analysis on the time schedule in the second half of 2023. Our recommendations for a next schedule uncertainty analysis chiefly concern prerequisites, planning and execution of the analysis and execution plan finalization.

With regard to prerequisites, we recommend the establishment of a high-level project design with an affiliated execution strategy and a detailed draft execution schedule. On planning, preparations and execution, we recommend establishment of a more detailed planning network for the uncertainty analysis, quantification of general uncertainties before estimate accuracy uncertainties, quantification of the uncertainty drivers on activity level rather than overall project level, and documentation of all experience data applied by the workshop participants. In finalization of the execution schedule, we recommend that the project considers how the results from the uncertainty analysis and likely effects of risk reducing measures may warrant changes to the detailed execution plan and that a concise management plan should be prepared.

Quality Assurance of Project Preparations

Introduction to Quality Assurance of Project Preparations

In the 1980s and the 1990s, Norway experienced significant cost overruns on several large public projects. Consequently, from the year 2000 onwards the Ministry of Finance introduced mandatory governance arrangements for major government funded public projects, including requirements for independent external quality assurance of the project management documentation (project preparations) and the project's cost estimate (KS2). Dovre Group has held frame agreements with the Ministry of Finance since the year 2000 for quality assurance assignments, from 2005 in a consortium with TØI, up to today. Since the year 2000, Dovre and TØI have undertaken quality assurance of project preparations and cost estimates for close to 80 projects. The Ministry's associated quality assurance requirements and guidelines have later been revised and further elaborated (Finansdepartementet 2008, 2019a, 2019b and 2020 and Direktoratet for økonomistyring 2021). Quality assurance of project preparations is not needed for parliamentary approval in Sweden, but we still consider quality assurance of the project preparations as highly advantageous also in a Swedish context, in order to reduce risks for cost overruns and project delays.

The quality assurance of project preparations investigates the project documentation within three main topics – the project's overall framework, project strategy and project control basis. Each of the main topics includes four to six subtopics, such as the project's identification of its critical success factors, interfaces, strategy descriptions, project ownership and project execution organization, quality of the cost estimate and of the project schedule. The Norwegian requirements for project preparations are in accordance with sound project practice, and similar requirements can be found in many large international corporations which regularly implement large investment projects, such as energy projects. Furthermore, the consistency between the topics is also reviewed in the quality assurance process, such as consistency between the work break-down structure (WBS), estimate, project time schedule and organization structure.

In the Norwegian quality assurance scheme for major public investments, for projects where the managing documents are found insufficient and the project is deemed immature, the quality assurer will call for more documentation before national government and parliamentary approval. Such a requirement does not exist in Sweden, but to minimize the risk of budget overruns and ensure predictability of the project, it is still recommendable to have thoroughly processed documents for project organization and governance setup.

Summary and Recommendation on Documentation Needs Concerning Project Preparations

Overall, our review of decision preparation documents on project organization and implementation shows a considerable amount of missing documentation. This holds for all key aspects of the affiliated documentation, including the project's overall framework, strategy project and control basis. Moreover, none of the topics assessed in the Norwegian quality assurance scheme for large national government investments were considered having complete documentation, as depicted in Table S.1.2.

For the overall framework, the documentation on purpose, requirements and main concept, and critical success factors, would have met the minimum requirement for quality assurance by the Norwegian quality assurance scheme, despite some weaknesses. The documentation for the other topics would have been considered insufficient to move forward for parliamentary approval in Norway, either due to decisive deficiencies in the documentation (i.e., project framework and project objectives) or non-existing documentation (i.e., interfaces).

For the project strategy, none of the topics met the documentation requirements set by the QA team. The documentation was deemed to involve decisive deficiencies for the execution strategy and the organization and management, while no documentation was found for the strategies on risk management and contract design.

For the project control basis, work breakdown structure and cost estimate, as well as budget and phasing, there was sufficient documentation to move forward in the Norwegian quality assurance scheme, despite some weaknesses. Yet, other documentation would have been deemed insufficient by the Norwegian scheme due to decisive deficiencies (i.e., project schedule and scope of work, including management of change) and non-existing documentation (i.e., benefits realization plan and quality assurance and control).

Table S.1.2: Assessment of missing project preparations – overall framework. Green color: Sufficient documentation. Yellow color: Documentation with some weaknesses. Orange/red color: Documentation with decisive deficiencies. Dark red color: No documentation

Main topic	Subtopic	Missing descriptions / documents	Status
Overall framework	Purpose, requirements and main concept	Purpose described in Government assignment. Precise descriptions of concept, requirements and expected performance missing	
	Project objectives	Objectives included in UA document neither complete, measurable nor prioritized	
	Critical success factors	Not specifically described, but several measures included in UA report can be regarded as success factors	
	Project framework	Descriptions on TrV / MSB's project planning / execution framework, as well as laws and regulations missing	
	Interfaces	No descriptions (technical, organizational, commercial interfaces)	
Project strategy	Risk management strategy	Not described in documents received to date	
	Execution strategy	Brief description only in the Rakel G2 Planning and Preparation Report (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021)	
	Contracts strategy	Not described in documents received to date	
	Organization and management	Division of roles/duties between MSB and TrV is described. Other information on how project is organized and managed is missing	
Project control basis	Scope of work, including management of change	Detailed descriptions of project scope are missing, but quantities are given in the project's cost estimate. No information on change management.	
	Work breakdown structure	Described in UA report from May 2022, but need information/confirmation on final structure	
	Cost estimate, budget and phasing	Detailed estimate received, but overview and verifiability are challenging. Investment estimate not structured in accordance with WBS.	
	Benefits realization plan	Not yet received	
	Project schedule	Brief description only in project's final report	
	Quality assurance and control	Overview of QA/QC procedures and requirements for the project not yet received.	

The quality assurance group was asked to do the quality assurance of the project preparations on project management, governance and organization at a point in time when the project preparations still were not complete. Before the project launch, we strongly recommend that the MSB and TrV prioritize to improve the project preparations and its documentation on project preparations, similar to the Norwegian requirements. We also encourage quality assurance of these documents. However, we acknowledge that the requirements for quality assurance set by the Norwegian quality assurance scheme for large national government investments do not apply to Sweden. Accordingly, the project may have more flexibility with regard to documentation than major Norwegian investment projects.

Analyses of Impacts External to the Infrastructure Project

Introduction and Motivation for Investigation of Impacts External to the Infrastructure Project

In this chapter, we analyze impacts of Rakel G2 that are external to the Nova project. These impacts are in some way assessed at the first stage of the Norwegian quality assurance system (KS1). In addition, except for the user cost analysis, we evaluate the impacts of Rakel G2 against a reference scenario, where Rakel G1 is gradually phased out and replaced by uncoordinated use of mobile network services for public protection and disaster relief (PPDR) purposes. The five impact analyses carried out in this chapter are listed in the following:

- **Direct user impacts**: When focusing solely on the cost side of infrastructure projects, there will always be a danger that one disregards the user benefits, which constitute the motivation for the project solution in the first place. Here, we will explore the user benefits applying a multi-criteria analysis for various stakeholders, reflecting direct beneficial effects of the quality of the mobile network.
- **Gross user costs:** While infrastructure project analysis typically constitutes the core of the appraisal in public infrastructure investment projects, user costs are often ignored, even though they may be substantial. We estimate the gross user costs associated with the whole system integration project, where the term “gross” reflects that the alternative user costs have not been assessed.
- **Indirect impact:** Much of the attention in public debate on public emergency networks is directed towards indirect impacts, which are typically non-monetized. In our investigation, we provide a qualitive overview of indirect impacts, including impacts on aspects of spectrum utilization, cooperation, production economy, knowledge generation, security and environmental issues.
- **Marginal costs of public funds:** In both Norwegian and Swedish methodology for cost-benefit analysis from a society point of view, marginal costs of public funds usually constitute a considerable component of the total net and gross costs. In this investigation, we estimate the net marginal costs of public funds of infrastructure cost and the gross marginal costs of public funds of user costs, as well as assessing tax distortions originating from non-monetized impacts qualitatively.
- **Distributional considerations:** Public decision-makers should not and do not only care about the net benefit of a project, but also about distributional aspects. Towards the end of the project, we have assessed the distribution impacts of the infrastructure project, concerning various stakeholders (i.e., the horizontal dimension), groups with various socio-economic backgrounds (i.e., the vertical dimension), various geographical locations (i.e., the spatial dimension) and across time (i.e., the intergenerational dimension).

Summary of the Analyses of Impacts External to the Infrastructure Project

Public safety users need modern communication services that are reliable, secure and easy to use wherever they operate and in all situations. Based on interviews with several Rakel users, we assess that robustness is the most important user priority, followed by functionality, user experience and coverage. Interoperability and security are also important, while capacity was rated least important.

We have compared the current Rakel G2 setup with a reference scenario, where Rakel G1 is kept alive as long as possible and mobile data to PPDR users is delivered over regular comercial networks.

As the ultimate benefits of increased service quality caused by Rakel G2 are hard to address accurately, we proxy these impacts by addressing direct user benefits for the emergency services. Table S.1.3 shows a relative comparison of the project's assessment of expected user benefits in the Rakel G2 scenario and the reference scenario. Interoperability is the attribute with the highest expected improvement from the reference scenario to Rakel G2. Also, we expect improvements in robustness, user experience, coverage, security and capacity with Rakel G2 compared to the reference scenario. In terms of capacity, it is important to note that it will likely be possible to get priority in commercial mobile networks, which is an advantage with Rakel G2. The anticipated improvements in robustness and capacity both require a seamless multi-operator core network (MOCN) solution. The only attribute where we do not expect an improvement compared to the reference scenario is functionality.

Table S.1.3: User benefits in Rakel G2 versus reference scenario

Benefit	Weight	Rakel G2 scenario
Robustness	23	+
Functionality	21	0
User experience	20	+
Coverage	20	+
Interoperability	18	++
Security	17	+
Capacity	14	+

In addition to subscription fees, Rakel G2 users will incur other direct costs. First, they will have to pay for terminals and in some cases the installation of terminals. In addition, there will be costs for integrating Rakel G2 services with the users' applications and IT systems. We estimate initial terminal and integration costs to be around BSEK 1. This estimate does not include VAT, procurement or training costs. Annual costs are around MSEK 125 per year or BSEK 2.5 over a 20- year span. This means that total estimated user costs are BSEK 3. when both initial and recurring costs are included. Please note that these are the gross user costs of Rakel G2. The net user costs excluding the subscription fees will be lower, as there will be user costs in the reference scenario as well.

Nevertheless, the network subscription costs will most likely be higher than the additional subscription costs associated with Rakel G1 and private subscriptions in the reference scenario. Thus, we expect considerable net user costs associated with subscription fees, which should have been subtracted from the subscription revenues for the infrastructure project in a cost-benefit analysis.

Furthermore, implementation of Rakel G2 induces a wide range of indirect impacts. A brief overview is provided in Table S.1.4.

Table S.1.4: Overview of Indirect impacts

Indirect Impact Group	Description
Impacts on spectrum utilization	• Reduced spectrum availability for public mobile networks • Improved coverage in rural areas • Indirect spectrum impacts caused by competition impacts
Cooperation	• Interagency cooperation between the emergency services • Cooperation with others across networks
Economic	• Potential comparative advantage for Telia from the MOCN solution • Important assignment for the chosen system supplier • Available capacity and healthy competition prevent distortions within construction
Knowledge generation	• Learning outcomes on integration between civil and PPDR networks • Technology-specific training costs and learning outcomes
Security	• National security, network ownership and protection against hacking • Emergency preparedness for the civil emergency agencies and the military • Personal security and privacy • Perceived security
Environmental	• Construction affects landscape value at sites • Daily operations indirectly involve climate through the energy consumption

First, the spectrum utilization is affected by fewer frequencies available for auctions, additional construction of mobile coverage in rural areas and indirect influences through competition impacts. Second, Rakel G2 will affect cooperation between the emergency services and their interaction with other partners applying another network. Third, Rakel G2 will affect compete-tion and economic capacity in several markets, providing Telia and possibly systems suppliers (e.g., Ericsson) with competitive advantages in the market for telecommunication services and manufacturing, respectively. Competition in the market for telecommunication construction is on the other hand likely to be less affected due to available capacity and healthy competition.

Fourth, Rakel G2 will generate new knowledge on integration between civil and PPDR net-works, as well as on technology-specific training costs and learning outcomes. Fifth, Rakel G2 will influence PPDR security, mostly in terms of improvements such as network ownership and protection against hacking, and emergency preparedness for the civil emergency agencies. In addition, the network may enhance personal security and privacy, and contribute to higher perceived security. Last, the project will also entail some environmental impacts such as effects on landscape values at sites in connection with construction and greenhouse gas emissions through energy consumption related to daily operation.

As realization of Rakel G2 calls for tax funding and comes at the expense of tax cuts and wel-fare arrangements, it will involve distortion in the tax system. We estimate the net marginal costs of public funds for the infrastructure project to BSEK 3.84. Furthermore, we estimate the gross marginal costs of public funds related to the user costs to BSEK 1.05, where user costs in the alternative scenario are left unaccounted for. In addition, Rakel G2 will involve indirect tax distortion, especially in connection with the loss of public revenues from spectrum auctions.

Rakel G2 also involves considerable distributional impacts. Some of these are connected to tax funding, including infrastructure costs and user costs of the project, as well as the induced distortion in the tax system. Other distributional impacts relate to user benefits and indirect impacts, building further on the related non-monetized analyses.

Overall, the infrastructure project involves a redistribution to actual and potential users of emergency and preparedness services from taxpayers and receivers of welfare arrangements that alternatively would have been funded. Furthermore, Rakel G2 may contribute to improved mobile coverage in rural areas. If the project is funded by loans rather than grants, it will imply a redistribution to the current population from the future population.

SVENSKA **Sammanfattning**

Kvalitetssäkring av Nya svenska offentliga nödnetet, Rakel G2

Rapport från 30. juni

TØI rapport 1972/2023 • Forfattere: Rasmus Bøgh Holmen, Harald Wium Lie, Inge Mossige, Amund Kvalbein, Anders Ågotnes, Espen Sørlie, Guri Natalie Jordbakke, Jostein Tvedt, Lars Juvik, Sunniva Frislid Meyer • Oslo, 2023 • 124 sider

I den här undersökande rapporten så har vi kvalitetsgranskat projektet för det nya svenska räddningstjänsts- och katastrofskyddsnätverket (PPDR-nätverket) Rakel generation två (Rakel G2). Rakel G2 planeras som ett hybridnätverk där ett statligt ägt kärnnät är sammankopplat till en eller flera kommersiella mobila nätverk genom ett så kallat multi-operatörs kärnnät (multi-operator core network, MOCN). Det nya 5G baserade nätverket kommer tillhandahålla datatjänster, inklusive video i tillägg till push-to-talk (PTT) och meddelandetjänster. Nyckelanvändare kommer att vara ambulans, brandförsvar, sjöräddningstjänst och polis. Vårt uppdrag är att utföra en ex-ante utvärdering av beslutsunderlag för nästa fas i infrastrukturprojektet, genom antagna metoder från det norska kvalitetsgranskningssystemet för stora statliga upphandlingar. Kvalitetsgranskningen inkluderar analys av projektkostnad och en osäkerhetsanalys samt kvalitetsgranskning av projektförberedelserna och även en analys av effekter externa till infrastrukturen.

I många länder närmar sig de äldre nödsystemen slutet av sin användbara livslängd. Svenska myndigheter vill ersätta dagens system (Rakel generation 1, Rakel G1) med ett nytt kommunikationsnät för räddningstjänsts och katastrofskydd (även kallat PPDR-nätverk eller blåljusnät), som i regeringsuppdrag benämnts Rakel generation två (Rakel G2). Dagens Rakel G1 system bygger på TETRA-teknik och består primärt av mission critical (MC) push to talk (PTT) och meddelandetjänst, medan Rakel G2 kommer besitta ytterligare funktioner för mobildata som inkluderar video och internet of things (IoT). Nya funktioner skapar möjligheter för nya användningsområden och för säker samverkan inom och mellan organisationer.

Rakel G2 planeras vara ett hybridnätverk för mobil elektronisk kommunikation, i ett statligt ägt 5G radioaccessnätverk i 700 MHz-bandet hängivet för att tillhandahålla kärnnätet. Hybridlösning er ment å skapa flexibilitet, där kommersiell och statlig infrastruktur för radioaccess kompletterar varandra gällande täckning, kapacitet och robusthet. Kärnnätet kommer vara sammankopplat med ett eller flera kommersiella mobila kommunikationsnätverk genom ett så kallat multi-operatörs kärnnät (multi-operator core network, MOCN). Nyckelanvändare kommer att vara ambulans, brandförsvar, sjöräddningstjänst och polis.

Regeringens uppdrag riktas gemensamt till Trafikverket (TrV), Myndigheten för samhällsskydd och beredskap (MSB) och Affärsverket svenska kraftnät. Enligt Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b) handlar Rakel G2 ytterst om att myndigheter som har i uppdrag att säkerställa samhällets säkerhet och trygghet och att medborgarna har rätt förutsättningar att göra det. Under 2023 levereras beslutsunderlag till den svenska regeringen för fortsatt etablering av Rakel G2.

Till skillnad från den svenska regeringen så har Norges regering utvecklat ett system för kvalitetssäkring av stora offentliga upphandlingar. I den här undersökande rapporten så har Transportøkonomisk institutt, Dovre Group och Analysys Mason anlitats för att utföra ex-ante kvalitetssäkring av beslutsunderlag för Rakel G2 projektet, i linje med det norska kvalitetssäkringssystemet. Detta kvalitetssäkringssystem måste utföras i två steg. Det första steget av kvalitetssäkring (KS1) utförs innan en förfrågan framförs till regeringen angående val av projektkoncept. Det andra steget av kvalitetssäkring (KS2) utförs innan en förfrågan framför till regering och riksdag för godkännande av projektets investeringsbudget.

I den utsträckning som tidigare granskningar av Rakel G2 utförts så har de inte följt den norska modellen. Vidare så är de svenska kraven utformade annorlunda än de norska, vilket innebär att projektförberedelserna har utförts i en annan ordningsföljd och med andra prioriteringar jämfört med det norska systemet. Därav innehåller denna kvalitetssäkring både komponenter som klassificeras som tidigt (KS1) och sent (KS2) stadie av kvalitetssäkring givet den norska modellen.

Vidare utsätts inte de svenska myndigheterna för samma granskningskrav som de som innefattas av den norska modellen, vilket innebär att de har en mindre stringent projektförberedelse och större flexibilitet i deras projektstyrning. Det har ändå varit en viktig premiss för denna KS-utredning att följa metodiken som används i Norge med viss anpassning till kontexten för de svenska projektförberedelserna. Det svenska projektet närmar sig nu Riksdagens godkännande.

En annan central premiss för kvalitetsgranskning är att valet av koncept redan är gjort. Det innebär att det dedikerade räddningstjänsts- och katastrofskyddsnätverket med MOCN-lösningen samt specificerade MC tjänster endast utvärderas mot ett referensscenario. I referensscenariot så är Rakel G1 gradvis ersatt av icke-koordinerad användning av kommersiella elektroniska kommunikationstjänster i kommersiella nätverk. Andra konceptuella variationer, bland annat de som berör andra grader av användning av kommersiella nätverk och andra krav på MC tjänster, beaktas inte.

Vårt uppdrag har varit att kvalitetssäkra projektförberedelserna för realisering och etablering av Rakel G2. Genom att använda modellen för norsk kvalitetssäkring för stora offentliga upphandlingar så har vi genomfört fyra huvudanalyser, där varje område tilldelats ett kapitel i vår granskningsrapport:

- **En projektkostnadsanalys**, där vi har granskat och utvärderat projektets egna grunduppskattning av projektkostnaderna för hela livscykeln, tagit fram en uppdaterad grunduppskattning och jämfört den mot interna projekt samt övervägt finansieringsalternativ
- **Osäkerhetsanalyser**, som innefattar en osäkerhetsanalys av KS-gruppens uppdaterade grunduppskattning för livscykelkostnader och en kvalitetsgranskning av projektets egna metoder och processer samt även en oberoende osäkerhetsanalys av kostnader och tidsplanen

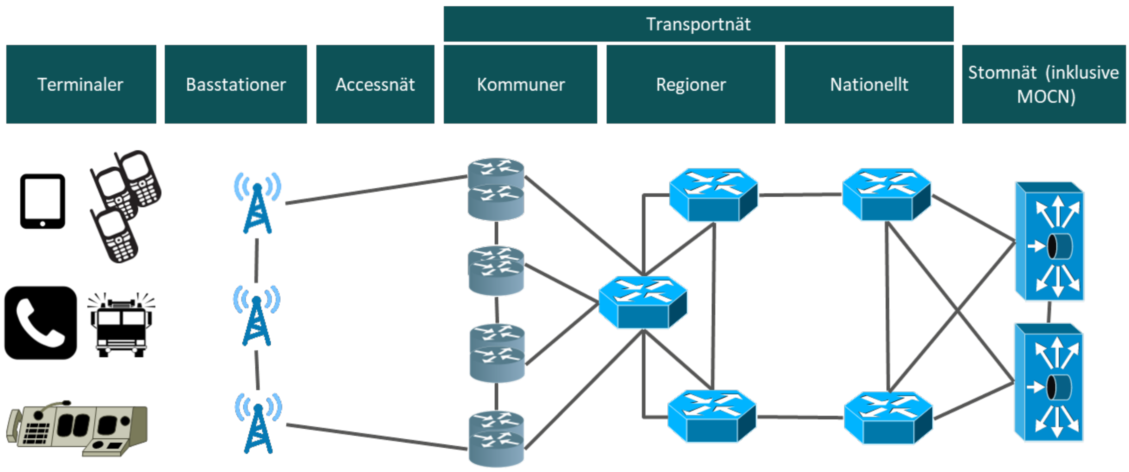
- **Kvalitetssäkring av projektförberedelserna**, vilket inkluderar nyckelkomponenter som projektinramning, styrnings- och kontrollprinciper och strategi och organisation
- **Analys av externa effekter av infrastrukturprojektet**, vilket inkluderar analys av direkta effekter för användare, bruttokostnader för användare, indirekta effekter, samt snedvridning inom beskattning och fördelning. Det utvalda projektkonceptet jämförs med ett referensscenario där det nuvarande PPDR-nätverket (Rakel generation ett, Rakel G1) är gradvis ersätts av kommersiella mobiltjänster utan central koordinering

Kvalitetssäkring av projektkostnadskalkyler och finansieringsalternativ

Introduktion till analys av projektkostnad och överblick av nätverket

Detta kapitel dokumenterar kostnadskalkylen från MSB och TrV och vårt arbete med att granska modellen. Detta kapitel beskriver också våra föreslagna förändringar till modellen baserat på prestandajämförelser och sju expertintervjuer. Vi refererar till originalmodellen som ”Novamodellen” och vår reviderade modell som ”Project Base Estimate” eller ”PBE”, mätt i svenska kronor i 2024 års prisnivå.

Detta kapitel innehåller också en övergripande beskrivning av Rakel G2s mobila nätverk samt de komponenter som är inkluderade i kostnadsanalysen. Ett mobilt nätverk består av flertalet komponenter, se Figur S.1, och kostnadsanalysen är strukturerad i linje med figuren.



Figur S.1: Systemöversikt

Figuren ovan består av ett systemdiagram för ett PPDR-nätverk som har utgjort grunden för vår kostnadsanalys.

Terminaler och kontrollrum

Terminaler är längst till vänster i Figur S-1. För de flesta slutanvändarna så är det en bärbar mobiltelefon men det kan också vara fasta terminaler i fordon och helikoptrar samt uppkopplade sensorer eller ställdon. Utöver det så kommer det finnas utrustning i kontrollrum (t.ex SOS alarm centraler), där Rakel G2 terminaler kommer vara integrerade med programvara för nödsituationer och allmän nätverksuppkoppling. Rakelorganisationen kommer specificera vilka typer av terminaler som kommer kunna vara möjliga att använda i G2 nätverket, men det är användarna som är ansvariga för inköp av terminaler. Kostnaderna för terminalerna är exkluderade från kostnadsanalysen, men de spelar en viktig roll för huruvida Rakel G2 kommer vara en framgång.

Basstationer

Terminalerna kommunicerar med basstationerna. Rakel G2 planerar för fler än 7000 basstationer i Sverige, med målbilden att leverera nationell radiotäckning, även i vissa zoner som inte täcks av dagens allmänna nätverk. Radiotäckningen kommer etableras genom att använda 2x10 MHz av dedikerat radiospektrum i 700 MHz-bandet. 700 Mhz-bandet karaktäriserats av god täckning och potential för lång räckvidd samt hög penetreringsgrad av husväggar och andra hinder. Kapaciteten av dataöverföring i detta band är däremot begränsad. Planen är att utöka kapaciteten för Rakel G2 genom avtal med en eller flera kommersiella mobiloperatörer.

Accessnätet

I fasta nätverk definieras ofta accessnätet som anslutningen mellan slutanvändare och operatörens närmsta knutpunkt/nod. I mobila nätverk så definierar vi accessnätet som anslutningen mellan en basstation och den närmsta aggregationspunkten. Mobila accessnät kan konstrueras på olika sätt. I kommersiella mobila nätverk så är ofta accessnätet utformat i en stjärnstruktur där en basstation har anslutning till en aggregationspunkt.

I Rakel G2 kommer accessnätet ofta vara byggt i en cirkelstruktur där varje sändarstation har två anslutningar till accessnätet. Det innebär att om en länk brister så leder inte det till att den sändande stationen mister uppkoppling till resten av nätverket. Anslutningarna i accessnätet kan utformas med punkt-till-punkt radioförbindelser (”radiolänk”), fibernätverk eller via satellit. Över tid så kommer sannolikt andelen fiberanslutningar öka på grund av nya servicekrav för nya generationer av mobil teknologi. Fibernätverk anses i de flesta fall inneha högre kapacitet än radiolänk.

Transportnätet

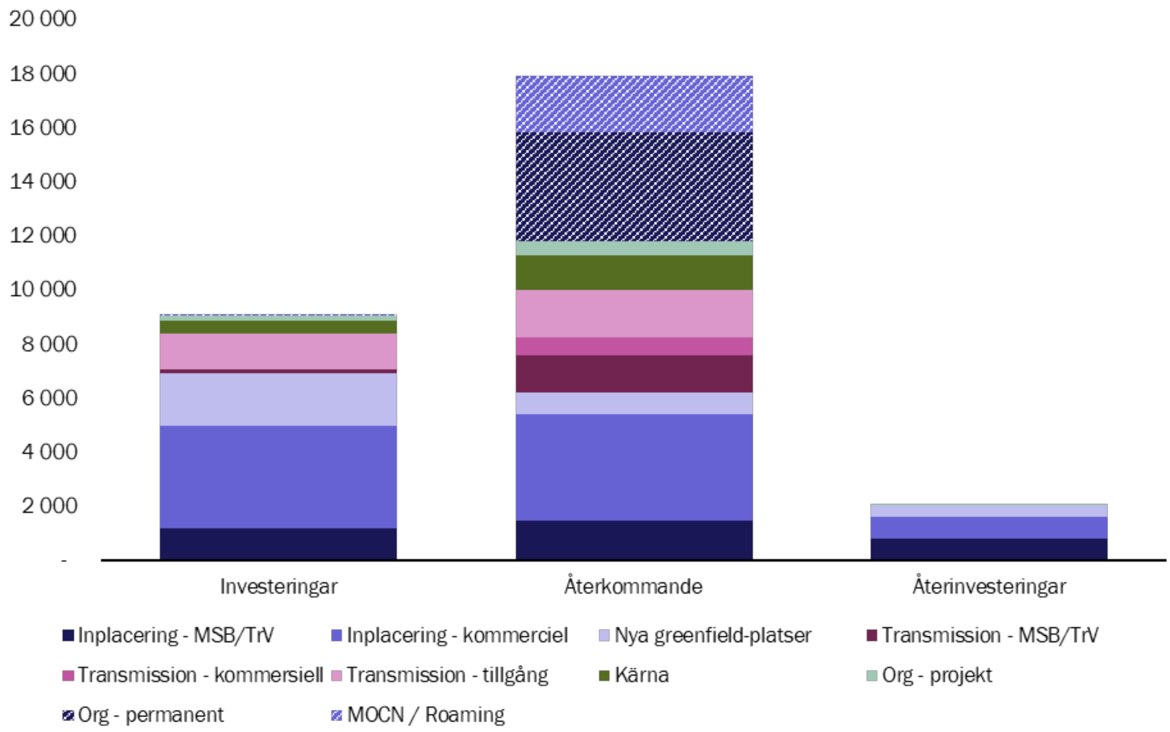
Figur S-1 illustrerar hur accessnätet förbinds med siter i kärnnätet. Rakel G2 kommer upprätta cirka 1200 knytpunkter (”kommun-siter”) för att förbinda basstationer till transportnätet. Därefter ansluter transportnätet dessa knytpunkter till centrala komponenter så som kärnnätet och serviceplattformar.

Kärnnätet och serviceplattformar

Kärnnätet består av flertalet komponenter som behandlar trafik och användare. Rakel G2 är planerat att vara ett 5G nätverk med ett fristående 5G kärnnät. 5G kärnnätet ansluter till en serviceplattform som ansvarar för tjänsteproduktionen. Rakel G2 kommer leverera kritiska räddningstjänsts- och katastrofsskyddstjänster så som röstsamtal, gruppröstsamtal och meddelandetjänster. Kapaciteten för mobila datatjänster kommer öka genom tillgång till multi-operatörkärnnät (MOCN) vilket innebär att användare kan kopplas upp mot Rakel G2 genom kommersiella radioaccessnät. Det finns i nuläget osäkerhet angående tidslinjen för lanseringen av de olika tjänsterna.

Summering av projektkostnadsanalysen

Novamodellen är en detaljerad Excel-arbetsbok som redogör nya investeringar, återkommande kostnader, återinvesteringar och intäkter. I vår analys så har vi omkonstruerat modellen för att skapa en tydligare uppdelning av kostnads- och intäktskomponenter. Figur S.2 visar att Novamodellen uppskattar kostnaderna för nya investeringar till 9,100 MSEK, 17,900 MSEK för återkommande kostnader och 2,100 MSEK för återinvesteringar för nätverkets 17 åriga livscykel. Kostnadsposterna summeras till 29,100 MSEK. Novamodellen estimerar intäkterna till 16,300 MSEK och därav är nettokostnaden 12,800 MSEK.



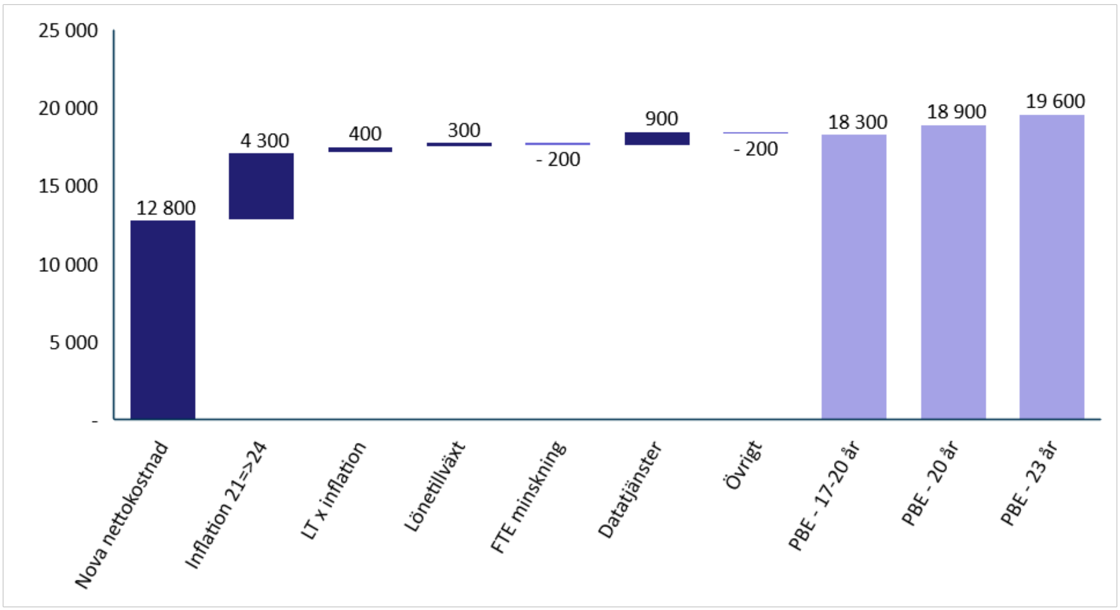
Figur S.2: Nova livscykelkostnader i MSEK

Vår bedömning är att Novamodellen är detaljerad och noggrann. De flesta estimaten har dokumenterad källhänvisning och kostnadskällorna är förklarade samt modellerade i detalj. Det finns dock några kritiska osäkerheter, det finns även några justeringar som vi anser bör appliceras i modellen. De viktigaste korrigeringarna är följande:

- De flesta kostnadsförslagen var insamlade under 2021 och 2022. Sedan dess har Sverige haft hög inflation, och vår bedömning är att i många fall så kommer kostnaderna i 2024 års prisnivå vara högre än estimaten i Novamodellen
- Vår bedömning är att över tid så kommer energi- och konstruktionskostnader stiga mer än andra kostnader. Notera att vi inte har inkorporerat de mest extrema energiprisökningarna för vintern 2022 och 2023. Dessa kostnadsposter är centrala i Novamodellen. Vi har korrigerat PBE till att inkludera en ytterligare årlig prisökning av 1 procentenhet för konstruktionskostnader och två procentenheter för energikostnader (utan att inkorporera de extrema energipriserna under vintern 2022/2023).
- Novamodellen inkluderar inte reallöneökningar för tillsvidareanställda. Över tid så bedömer vi att löneposterna kommer öka med 1.15 procentenheter mer än inflationen.

- På intäktssidan så har den förväntade lanseringstidpunkten försenats givet information från MSB och TrV. Vidare så är avgiften för mobilt bredband högre än vad vi tror användare av räddningstjänst och katastrofskydd[2] är villiga att betala. Således har vi minskat den förväntade intäkten från bredbandstjänster.
- Novamodellen räknar med 143 anställda i Rakel G2 över tid. Utöver det så kommer det finnas 63 anställda i TrV transportnätsenhet som hanterar Rakel G2. Vi bedömer att Rakel G2 är möjlig att bedriva med 130 anställda och har därav korrigerat PBE i linje med det.

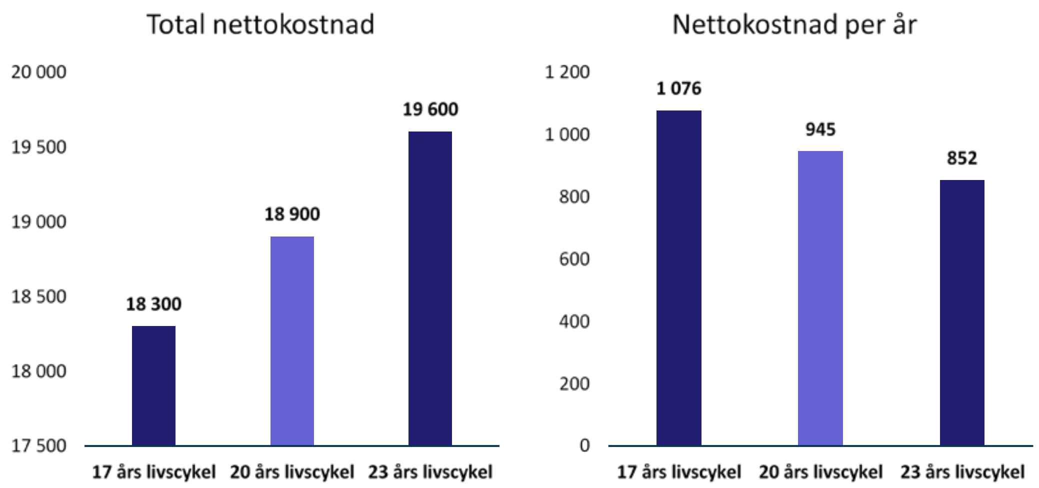
Vi har också utfört mindre korrigeringar för buggar i modellen samt för kostnader relaterade till transmissionsutrustning. De totala korrigeringarna har ökat nettokostnaden från 12,800 MSEK till 18,300 MSEK, vilket framgår i Figur S.3 med antagandet att livscykeln fortfarande är 17 år.



Figur S.3: Project Base Estimate i MSEK – förändringar i nettokostnad

De flesta mobilnätverk har en livscykel på mer än 17 år, vi tror att nätverkslivscykeln för Rakel G2 rimligtvis kan vara 20 år. Detta skulle leda till att nettokostnaden i PBE ökar från 18300 MSEK till 18900 MSEK ("PBE – 20 år"), men kostnaden per år minskar från 1076 MSEK (17 års livscykel) till 945 MSEK (20 års livscykel), vilket illustreras i Figur S.4. Det är möjligt att förlänga nätverkets livscykel ytterligare, men det skulle med stor sannolikhet leda till ytterligare återinvesteringar.

[2] I Sverige ofta refererade som «Blåljusmyndigheter ».

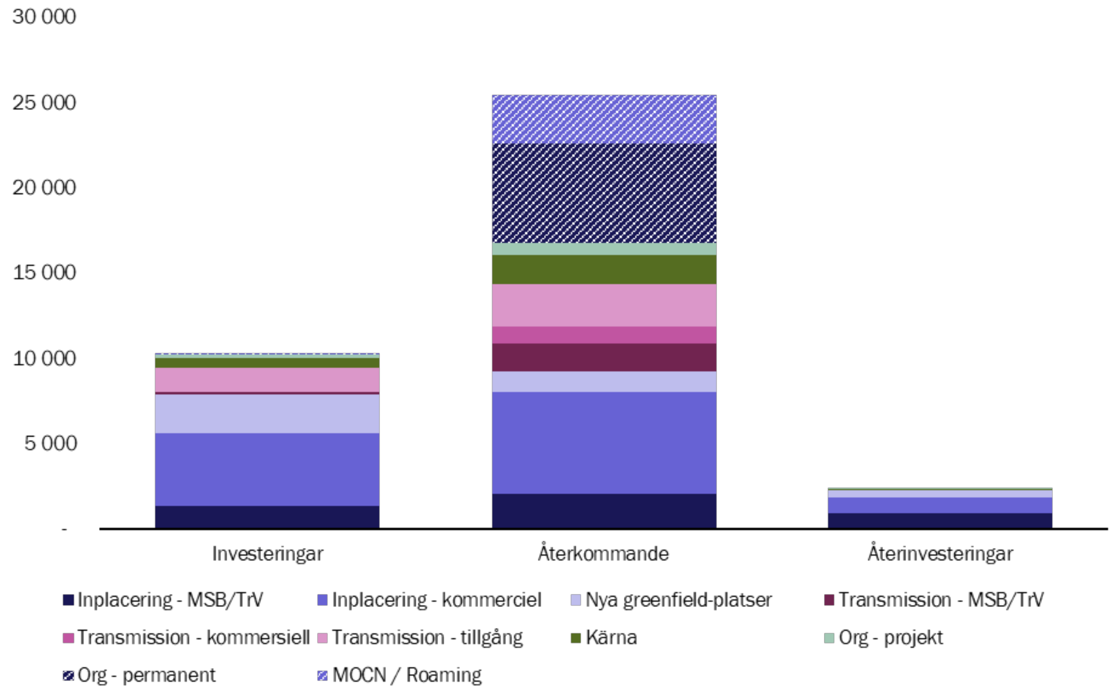


Figur S.4: Nettokostnader i a) totala (till vänster) och b) nettokostnader per år med olika livscyklar för nätverket (till höger)

Vi har inte gjort några förändringar för kostnader relaterade till basstationer eller till kärnnätet. Kostnaden för siter utgör mer än 50 procent av de totala kostnaderna i både Novamodellen och i PBE. En detaljerad radioplan krävs för att uppskatta antalet siter som behövs, vidare så varierar kostnaden per site markant beroende på vilken typ av site som upprättas. Kostnadsestimaten antar att basstationer i hög utsträckning kan upprättas på befintliga torn, som ägs av antingen Trafikverket eller av kommersiella tornbolag (TowerCos). Vi har fört diskussioner med flera svenska bolag som har erfarenhet inom nätverksetablering. Alla intygar att kostnader för att upprätta en site är förknippade med osäkerhetsfaktorer, men är trygga i att det i stor utsträckning finns tillgängligt utrymme för inplacering i kommersiella torn. Detta är den viktigaste kostnadsdrivaren i Novamodellen och vi bedömer att Novamodellens estimat är rimliga.

För kärnnätet är situationen annorlunda. Dessa kostnader utgör mindre än 10 procent av de totala kostnaderna, men viktiga faktorer är förknippade med osäkerhet gällande funktionalitet och design och är därav är kostnadsnivåerna svåra att bedöma. Osäkerhetsfaktorerna drivs av nivån av komplexitet för att sömlöst integrera Novas radionätverk med kommersiella radionätverk, samt utvecklingen och tidsplanen för utrullning av Rakel G2s tjänster. Vi har inte gjort några justeringar av kostnadsposterna relaterade till kärnnätet i PBE men vill understryka att dessa kostnader är associerade med risk och bör granskas igen i ett senare stadie.

Figur S.5 visar estimatet för livscykelkostnaderna i PBE efter att alla korrigeringar har tagits i åsyn och den utgår från en nätverkslivscykel på 20 år. Kostnaderna uppgår till 10,349 MSEK för nya investeringar, 25,478 MSEK för återkommande kostnader och 2,399 MSEK för återinvesteringar. Dessa kostnadsposter kommer att användas som grund för osäkerhetsanalysen av kostnader.



Figur S.5: Project Base Estimate i MSEK – Livscykelkostnader för 20 års livscykel

Sammanfattning och introduktion till osäkerhetsanalyserna

Introduktion till osäkerhetsanalyserna

Eftersom den svenska regeringen inte har en fastställd metod för kvalitetssäkring av stora offentliga investeringsprojekt, baseras kvalitetssäkringen (KS) av Rakel G2 projektet på kraven för KS av stora offentliga projekt i Norge, enligt de riktlinjer som fastställts av Norges finansdepartement. Ett av de centrala kraven i sådana norska kvalitetssäkringsprocesser är att genomföra en oberoende osäkerhetsanalys (OA) av projektets kostnadsestimat innan projektet presenteras för den norska regeringen och parlamentet för investeringsbeslut.

Detta kapitel beskriver metoden och analysresultaten av den oberoende osäkerhetsanalysen utförd av KS-gruppen avseende Rakel G2s grunduppskattning av kostnader vilket innefattar grunduppskattningen av investeringskostnader och grunduppskattningen av de återkommande kostnaderna i den operationella fasen av Rakel G2. Dessa estimat är beskrivna i detalj i vår prosjektkostnadanalys. Vi har också inkluderat en kort jämförelse av metoder och resultat mellan vår OA av kostnadsestimeringen för investeringen och OA för investeringskostnader etablerade av MSB och TrV i Maj 2022 (jfr. Erdalen 2022).

OA har huvudsakligen utförts via en workshop med alla huvudsakliga medlemmar från KS-gruppen. I workshopen har projektets egenskaper granskats med avseende på deras riskpotential, och ett register över osäkerheterna har etablerats genom brainstorming och granskning av de osäkerheter som identifierades vid OA-workshopen som hölls av MSB och TrV i Maj 2022. Dessa osäkerheter har grupperats I nio osäkerhetskällor. Vidare har den estimerade noggrannheten hos osäkerheterna undersökts. Tre punktestimat - P10 (tio procent sannolikhet att vara inom detta kostnadsintervall), mest sannolikt (ML) och P90 (nittio procent sannolikhet att vara inom kostnadsintervallet) - har etablerats för att kvantifiera osäkerheterna i förhållande till varje basestimat för varje osäkerhetselement, och därefter har Dovre Groups stokastiska analysmodell (AnRisk) använts för att beräkna resultaten av osäkerhetsanalysen.

Osäkerhetsanalysen av kostnader baseras på antagandet att det inte kommer att förekomma förseningar i projektets sanktionering (2024) eller i godkännandet av årliga budgetar. Extrema händelser (med marginell sannolikhet och stora konsekvenser), samt stora förändringar av projektets koncept eller premisser, har exkluderats från analysen. Osäkerhetsanalysen genomförs tidigt i projektets förberedelsefas, med begränsad dokumentation tillgänglig om projektets förberedelser. Därför antas det att projektet kommer att tillhandahålla dokumentation som visar att projektets förberedelser är godtagbara, med hänvisning till det Norska Finansdepartementets krav (Finansdepartementet 2019, se också Direktoratet for økonomistyring 2021). Osäkerhetsanalysen för kostnader bör uppdateras och färdigställas og slutföres når projektet har slutfört sin dokumentation om projektförberedelser.

Både KS-gruppens osäkerhetsanalys samt MSB och TrVs osäkerhetsanalys är baserade på metoden av successiva steg utvecklad av Steen Lichtenberg (2000). Dock så är jämförelse mellan två osäkerhetsanalyser utmanande p.g.a. skillnaderna i metodologi samt tid för utförande mellan analyserna. Den huvudsakliga skillnaden mellan analyserna relaterar till metodologin för analysen. Till skillnad från KS-gruppens analys, så är MSB och TrV analysen inte baserad på en deterministisk basestimering, utan baserad på ett sammanvägt estimat framtaget i en grupprocess.

Baserat på resultaten från osäkerhetsanalysen har KS-gruppen också gett rekommendationer om riskreducerande åtgärder för varje identifierad osäkerhetsfaktor i projektet. Den viktigaste åtgärden för riskreducering vid denna projekteringsfas, enligt bedömningen av KS-gruppen, är att utveckla en tydligare övergripande projektdesign för Nova-projektet. En sådan plan bör beskriva tjänsterna som kommer erbjudas i Rakel G2, tidpunkten och tågordningen för introduktion av tjänsterna, samt realiseringsplanen för tjänsterna.

Den norska kvalitetssäkringsprocessen för stora offentliga investeringar innefattar inte obligatoriska krav på att genomföra osäkerhetsanalyser av projektets tidsplan under projektets genomförande. Trots detta är osäkerheten relaterad till projektets genomförande över tid oftast betydande. En osäkerhetsanalys av tidplanen för Rakel G2 har också genomförts av MSB och TrV och har dokumenterats i ett internt project i en granskande rapport av MSB och TrV (Erdalen et al. 2022). Till sist tillhandahåller vi en kort jämförelse av tidslinjen i Rakel G2s planerings- och förberedelserapport (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021b, offentliggjord Mars 2023) samt resultaten av MSB och TrVs osäkerhetsanalys av tidsplanen (2022).

Huvudsakliga resultat från osäkerhetsanalyserna

De huvudsakliga resultaten av den preliminära osäkerhetsanalysen av kostnader visas i Tabell S.1. Värden anges som MSEK med kostnadsnivå 2024. Återkommande kostnader (dvs. operationella kostnader) begränsas till 20 års längd. Återinvesteringar exkluderar investeringar i betydande teknologiska förbättringar och ny teknik. Notera att terminaler och andra användarkostnader inte inkluderas i PBEn eller analysen, då dessa rör användarna och inte kostnaderna för infrastruktur.

*Tabell S.1: Resultat från osäkerhetsanalyserna - preliminära. * Ej jämförbart med summan av investeringar, återkommande kostnader och återinvesteringar på grund av portföljeffekter*

Parameter	Investments (MSEK)	Recurring costs (MSEK)	Reinvestments (MSEK)	Total (MSEK)
Grunduppskattning	10,349	25,478	2,399	38,225
Varians	1,467	242	143	1,853
Förväntad kostnad (P50)	11,816	25,720	2,542	40,078
Projektledningsreserv	2,502	3,467	1,110	4,440*
P85	14,318	29,187	3,652	44,518*
Relativ varians (%)	14 %	1 %	6 %	5 %
Relativ standardavvikelse (%)	20 %	13 %	42 %	11 %

Osäkerheten för (initiala) **investeringskostnader** domineras av marknadsosäkerhet, antennplats- och transmissionsförhållanden samt osäkerhet relaterad till uppskattningen av enhetskostnader för utrustning. Variansen på 14 procent av PBEn (rörande investeringar) samt standardavvikelsen på 20 procent av den förväntade kostnaden är inom det normala spannet för ett projekt i detta utvecklingsskede.

Osäkerheten för **återkommande kostnader** domineras av osäkerhet relaterad till den operativa organisationens förmåga att säkerställa framgångsrik drift och övervakning av nätverket, via osäkerhet i estimeringen av antalet anställda som krävs för den operationella organisationen, samt via osäkerhet i estimeringen relaterad till enhetskostnader inom ramen för driften, som är OPEX kostnader (operating expenditure, dvs återkommande kostnader för den operationella fasen). Den övergripande variansen om 1 procent för PBE (för återkommande kostnader) indikerar att basestimaten ligger på en sannolik nivå. KS-gruppen har identifierat att kostnadsuppskattningen för återkommande kostnader är baserad på dokumenterade och trovärdiga referensdata med låg osäkerhet. Vidare bedöms de flesta osäkerhetselement med symmetriska osäkerhetsintervall. Omfattningen av den aggregerade osäkerheten uttryckt som en standardavvikelse om 13 procent av den förväntade kostnaden är förhållandevis låg, men detta måste ses i relation till kvalitén på referensdatan.

Osäkerheten för **återinvesteringskostnader** domineras av osäkerhet relaterad till uppskattningens noggrannhet för det procenttal som används för att beräkna återinvesteringsbehov, av marknadsosäkerhet samt av förhållanden på antennplatser och transmissionsförhållanden. Den övergripande variansen om 6 procent för PBE (för återinvesteringar) är låg. Dock beror osäkerheten främst på att återinvesteringarna ligger långt fram i tiden, vilket leder till att många av osäkerhetselementen kvantifieras symmetriskt. Den låga variansen bör också ses i sammanhanget med det mycket breda osäkerhetsomfånget från analysen, representerad av en standardavvikelse på 42 procent av den förväntade kostnaden. Detta beror på att flera bidragande orsaker till osäkerheten kvantifieras med breda osäkerhetsomfång, inklusive den tidigare nämnda uppskattade noggrannheten för osäkerhet relaterad till återinvesteringsbehov.

Återkommande kostnader summerar till ungefär två tredjedelar av de totala kostnaderna, både i termer av PBE och i termer av de förväntade kostnaderna. Följaktligen så har analysresultaten för återkommande kostnader en djupgående påverkan på den övergripande variansen och den relativa standardavvikelsen för de totala projektkostnaderna. Den övergripande osäkerheten i projektet domineras av osäkerhet relaterad till organisationen och ledningen, vilket är dominerande både under investeringsfasen, driftsfasen och för återinvesteringar.

Dessutom påverkas kostnadsosäkerheten i hög grad av marknadsosäkerhet och av precisionen i osäkerhetsuppskattningar för återkommande kostnader.

Vi genomför ingen osäkerhetsanalys av tidsplanen förankrad i projektets kostnadsanalys, eftersom vi anser att den tillhörande dokumentationen är otillräcklig i vår kvalitetssäkring av projektförberedelserna. Av samma anledningar har vi inte heller utfört en kvalitetssäkring av projektets planer och tidsramar, eftersom ingen aktuell och tillräcklig detaljerad tidsplan existerar. Vidare så är den dokumentation vi tagit del av utarbetad för MSB och TrV redovisning av regeringsuppdraget för planering och förberedelse av den fortsatta utvecklingen och etableringen av Rakel G2 (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021), samt för projektets interna osäkerhetsanalys (Erdalen et al. 2022). Båda har utarbetats i en tidig planeringsfas. Dessutom är båda på en mycket övergripande nivå med ett mycket begränsat antal aktiviteter, och där logiken och tidsramarna för de två befintliga tidsplanerna skiljer sig avsevärt åt.

Istället har vi utfört en komparativ analys av metoden och processen av MSB och TrVs osäkerhetsanalys för tidsplanen (Erdalen et al. 2022). Då analysen utfördes i en tidig planeringsfas var endast ett fåtal strategier och detaljer dokumenterade. Förutom för generella osäkerheter, så innehåller studien ingen dokumentation av underliggande data, och inte heller resonemanget bakom tidsramar och osäkerhetsfaktorer. Dessutom visas endast effekten av allmänna osäkerheter för den totala projektplanen och inte fördelad till relevanta aktiviteter och deras kostnadseffekter. Därmed finns det en hög sannolikhet för överlapp i kvantifieringen av osäkerhet för enskilda aktiviteter och kvantifieringen av allmänna osäkerheter. På samma tema så har MSB och TrVs interna rapport brutit ner projektet i endast sju övergripande faser, och lämnat underaktiviteter och deras beroenden som odefinierade och obehandlade. Dessutom så kan begränsad identifiering av nätverksprocesser och beroenden, samt långa tidsramar för aktiviteter ge felaktiga analysresultat (ibid.)

Baserat på våra farhågor och vår uppfattning av förändrade planeringsantaganden sedan maj 2022 (när MSB och TrVs interna osäkerhetsanalys utfördes) stödjer vi Nova-projektets planer på en ny osäkerhetsanalys för tidsplanen under den andra halvan av 2023. Våra huvudsakliga rekommendationer för en nästa osäkerhetsanalys av tidsplanen gäller förutsättningar, planering och genomförande av planen samt färdigställande av genomförandeplanen.

Vad gäller förutsättningar, så rekommenderar vi att en övergripande projektdesign etableras med en associerad genomförandestrategi och ett detaljerat utkast av genomförandeplanen. För planering, förberedelse samt utförande, rekommenderar vi etableringen av ett mer detaljerat planeringsramverk för osäkerhetsanalysen, kvantifiering av generella osäkerheter innan estimering av noggrannheten hos osäkerheter utförs, kvantifiering av osäkerhetskällor på aktivitetsnivå snarare än på övergripande projektnivå samt dokumentation av all erfarenhetsdata använd av workshop-deltagarna. Vid färdigställandet av genomförandeplanen rekommenderar vi att projektet överväger hur resultaten från osäkerhetsanalysen och de sannolika effekterna av riskreducerande åtgärder kan motivera ändringar i den detaljerade genomförandeplanen, samt att en förvaltningsplan bör upprättas.

Kvalitetssäkring av projektförberedelserna

Introduktion till kvalitetssäkring av projektförberedelserna

På 1980- och 1990-talen upplevde Norge signifikanta budgetöverskridanden för flera stora publika projekt. Som en konsekvens så införde Finansministeriet obligatoriska styrkrav för större publikt finansierade projekt, inklusive krav på oberoende extern kvalitetssäkring för projektledningsdokumentationen (projektförberedelser) samt projektets kostnadsestimat (KS2). Dovre har haft ramavtal med Finansministeriet sedan år 2000 för kvalitetssäkringsuppdrag, från år 2005 i ett konsortium med TØI, fram till idag. Sedan år 2000 så har Dovre och TØI genomfört kvalitetssäkring av projektförberedelser samt kostnadsestimat för närmare 80 projekt. Ministeriets associerade krav för kvalitetssäkring och guidelinjer har senare genomgått översyn samt blivit mer detaljerade (Finansdepartementet 2008, 2019a, 2019b och 2020 och Direktoratet for økonomistyring 2021). Kvalitetssäkring projektförberedelserna krävs inte för parlamentariskt godkännande i Sverige, men vi anser oavsett att kvalitetssäkring av projektförberedelser som mycket fördelaktiga också i en svensk kontext, med syfte att reducera risken för att budgeten överskrids eller projektet försenas.

Kvalitetssäkringen av projektförberedelserna undersöker projektets dokumentationen inom tre huvudsakliga områden – projektets övergripande ramverk, projektstrategi samt projektets kontrollbas. Vart och ett av de huvudsakliga områdena inkluderar 4-6 underkategorier, såsom projektets identifiering av dess kritiska framgångsfaktorer, gränssnitt, strategibeskrivningar, projektägarskap och projektets utförandeorganisation, kvaliteten på kostnadsestimat samt projektets tidsplan. De norska kraven för projektförberedelser är i samklang med sund projektpraxis, och liknande krav återfinns i flertalet stora internationella organisationer som återkommande implementerat stora investeringsprojekt, såsom energiprojekt. Dessutom granskas även samstämmigheten mellan ämnen i kvalitetssäkringsprocessen, såsom samstämmigheten mellan struktur för arbetsuppdelning (work break down structure, WBS), kostnadsuppskattning, projektets tidsplaner och organisationsstruktur.

I det norska kvalitetssäkringssystemet för stora statliga investeringar där den styrande dokumentationen bedöms vara otillräcklig och projektet bedöms vara omoget, kommer den kvalitetssäkrande organisationen att efterfråga kompletterande dokumentation innan regeringens och parlamentets godkännande. Ett sådant krav ställs inte i Sverige, men för att minska risken för budgetöverskridanden och säkerställa förutsägbarheten i projektet är det ändå rekommenderbart att ha noggrant bearbetade dokument för projektets organisationsstruktur och styrning.

Sammanfattning och rekommendation om dokumentationsbehov gällande projektetförberedelser

Överlag bedömer vi att förberedelserna för beslut angående projektorganisation och implementering i stor utsträckning saknar dokumentation. Detta gäller för all dokumentation av tillhörande nyckelfaktorer, inklusive projektets ramverk, projektstrategi och kontrollunderlag. Inget av de områden som granskats genom den norska metoden för kvalitetssäkring av stora statliga upphandlingar bedöms ha fullständig dokumentation, vilket redogörs för i Tabell S.2.

För det övergripande ramverket så hade den befintliga dokumentation, kraven och det centrala konceptet samt de avgörande framgångsfaktorerna tillgodosett minimumkraven som ställs enligt den norska kvalitetsgranskningsmodellen, dock till viss del med svagheter. Dokumentationen för andra områden skulle bedömas som bristfällig och hade inte kunnat framföras till det norska parlamentet för godkännande, antingen beroende på väsentliga brister i dokumentationen (i projektets ramverk och projektets målsättningar) eller helt saknad dokumentation (t.ex., gränssnitt).

För projektstrategin så tillgodoser dokumentation inte kraven från KS-gruppen för något av områdena. Dokumentationen bedöms ha väsentliga brister gällande utförandestrategin, organisation och ledning. Vidare så kunde ingen dokumentation hittas för strategier gällande riskhantering och avtalsutformning.

För projektets kontrollunderlag, struktur av arbetsuppdelning och kostnadsuppskattning samt budget och fasindelning så finns tillräcklig dokumentation för att projektet ska fortlöpa givet det norska kvalitetssäkringssystemet, dock till viss del med svagheter. Annan dokumentation hade bedömts som otillräcklig enligt metoden för norsk kvalitetssäkring (för projektschema och arbetsomfattning som också innefattar förändringshantering) och ingen dokumentation (plan för realiserade av fördelar, samt kvalitetssäkring och kontroll).

Tabell S.2: Bedömning av bristande projektförberedelser - övergripande ramverk. Grön färg: Fullgod dokumentation. Gul färg: Dokumentation med vissa brister. Orange/röd färg: Dokumentation med avgörande brister. Mörkröd färg: Ingen dokumentation

Huvud-ämne	Underkategori	Saknade beskrivningar / dokument	Status
Överripande ramverk	Syfte, krav och huvudkoncept	Syfte beskrivet i regeringsuppdrag. Precisa beskrivningar av koncept, krav och förväntad prestanda saknas	(gul)
	Projektmål	Syften beskrivna i UA dokument varken kompletta, mätbara, eller prioriterade	(orange/röd)
	Kritiska framgångsfaktorer	Ej specifikt beskrivna, men åtskilliga åtgärder beskrivna i UA-rapporten kan betraktas som framgångsfaktorer	(gul)
	Projektramverk	Beskrivningar av MSB och TrVs projektplanering / genomförandeplan, tillika lagar och reglering saknas	(orange/röd)
	Gränssnitt	Inga beskrivningar (tekniska, organisationella, kommersiella gränssnitt)	(mörkröd)
Projektstrategi	Riskhanteringsstrategi	Ej beskriven i dokumentation mottagen hittills	(mörkröd)
	Utförandestategi	Endast kortfattad beskrivning i Rakel G2 planerings- och förberedelserapporrt (MSB och TrV 2021	(orange/röd)
	Kontraktsstrategi	Ej beskriven i dokumentation mottagen hittills	(mörkröd)
	Organisation och ledning	Fördelning av roller/ansvar mellan MSB och TrV finns beskriven. Annan information om hur projektet är organiserat och dess styrning saknas	(orange/röd)
Projektets kontroll-bas	Arbetsomfång, inklusive hantering av förändringar (change management)	Detaljerade beskrivningar av projektomfånget saknas, men kvantiteter är angivna i projektets kostnadsestimat. Ingen information om hantering av förändringar.	(orange/röd)
	Struktur för arbetsuppdelning	Beskriven i UA rapport från Maj 2022, men saknar information / konfirmering av slutgiltig struktur	(gul)
	Kostnadsuppskattning, budget och fasning	Detaljerad estimering mottagen, men översikt samt verifierbarhet är utmanande. Investeringsestimat inte strukturerat enligt WBS	(gul)
	Plan för att uppnå fördelar	Ej beskriven i dokumentation mottagen hittills	(mörkröd)
	Projektschema	Endast kortfattad beskrivning I projektets slutgiltiga rapport	(orange/röd)
	Kvalitetssäkring och kontroll	Översikt av processer och krav för kvalitetssäkring och kontroll för projektet ej mottagna	(mörkröd)

Gruppen för kvalitetssäkring var ombedda att utföra en kvalitetsgranskning av projektets förberedelser för projektledning, styrning och organisation vid en tidpunkt då projektets förberedelser ännu inte var färdigställda. Vi rekommenderar starkt att MSB och TrV innan projektstart prioriterar att förbättra projektförberedelser och dokumentation för projektförberedelser, i linje med de norska kraven. Vi förespråkar även kvalitetsgranskning av dessa dokument, även om vi noterar att kraven för kvalitetssäkring vid stora statliga upphandlingar i Norge inte appliceras i Sverige. Därav kan projektet ha mer flexibilitet för dokumentation än vad stora norska investeringsprojekt har.

Analyser av externa effekter kopplat till infrastrukturprojektet

Introduktion och motivering för utvärdering av externa effekter till infrastrukturprojektet

I detta kapitel analyserar vi de effekter Rakel G2 medför som är externa till Nova-projektet. Dessa effekter har redan hanteras, i viss mån, under det inledande skedet av det norska kvalitetssäkringssystemet (KS1). Vi utvärderar även, bortsett från användarkostnadsanalysen, effekterna av Rakel G2 gentemot ett referensscenario där Rakel G1 gradvis fasas ut och ersätts med icke-koordinerad användning av det mobila nätverket för räddningstjänst och katastrofskydd (eng. PPDR). Detta kapitel består av följande fem analyser:

- **Direkt påverkan på användare**: När kostnadssidan är det enda som värderas inom infrastrukturprojekt finns det alltid risk att användarnyttan bortses från, vilket motverkar det ursprungliga syftet med projektet. För att analysera detta kommer vi utforska fördelarna för användare genom en multi-kriterie-analys för olika intressenter i syfte att visa de direkta fördelarna av mobilnätets kvalitet.
- **Bruttokostnad för användare**: Trots att utvärdering av infrastrukturprojekt vanligtvis utgör kärnan i bedömningen av offentliga infrastrukturinvesteringar bortses ofta användarnas kostnader, även om de är betydande. I denna analys uppskattar vi bruttokostnader för användare associerat med hel systemintegrationsprojektet, där ”brutto” reflekterar att alternativa användarkostnader inte utvärderats.
- **Indirekta effekter**: Indirekta effekter är ofta det som får uppmärksamhet i den offentliga diskussionen då de typiskt är svårt att mäta i monetära medel. Vi förser därför en kvalitativ överblick av indirekta effekter, däribland indirekta effekter på spektrumanvändning, samarbete, produktionsekonomi, nya kunskaper, säkerhet och klimatfrågor diskuteras.
- **Marginalkostnader kopplade till offentlig finansiering**: Inom både norsk och svensk metodologi för samhällsekonomisk kostnadsnyttoanalys tenderar marginalkostnader för publika medel utgöra en väsentlig del av totala brutto- och nettokostnader. I denna undersökning uppskattar vi marginalkostnader i netto för offentlig finansiering av infrastrukturkostnader och marginalkostnader i brutto för offentlig finansiering av användarkostnader, samt en kvalitativ genomgång av de skatteeffekter som är hänförliga till icke-monetära effekter.
- **Fördelningshänsyn**: Offentliga beslutsfattare bör inte endast värdera nettoeffekten av ett projekt, utan bör även lägga hänsyn till hur det distribueras. Vi har, mot slutet av vårt uppdrag, bedömt hur infrastrukturprojektet inkluderat olika intressenter (horisontell

dimension), grupper med olika socio-ekonomiska bakgrunder (vertikal dimension), olika platser (geografisk dimension) och över tid (inter-generationell dimension).

Sammanfattning av analyser av externa effekter kopplat till infrastrukturprojektet

Offentlig säkerhet behöver moderna kommunikationstjänster som är tillförlitliga, säkra och enkla att använda oavsett plats och situation. Baserat på intervjuer med flertalet Rakel-användare bedömer vi att nätverkets robusthet är det som värderas högst hos användare, följt av funktionaliteten, användarupplevelsen och täckningen. Interoperabilitet och säkerhet värderades även högt, medan kapacitet värderades lägst av variablerna.

Vi har jämfört det nuvarande Rakel G2-systemet med ett referensscenario, där Rakel G1 används så länge som möjligt och mobildata till PPDR-användare skickas över vanliga kommersiella nätverk.

Rakel G2:s faktiska fördelar sett till ökad kvalitet är svåra att adressera på ett korrekt vis. På grund av detta approximerar vi effekterna via de direkta effekter som användarna av nätverket för räddningstjänst och katastrofskydd kommer att uppleva. Tabell S.3 innehåller en relativ jämförelse av projektets utvärdering av de förväntade användarfördelarna inom både Rakel G2-scenariot och referensscenariot. I jämförelsen förväntas interoperabilitet bli den största förbättringen vid en övergång från referensscenariot till Rakel G2. Även bättre robusthet, användarupplevelse, täckning, säkerhet och kapacitet förväntas uppnås i Rakel G2 jämfört med referensscenariot. Viktigt att poängtera, när det gäller just kapacitet, är att det troligtvis kommer finnas möjligheter till prioritet inom kommersiella mobila nätverk, vilket är en av fördelarna med Rakel G2. De förväntade förbättringarna inom både robusthet och kapacitet kräver ett multi-operatörs kärnnät (multi-operator core network, MOCN). Av samtliga variabler i jämförelsen är det endast funktionalitet som förväntas vara lika mellan Rakel G2-scenariot och referensscenariot.

Tabell S.3: Användarfördelar i Rakel G2-scenariot gentemot referensscenariot

Fördelar	Vikt	Rakel G2-scenario
Robusthet	23	+
Funktionalitet	21	0
Användarupplevelse	20	+
Täckning	20	+
Interoperabilitet	18	++
Säkerhet	17	+
Kapacitet	14	+

Användare av Rakel G2 kommer få både abonnemangskostnader och andra direkta kostnader. Först och främst kommer de behöva betala för terminaler och i vissa fall kostnader kopplat till att installera terminaler. Vidare kommer kostnader uppstå i samband med integrering av Rakel G2-tjänster till användarnas applikationer och IT-system. Vi uppskattar att de initiala terminal-och integrationskostnaderna kommer uppgå till runt 125 miljoner SEK (eller 2,5 miljarder SEK över 20 år). Detta innebär att den totala uppskattade kostnaden, både sett till initiala och löpande kostnader, förväntas hamna runt 3,5 miljarder SEK. Värt att notera är att detta är användarnas bruttokostnader för Rakel G2. Nettokostnad per användare exklusive abonnemangskostnad kommer att bli lägre, eftersom det också kommer att finnas användarkostnader i referensscenariot.

Trots detta förväntas abonnemangskostnaden för nätverket bli högre än de tillkommande abonnemangskostnaderna i referensscenariot för Rakel G1 och privata abonnemang. Vi tror därför att nettokostnaden för användare relaterat till abonnemangskostnader kommer vara betydande, vilket borde ha blivit subtraherat från abonnemangsintäkterna för infrastrukturprojektet i en kostnadsintäktsanalys.

Vidare, implementeringen av Rakel G2 kommer generera flera olika indirekta effekter. I Tabell S.4 nedan ges en kort överblick av dessa.

Tabell S.4: Överblick av indirekta effekter

Typ av indirekta effekter	Beskrivning
Påverkan på spektrumutnyttjande	• Minskad tillgång av spektrum för offentliga mobila nätverk • Ökad täckning på landsbygden • Indirekta spektrumeffekter orsakat av konkurrens
Samarbete	• Samarbete mellan olika myndigheter kopplat till tjänster för räddningstjänst och katastrofskydd • Samarbete mellan olika aktörer över flera nätverk
Ekonomiskt	• Potentiell relativ fördel för Telia från MOCN-lösningen • Viktig uppgift för systemleverantören • Tillgång till kapacitet kombinerat med en god konkurrens kommer förebygga snedvridning inom konkurrens inom byggnation
Kunskapssamling	• Generera kunskap kopplat till integration mellan civila och PPDR-nätverk • Kostnad för teknologispecifik utbildning och uppföljning av lärdomarna
Säkerhet	• Nationell säkerhet, ägandeskap av nätverk och skydd mot intrång • Krisförberedande för myndigheter inom samhällsskydd och militären • Personlig säkerhet och integritet • Uppfattad säkerhet
Klimat och miljö	• Telekomutrustning och infrastruktur påverkar värdet av underliggande tomtar och landskap • Energiförbrukning på en daglig basis påverkar klimatet

Fört och främst uppstår påverkan på spektrumutnyttjande i samband med att färre frekvenser finns tillgängligt för auktion, nya siter byggs på landsbygden och ytterligare indirekta effekter från förändringar i konkurrens. För det andra kommer Rakel G2 påverka samarbetet mellan befintliga tjänster för samhällsskydd och hur de interagerar med andra partner som tillämpar ett annat nätverk. För det tredje kommer Rakel G2 påverka konkurrensen och aktörers ekonomiska kapacitet i flera marknader genom att Telia och möjligen systemleverantörer (t.ex. Ericsson) får konkurrensfördelar i telekom- respektive tillverkningsindustrin. Konkurrensen i marknaden som bygger telekominfrastruktur förväntas däremot påverkas mindre på grund av befintlig kapacitet och en god konkurrenssituation.

För det fjärde kommer Rakel G2 generera ny kunskap om hur civila- och PPDR-nät kan integreras, samt insikter i kostnad för teknologispecifik utbildning och utfallet av en sådan. För det femte kommer Rakel G2 influera PPDR-säkerhet, framför allt genom förbättringar som ägandeskap av nätverket och skydd mot intrång och öka förberedelsenivån för akuta krissituationer hos myndigheter för samhällsskydd. Slutligen kommer projektet också inkludera klimat- och miljömässiga aspekter som hur värdet av en tomt påverkas av ny telekominfrastruktur och hur energiförbrukning på en daglig basis genererar utsläpp av växthusgaser.

Eftersom Rakel G2 är beroende av skattefinansiering, vilket sker på en bekostnad av allmänheten och välfärden, kommer det påverka skattesystemet. Vi uppskattar den marginella nettokostnaden för infrastrukturprojektet till 3,84 miljarder SEK. Vidare uppskattar vi att den marginella bruttokostnaden av offentlig finansiering kopplat till kostnader för användare kommer hamna runt 1,05 miljarder SEK, där användarkostnader i det alternativa scenariot inte tas i hänsyn. Vidare kommer Rakel G2 ha en indirekt effekt på skatt kopplat till minskade intäkter från spektrumauktioner.

Projektet innebär också betydande fördelningsmässiga effekter. En del av dessa är kopplade till skattefinansiering, inklusive infrastrukturkostnader och användarkostnader för projektet, samt den inducerade snedvridningen i skattesystemet. Andra fördelningsmässiga effekter avser användarfördelar och indirekta påverkningar, och bygger vidare på de relaterade icke-monetära analyserna.

Övergripande innebär infrastrukturprojektet en omfördelning till faktiska och potentiella användare av nöd- och beredskapstjänster från skattebetalare och mottagare av alternativa offentliga åtgärder som annars skulle ha kunnat finansieras. Projektet kan bidra till förbättrad mobiltäckning i landsbygdsområden. Om projektet finansieras genom lån istället för bidrag kommer det innebära en omfördelning till den nuvarande befolkningen från framtida befolkning.

1 Introduction

1.1 Project Background

In 2023, the Swedish government approaches the final phase of ex-ante evaluation of a new public protection and disaster relief (PPDR) network and initiation of the implementation and construction phase. The government assignments have been delegated to the Swedish Transport Administration (Trafikverket, TrV), the Swedish Civil Contingencies Agency (Myndigheten för samhällsskydd och beredskap, MSB) and the Swedish electricity transmission system operator, Svenska kraftnät.

The ex-ante evaluation consists of several related assignments. First and foremost, the authorities have ordered an assignment to plan and prepare for further development and establishment of Rakel Second Generation (Rakel G2) (Justitiedepartementet 2021). Second, an assignment is given to analyze and make suggestions on how the overall need for one developed and secure communication system for actors in public order, security, health and defense can best be met (Justitiedepartementet 2020). Third, a government assignment has been delegated to procure and offer mobile data communication services to the actors authorized to connect to Rakel (Myndigheten för samhällsskydd och beredskap 2022).

Implementing a new Swedish public emergency network is essential for Swedish society economically and socially, as well as in terms of safety and security. Accordingly, the public contracting authorities request a quality assurance of impact assessments and other evaluations over the ex-ante evaluation phase. The current assignment includes planning in its entirety, including implementation plan, organization and division of responsibilities in future phases and even the phase-out phase of the current technical system used.

Before this quality assurance project was initiated, the Swedish Civil Contingencies Agency had already carried out assignments and funding for procuring core network functionalities and establishing the capabilities for offering mobile broadband services. These functionalities cover operation of core networks, SIM cards, commercial radio coverage and signing of supplier agreements. What remains is the national establishment of a replacement system. The procurement can begin at the earliest when the government decides the ordinary budget process for 2024 in late 2023.

1.2 Network and Service Design of Rakel G2

As in many other countries, the legacy emergency network in Sweden is approaching the last leg of its useful life. Swedish authorities will replace the current Rakel First Generation (Rakel G1) network with a new "public protection and disaster relief" (PPDR) network, Rakel Second Generation (Rakel G2). Rakel G2 is planned as a hybrid network, where a dedicated and state-owned core network is connected to a state-owned 5G radio access network in the 700 MHz band together with one or more commercial mobile networks, using a so-called multi-operator core network (MOCN) solution.

Rakel G2 design allows for commercial and public infrastructure to complement each other in terms of robustness, coverage and capacity. The dedicated state-owned network forms the basis of Rakel G2, while the integration with commercial mobile networks makes it possible to benefit from the commercial operators' frequencies and established infrastructure through a so-called multi-operator core network (MOCN) solution. Collaboration with commercial operators is also likely to improve indoor coverage for Rakel G2 users.

Rakel G2 new sites will be established with redundant transmission and reserve power to increase availability and robustness. The core network will be placed in geographically redundant and distributed data centers.

Rakel G1 builds on Tetra-technology and has provided mission critical voice and messaging services to its users for more than 15 years. Rakel G2 will initially provide three “mission critical” (MC) services – MC push-to-talk and messages, and MC data including video. The current Rakel network only provides MC push-to-talk and messages. MC data, on the other hand, creates new possibilities and areas of use for management and collaboration within and between user organizations. These services may, for example, enable transfer of video from an injury scene, exchange of location images, data logging and transfer of information between different data systems and more. In addition, Rakel G2 will enable the connection of different types of sensors to the users’ own mission critical applications. Besides, Rakel G2 is expected to have considerably more users than Rakel G1. Key users will include ambulance services, fire services, sea rescue services and the police.

1.3 Use of the Norwegian Quality Assurance Scheme for Large National Government investment projects

While the central Swedish government does not have a fixed scheme for quality assurance of large national government investment projects, the Norwegian government has followed and developed such a scheme since the turn of the millennium. As the Norwegian quality assurance methodology in principle is transferable to Swedish investment projects, the public contracting authorities seek relevant expertise to apply the Norwegian methodology to ex-ante quality assurance of the new Swedish Public Safety Network.

The Norwegian scheme for quality assurance of major public investments comprises two extensive appraisal investigations, followed by external quality assurance reviews in the planning process of investment projects. Quality assurance at the first stage (kvalitetssikring 1, KS1) involves a quality assurance of choice of concept prior to the Parliament deciding whether to initiate a pre-project. Quality assurance at the second stage (kvalitetssikring 2, KS2) involves quality assurance of the management base and cost estimates, before the project is considered by the Parliament for approval and funding. We refer to Direktoratet for økonomistyring (2014 and 2021) and Finans-departementet (2008, 2019a and 2019b, and 2021b) for details beyond our short description here.

The purpose of KS1 is to ensure sufficient political control over the process and that the documents underlying the decision base are of high quality. The choice of concept is quality assured by the end of the concept appraisal phase, before the decision is made by the cabinet to initiate a pre-project. In this sense, the impact assessments for the new Swedish public emergency network have already gone beyond the point of KS1. In Norway, the KS1 investigation document includes a description of the current problem, needs analysis, overall strategy, overall requirements, possibility study, alternatives analysis and guidance for the pre-project phase.

The analyses follow the form of a cost-benefit analysis, where all relevant and monetizable costs and benefits are monetized. Other methods, such as a multi-criteria analysis, a break-even analysis and an uncertainty analysis may address other relevant impacts. The uncertainty analysis should be carried out in any case, and we note that it is already available for this project. Throughout this process, we must review the documentation and ensure consistency through the evaluations. Furthermore, we must ensure that the alternatives provided are relevant to needs, strategy and requirements, and fully cover the opportunity space. Based on the assessment, the consultant should rank the potential project alternatives, which is less relevant here, as the project alternative has already been chosen. In KS1, the consultant should provide advice on project planning and implementation strategy.

KS2 involves a quality assurance of the management base and cost estimates in the chosen project alternative illuminating the uncertainty of the project cost estimates and charting of potential management challenges for the project in the future project phases. A KS2 investigation includes a parent project steering document, documentation of changes from the initial project evaluations, complete cost estimates, an assessment of alternative contract strategies and an updated project cost analysis and plan for realizing benefits. Relevant documents are reviewed systematically, before investigators undertake an independent assessment of success factors and pitfalls, and quantify the uncertainty related to total cost.

1.4 Status of the Quality Assurance Investigation Process for Rakel G2

The concept choice for the new Swedish Public Emergency Network was made prior to our investigation, and it is now primarily a matter of planning the design and realization of the new communication system in more detail. Before our quality assurance project, the quality assurance process for the new Swedish Public Emergency Network lay somewhere between early-stage quality assurance (KS1) and late-stage quality assurance (KS2) in the Norwegian quality assurance scheme. Some the evaluation material usually produced at or in parallel to the KS1 investigation step and needed for a KS2 investigation was available at the beginning of our project, while other documents were updated and made ready in parallel to our project.

What needs the stakeholders face and what requirements the government should set has been evaluated in chapter 5 in Justitiedepartementet (2017). In 2017, Analysys Mason addressed the concept choice for the realization of a PPDR network in an unpublished cost-benefit analysis on behalf of Telia, which was presented to the Swedish parliament. The need for secure communication services is further investigated and accounted for in chapter 2 in Myndigheten för samhällsskydd och beredskap (2021), which also assesses stakeholder categories with partly opposing interests and prioritization arrangements in the electronic communication networks. Adaptions to regulations to handle potential challenges related to conflicts of interest are proposed in Myndigheten för samhällsskydd och beredskap and Trafikverket (2021a).

Notably, the Swedish government has not conducted any economic calculations that evaluate the benefit or opportunity cost of possible alternatives. Yet, various alternative conceptual solutions for the design of the new system have already been considered in the political decision process. In connection to this quality assurance, MSB and TrV have also asserted that they have passed the investigation stage, where inter alia needs should be identified and alternative concepts should be considered. Furthermore, wider non-monetized impacts and related distributional considerations were yet to be considered. Prior to this investigation, an internal project cost analysis had been conducted without documentation. Minor adjustments to this model were carried out in parallel to the beginning of our project.

In addition, an uncertainty analysis without anchorage in the cost estimate had both been carried out and documented by an internal team within MSB and TrV before our quality assurance was initiated (Erdalen et al. 2022). Note that in the Norwegian quality assurance scheme for major public investments, uncertainty analyses are usually not carried out before the KS2 evaluation step.

Still, some of the documentation on organizational governance and strategy was missing. Moreover, we did not have access to a plan for project organization, management, governance and strategy, including determination of project objectives, which fulfilled the same standard as required by the Norwegian quality assurance scheme at the KS2 investigation step. However, some steps related to planning and preparation of the further development and establishment of Rakel G2 are documented in Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b).

Moreover, we considered the planning work to be in a maturation phase somewhere in between KS1 and KS2. This is obviously partly due to lack of such a requirement and a different organization of investment projects in Sweden than in Norway.

Earlier investigation reports of the PPDR networks have also been carried out in Norway (e.g., Kvalbein et al. 2017 and Kvalbein, Lie and Holmen 2017 and Agenda Kaupang 2021).

1.5 The Current Quality Assurance Investigation

In this project, our mandate from the public contracting authorities is not to focus on alternative project concepts, concerning different extents of utilization of commercial networks and other requirements to MC services. Instead, the assignment is rather to address the matter of planning the design and realization of the new communication system in more detail and quality assure the earlier work. Yet, we still have to account for the project costs and benefits in the chosen project alternative and in the reference alternative, where no measures regarding a new Swedish public safety network are carried out. In this reference scenario, Rakel G1 is gradually replaced with uncoordinated use of electronic communication services in commercial mobile networks.

In line with standard investigation procedure associated with the Norwegian quality assurance scheme for large national government investment projects, we conduct a project cost analysis. Our focus is on net costs for the project and not net benefits for society. The results are compared to similar cost estimates from the previous internal project investigation of project costs. In connection to this assignment, we have also carried out an assessment of the project's funding options to illuminate the funding decision for the public authorities with budget responsibility.

Project costs are uncertain due to parameter uncertainties, project implementation and general risk. An uncertainty analysis is carried out in this regard anchored in the cost estimate. Note that the parametric uncertainties here do not only concern the size of costs and benefits, but also some unresolved features of the network design, such as the construction and sharing of base stations with commercial actors and the design of electronic equipment adapted for the safety network. To broaden our investigation into uncertainty further, we have mapped risk-reducing measures and carried out an uncertainty analysis of the time schedule. Based on our investigations, we provide recommendations on the project's total cost frame, which should include necessary contingency reserves to deal with uncertainty, and the responsible agencies' cost frame. We will also provide recommendations on project management to maximize the probability that the cost frame will hold. Our results are discussed in relation to the results from the internal uncertainty analysis by MSB and TrV (Erdalen et al. 2022).

Next, we carry out a quality assurance of the project implementation strategy and progress plan. Key features in this regard include overall project frames, management basis and strategy implementation. We assess whether the management document provides a sufficient basis for estimation, the progress schedule, the uncertainty assessments over time and the subsequent management of the project. Here, mapping and review of the relevant project documents is important to consider the maturity of the project organization and governance, and to consider whether the project is mature enough for a full assessment of the project organization. Key elements in this process include overall project frames, management basis and strategy implementation. Contingent on sufficient project maturity, key objectives would be to address how organization and management contribute to realizing the project in the most cost-effective way, and whether the governance regime provides the best incentive to use as little of the uncertainty provision as possible. Special management challenges would be assessed by considering the need for special measures to strengthen management or adapt the management structure.

To obtain a more complete quality assurance of Rakel G2, we investigate impacts external to the infrastructure project. Hereby, we aim to contribute to a broader understanding of the whole system integration project and shed light on and systematize the benefits and costs of the new emergency network. As opposed to the three main investigation analyses, this analysis relates to the KS1 investigation step in the Norwegian quality assurance scheme, and not KS2. Our analysis of the impacts external to the infrastructure project consists of five subanalyses. First, we carry out an estimation exercise on the gross user cost analysis. Second, we address the direct non-monetized user impacts, conducting a multi-criteria analysis of user attributes with several stakeholders. Third, we analyze indirect non-monetized impacts of Rakel G2 by qualitative assessments, involving impacts on spectrum utilization, cooperation, production economic aspects, knowledge, security and environmental factors. Fourth, we analyze the tax distortions directly or indirectly induced by the project, which constitutes an integrated part of conventional cost-benefit analysis in both Norway and Sweden. Fifth, we analyze distributional impacts of Rakel G2 across groups of stakeholders, social layers, space and generations.

1.6 Report Structure

We start this investigation report by reviewing the project background and the quality assurance assignment here in chapter 1. Then, in line with the needs of the client, we have in this investigation conducted four analyses that each contribute to the quality assurance of the new Swedish public emergency network, Rakel G2.

In chapter 2, we present our quality assurance of cost estimates and funding options, where we have calculated new cost estimates and compared them to the internal cost estimates. In chapter 3, we have conducted a quality assurance of the uncertainty analysis, involving a new uncertainty analysis, which is utilized to quality assure the internal uncertainty analysis with regard to cost estimates, timeline and general uncertainties. In chapter 4, we carry out quality assurance of organization and governance, both concerning project implementation strategy and progress plan. Finally, in section 5, we conduct an analysis of non-monetized impacts and distributional considerations, covering aspects of user functionality and wider impacts of the new emergency network.

Throughout our study, interviews have constituted an important source of primary information. The interview setups including interview guides and a list of informants are listed in appendix A.

2 Quality Assurance of Project Cost Estimates and Funding Options

2.1 Summary and Introduction for the Cost Analysis

2.1.1 Introduction to the Project Cost Analysis and Network Overview

This chapter documents the cost model received from MSB and TrV, and our work to review the model. This chapter also describes our proposed changes to the model based on benchmarking and seven expert interviews. We refer to the original model as the “Nova Model” and our revised model as the “Project Base Estimate” or “PBE", measured in Swedish 2024-krones.

The chapter also contains an overall description of the Rakel G2 mobile network and the elements that are included in the cost analysis. A mobile network consists of several elements as shown in Figure 2.1, and the cost analysis is structured according to this figure.

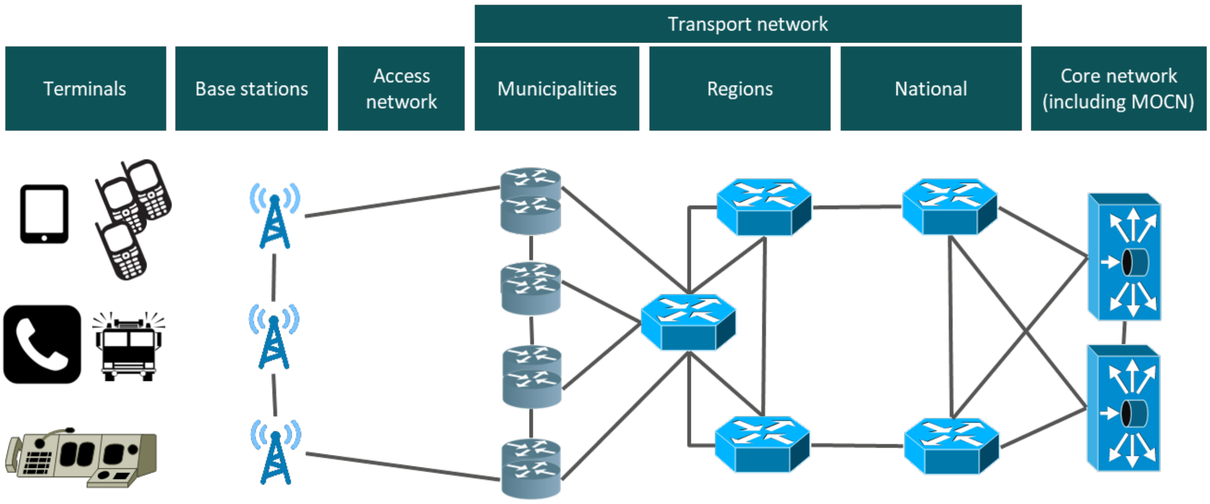


Figure 2.1: System overview

The figure above shows the system diagram for a dedicated public protection and disaster relief (PPDR) network that we have used as a basis for the cost analysis.

2.1.1.1 *Terminals and Control Rooms*

Terminals are shown to the far left in Figure 2.1. For most end users this means a handheld mobile phone, but it can also mean fixed terminals in vehicles and helicopters or connected sensors and actuators. In addition, there will be equipment in control rooms (such as SOS alarm centrals), where Rakel G2 terminals will be integrated with emergency software applications and public network connectivity. The Rakel organization will specify which types of terminals can be used in the G2 network, but the users are responsible for terminal purchase. Terminal costs are excluded from the cost analysis, while handling of terminals will be an important success factor for Rakel G2.

2.1.1.2 *Base Stations*

The terminals communicate with base stations. Rakel G2 plans for more than 7,000 base stations across Sweden, with an aim to provide national radio coverage also in some areas that are not covered by public networks today. The radio coverage will be established using 2x10 MHz of dedicated radio spectrum in the 700 MHz band. The 700 MHz band has good coverage properties with a potentially long range and high penetration of house walls and other obstacles. The data capacity available in this band is, however, limited. The plan is to add extra capacity to Rakel G2 through agreements with one or more commercial mobile network operators.

2.1.1.3 *Access Network*

In wired networks, it is common to define the access network as the connection between the end user and the nearest operator node. In mobile networks, we define the access network as the connection between the base station and the nearest aggregation point. Mobile access networks can be built in several ways. In commercial mobile networks, the access network often looks like a star network where one base station has one connection to an aggregation point.

In Rakel G2, the access network will often be built as a ring where each transmitting station has two access network connections. This means that a link failure does not have to mean that the transmitting station loses its connection to the rest of the network. Connections in the access network can be realized in the form of a point-to-point radio connection ("radio link"), a fiber network or even from satellite access. Over time, the proportion of fiber access will probably increase due to new service requirements associated with the new generations of mobile technology. Fiber networks usually have considerably higher capacity than radio links.

2.1.1.4 *Transport Network*

Figure 2.1 shows how the access network connects to the core network sites. In Rakel G2, about 1,200 nodes (“kommun-siter” or municipal sites) will be established to connect the base stations to the transport network. Then, the transport network connects these nodes to central elements such as the core network and service platform.

2.1.1.5 *Core Network and Service Platform*

The core network consists of several elements that manage traffic and users. Rakel G2 is planned as a 5G network with a standalone 5G core network. Connected to the 5G core is a service platform responsible for service production. The Rakel G2 will deliver important PPDR services such as voice, group voice and messaging services. In addition, Rakel G2 will provide data services. Mobile data capacity will be increased through access to commercial networks using a multi-operator core network (MOCN) solution where users can connect to the Rakel G2 core network through a commercial radio access network. There are still uncertainties associated with the timeline and scope for the introduction of different services.

2.1.2 Summary of the Project Cost Analysis

The Nova Model is a detailed excel spreadsheet describing new investments, recurring costs, reinvestments and revenues. The model is developed by experts at MSB and TrV. In our analysis, we have restructured this model to achieve a clearer break-down of cost and revenue elements. Figure 2.2 shows that the Nova Model estimates MSEK 9,100 for initial investments, MSEK 17,900 in recurring costs and MSEK 2,100 for reinvestments over a network lifetime of 17 years. This adds up to a total cost of MSEK 29,100. The Nova Model further estimates revenues of MSEK 16,300, so that the net cost is MSEK 12,800.

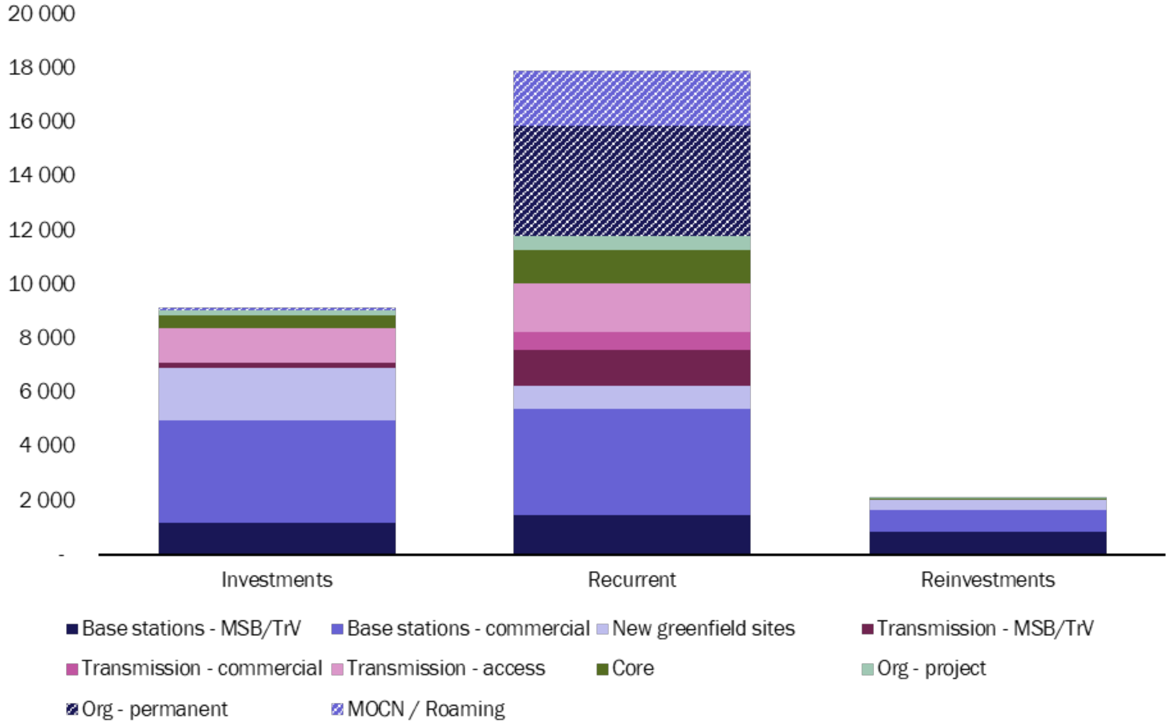


Figure 2.2: Nova lifetime costs in MSEK

In our opinion, the Nova Model is detailed and thorough. The sources for most estimates have been documented, and cost drivers are explained and modelled in detail. There are, however, important uncertainties that remain and some adjustments that we believe should be made to the model. The most important adjustments are the following:

- Most cost estimates were collected in 2021 and 2022. Since then, inflation in Sweden has been high, and we believe the costs in Swedish 2024-krones" will be higher than many of the Nova Model estimates.
- Over time, we assess that energy and construction costs will increase more than other prices. Note that we for energy prices have not included the most extreme price increase in the winter of 2022/2023. These are important cost elements in the Nova Model. We have adjusted the PBE to include an extra annual price increase of one percentage point for construction and two percentage points for energy (not accounting for the extreme energy prices in the winter of 2022/2023).
- The Nova Model does not account for real wage increases for permanent employees. Over time, we expect salaries to increase by 1.15 percentage points higher than inflation.
- On the revenue side, the expected launch of mobile broadband services has been delayed based on input from MSB and TrV. Also, the Nova pricing for mobile broadband is quite a bit higher

than what we believe PPDR users[3] will be willing to pay. Therefore, we have reduced expected broadband revenues.

- The Nova Model plans for 143 Rakel G2 employees over time. In addition, there will be 63 additional employees in TrV's transport network divisions to handle Rakel G2. We believe it is possible to run Rakel G2 with 130 employees and have adjusted the PBE to reflect that.

We have also made a few minor adjustments related to model bugs and the cost of transmission equipment. In total, the changes increase the estimated net cost from MSEK 12,800 to MSEK 18,300 as shown in Figure 2.3 as long as network lifetime is kept at 17 years.

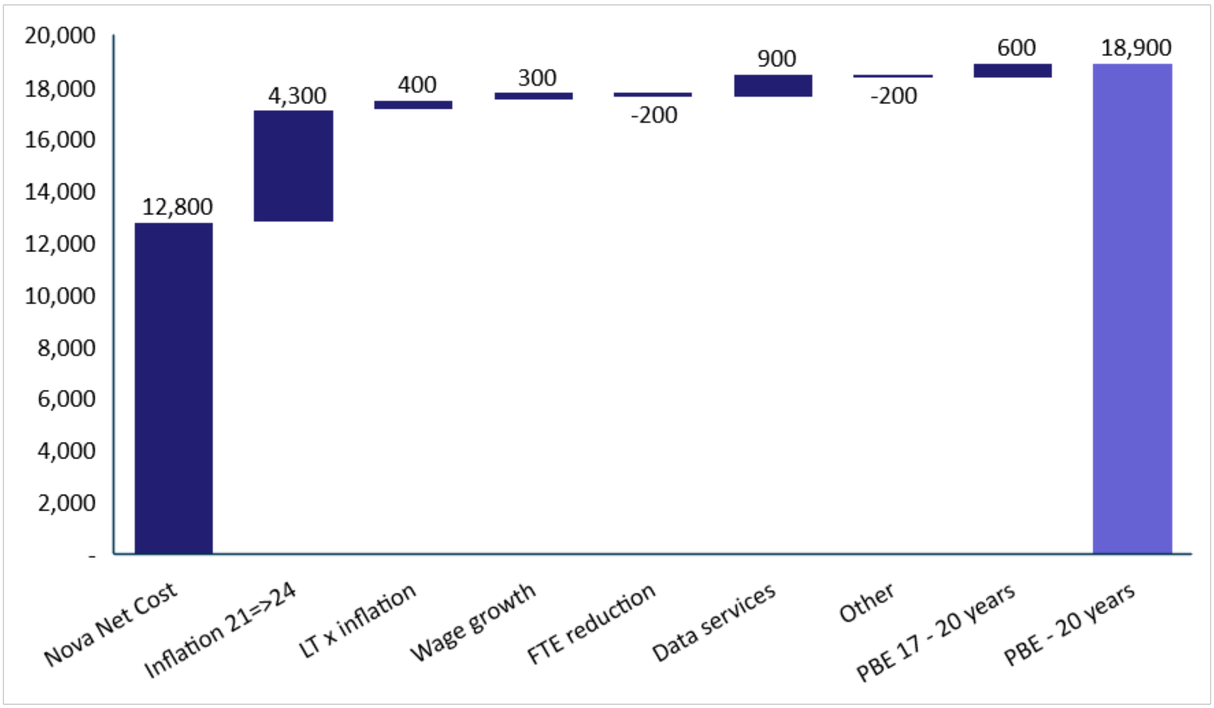


Figure 2.3: Project Base Estimate in MSEK – changes in net cost

Most mobile networks have a longer lifetime than 17 years, and we believe a network lifetime of 20 years for Rakel G2 is reasonable. This increases the PBE net cost from MSEK 18,300 to MSEK 18,900 ("PBE – 20 years"), but the cost per year decreases from MSEK 1,076 (17 years lifetime) to MSEK 945 (20 years lifetime) as shown in Figure 2.4. It is possible to extend the network lifetime even further, but this will likely require a higher level of reinvestments.

[3] PPDR: Public Protection and Disaster Relief. In Sweden often referred to as «Blåljus-etater» (directly translated – blue light agencies).

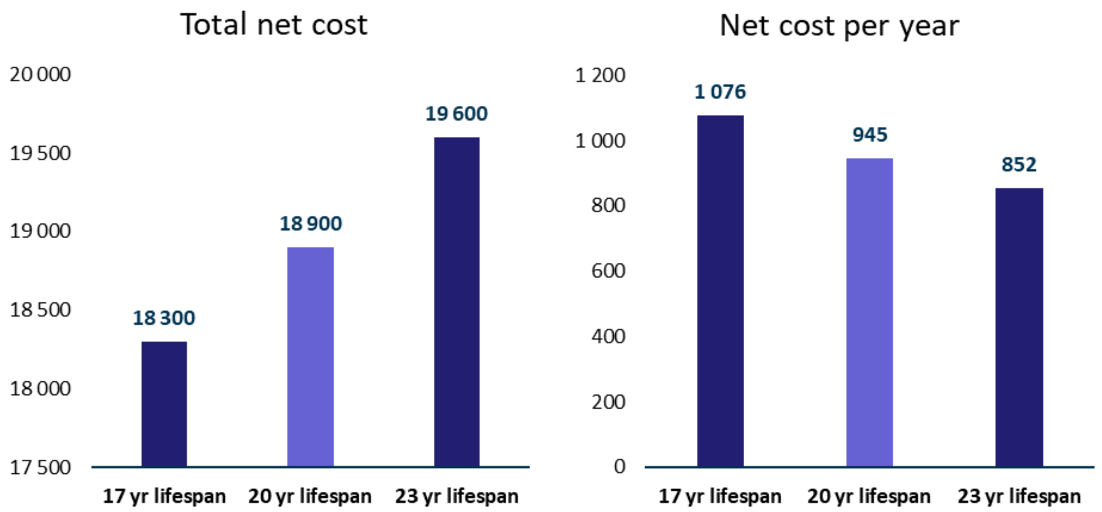


Figure 2.4: Net project costs in MSEK in a) total (l.h.s.) and b) per year with different network lifetimes (r.h.s.)

We have not made any changes to costs associated with base stations ("sites") and the core network. Site costs are more than 50 percent of total costs in both the Nova Model and the PBE. A detailed radio plan is necessary to estimate the number of sites needed, and the cost per site varies significantly with the types of sites that are deployed. In particular, the cost estimates assume that base stations to a large extent can be placed in existing towers, owned either by Trafikverket or by commercial tower companies. We have discussed the estimates with several experienced Swedish network builders. They all underline the uncertainty associated with site deployment costs, but we are confident that there will to a large extent be space available on commercial towers. This is the most important driver for Nova site costs and we therefore assess that the Nova Model estimate is reasonable.

The situation is different with regard to Core network costs. These costs make up less than 10 percent of total costs, but important uncertainties with regards to functionality and design have made it difficult to assess the cost levels. Uncertainties are related to the complexity of seamlessly integrating the dedicated Nova radio network with commercial radio networks, and the development and timing of the Rakel G2 services. We have not made any changes to Core network costs in the PBE, but underline that these costs are uncertain and that they should be re-assessed at a later stage.

Figure 2.5 shows the PBE estimated lifetime costs after all adjustments have been taken into account and we use a network lifetime of 20 years. The costs amount to MSEK 10,349, 25,478 and 2,399 for initial investments, recurring costs and reinvestment costs respectively. These are the costs which will be used as the base estimate in the cost uncertainty analysis.

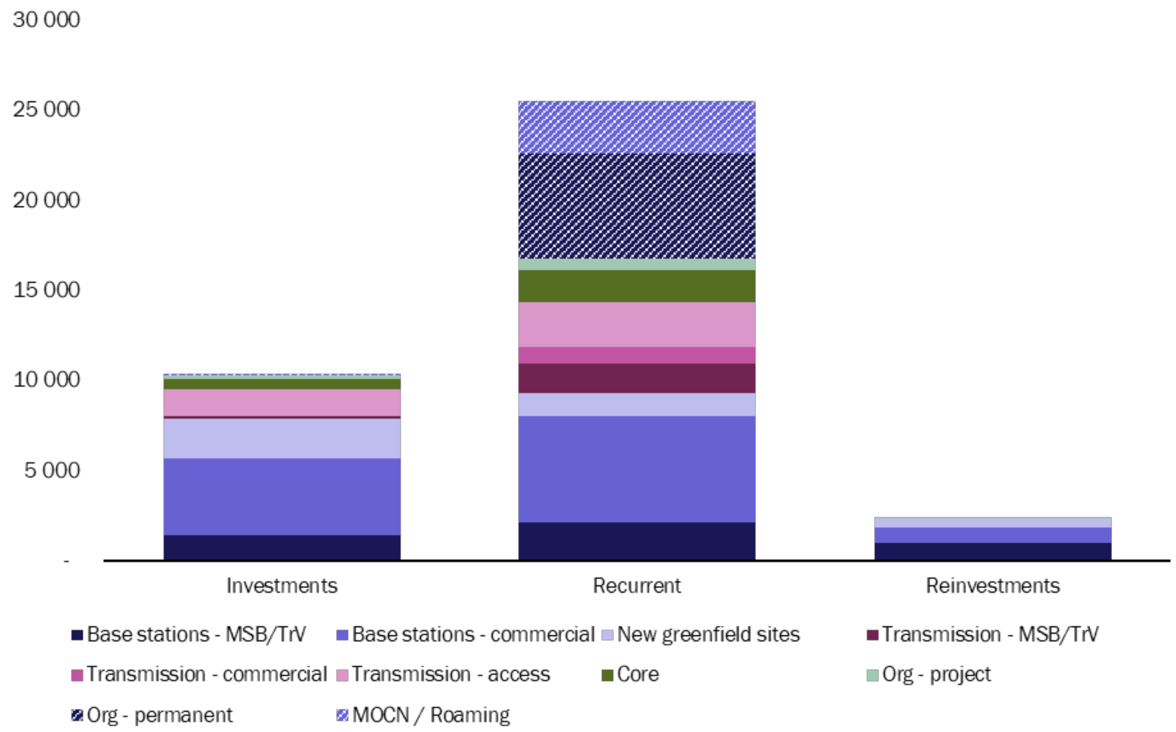


Figure 2.5: Project Base Estimate in MSEK – Lifetime cost with 20 years' lifetime

2.2 Method and Assumptions for the Cost Analysis

2.2.1 Methodological Framework for the Cost Analysis

In our quality assurance of the project cost estimates and funding options, we utilize the project cost methodology associated with the Norwegian quality assurance scheme for large national government investment projects with some adaptions and modifications to the Swedish appraisal methodlogy. In essence, the methodology applied does not deviate much from the one applied in the Swedish Transport Administration and the Swedish Civil Contingencies Agency's model for project costs, the so-called Nova model.

In Norway, the framework for the quality assurance scheme for large public investments is provided by the Norwegian Ministry of Finance (Finansdepartementet 2019). Furthermore, general advice on conducting economic appraisals is provided by the Norwegian Ministry of Finance (Finansdepartementet 2021b) and the Norwegian Government Agency for Financial Management (Direktoratet for økonomistyring 2018, with a new revision expected in 2023). There are further specifications to be found in sectorial guidelines, such as by the Norwegian Road Administration for measures in the road sector (Statens vegvesen 2021).

Sweden does not have general and overarching economic appraisal guidelines, although a Swedish Government Official Report (Statens offentliga utredningar, SOU) on economic appraisal is under development (confer Almerud et al. 2015 and Aggeborn et al. 2019 for previous reports). Instead, the economic appraisal guidelines for the Swedish transportation sector provided by the Swedish Transport Administration (Trafikverket 2021) are often applied to other sectors as well, with some flexibility.

Wangsness, Holmen and Hansen (2022) map differences between Norwegian and Swedish transportation appraisal practices. In connection with this project, we have interviewed experts on economic appraisal at the Swedish Transport Administration about Swedish economic appraisal practices. This was useful for ensuring that the current setup for Swedish economic appraisal was correctly followed and for becoming aware of unpublished and upcoming changes in the methodology.

Beyond the public guidelines, both the Swedish and the Norwegian economic appraisal methodology involve assumptions about inter alia demographic and economic development. The inflation targets of the Norwegian and Swedish central banks (e.g., Norges Bank and Sveriges Riksbank respectively) constitute the basis for future core inflation. In Norway, assumptions about economic growth figures are stated in the Ministry of Finance's report on long-term perspectives for the Norwegian economy (Perspektivmeldingen, confer Finansdepartementet 2021a). At the same time, demographic prognoses and price developments are provided by Statistics Norway (Statistisk sentralbyrå, SSB). By the same token, Statistics Sweden (Statistiska centralbyrån, SCB) provides demographic estimates and historical price developments for Sweden, while Swedish Government Official Reports processed with the involvement of the National Institute of Economic Research (Konjunkturinstitutet, KI) report estimates on economic growth figures.

2.2.2 Information Collection for the Cost Analysis

In the quality assurance of the cost estimates and funding options, we have utilized several information sources. These are the internal cost model (the 'Nova Model'), previous parameter estimates, project information, interviews, a reference group and sources of guidance, documents and statistics associated with public appraisal methodology.

2.2.2.1 *The Internal Cost Model*

The internal cost model for Rakel G2 is known as the 'Nova Model', developed jointly by the Swedish Civil Contingencies Agency and the Swedish Transport Administration. The model was presented and discussed with the lead developers at the relevant governmental agencies, as well as with the lead principals of this project.

2.2.2.2 *Previous Cost Estimates*

In the parameter determination of our baseline cost model, we have considered and exploited cost estimates from both internal and external sources. In 2016, the Swedish Post and Telecom Authority collected detailed cost information from Swedish public mobile networks and developed a so-called Long Run Incremental Cost (LRIC) model (Post- och telestyrelsen 2016). We have used this model to compare cost levels with the Nova Model. Other relevant reports written by members of the project group include Kvalbein, Lie and Holmen (2017) and Kvalbein and Lie (2018). We also utilized local expertise on cost components at the Analysys Mason offices in Oslo and Stockholm, as well as data from Analysys Mason Datahub. As for external cost estimates, we have reviewed previous studies such as Direktoratet for nødkommunikasjon (2013), Post- och telestyrelsen (2016) and Agenda Kaupang (2021).

2.2.2.3 *Interviews*

In connection with the project cost analysis, we have conducted seven interviews with relevant stakeholders. Two interviews were carried out with emergency network users. We had one interview with each of the following groups: governmental telecommunication operators, economic expertise, private telecommunication operator, telecommunication construction company and telecommunication infrastructure company. We refer to appendix section A.1.1 for the applied respondent-specific interview guides and appendix section A.2.3 for the list of respondents.

2.2.2.4 *Project Information*

Project information was obtained both from the key informants at the principal organizations (i.e., Swedish Transport Administration and the Swedish Civil Contingencies Agency) and previous investigation documents. Key personnel at the Swedish Transport Administration and the Swedish Civil Contingencies Agency presented their work, as elaborated on in appendix section A.2.1. This also includes the council responsible for the investment project, known as the Nova council.

2.2.2.5 *Reference Group*

In connection with the subproject, a reference group meeting was held, where the main methodlogy and results for the project cost estimates were presented and discussed. The reference group consisted of four members, including three Norwegian participants and one Swedish participant. The Norwegian participants included one expert on the economics of public investments, a telecom security expert and a director from Norway's PPDR directorate. The Swedish participants included representatives from one governmental agency and two ministries. We refer to appendix section A.2.2 for details. In addition to the reference group members and the consultants, the project principals at the Swedish Transport Administration and the Swedish Civil Contingencies Agency participated in the meeting.

2.2.2.6 *Public Appraisal Methodology*

In our study, we largely follow the economic appraisal guidelines for the Swedish transportation sector provided by the Swedish Transport Administration (Trafikverket 2021). These documents are described in more detail in section 2.2.1 and for some applications in section 2.2.3. In addition, the inflation target of the Swedish Central Bank is applied, while specific price indexes are collected from Statistics Sweden as well as official Swedish forecasts (Almerud et al. 2015 and Aggeborn et al. 2019). Furthermore, as reference work, we have applied Norwegian appraisal practices (Direktoratet for økonomistyring 2018, Finansdepartementet 2021b and Statens vegvesen 2021), international appraisal practices (Wangsness, Holmen and Hansen 2022), Norwegian economic forecasts (Finansdepartementet 2013, 2017 and 2021a) and international economic statistics (mainly from the International Monetary Fund).

2.2.3 Macroeconomic Assumptions

In the following, we present and justify the macroeconomic assumptions applied in our cost estimation model. These are mainly dynamic in nature. Our macroeconomic baseline assumptions and the assumptions applied in the Nova model are listed in Table 2.1. Note that the price series for energy prices ends before the extreme winter of 2022/2023.

Table 2.1: Summary of the macroeconomic assumptions in the Nova model and our baseline model

Assumptions	Nova assumption	Baseline assumption
Analysis length	17 years	20 years
Infrastructure lifespan	17 years	20 years
Discount rate	0.00 %	0.00 %
Annual population growth	0.00 %	0.40 %
Annual real growth rate	0.00 %	1.15 %
Annual core inflation	2.00 %	2.00 %
Annual additional construction inflation	2.00 %	3.00 %
Annual additional energy inflation	2.00 %	4.00 %

Assumptions regarding price and volume on the cost and revenue components are accounted for in section 2.3. These are largely static, but also dynamic in connection with the technical and user-related network expansions.

Analysis Period and Life Span

In the Nova model, Rakel G2 is assumed to have a life span of 17 years. However, it is clear from the conversations with the project principals model developers that the project period was originally intended to be 20 years. Still, the project period was not extended beyond 2040 after years went by. The Swedish Transport Administration does not report assumptions on the lifespan of the general telecommunication network, but signal facilities are assumed to last 30 years (Trafikverket 2020). The project delimitation suggests that the Rakel G2 in the appraised version will mainly be maintained as a telecommunication network without being subject to considerable quality improvements. Thus, we assume that the network will last 20 years. Note that the reference groups argued that the life span should be much longer than that, given the assumption of limited quality improvements. The conversations with our interviewees also support this choice. In robustness checks, we assume a life span of 17 years or 23 years.

The expected life span of assessed infrastructure is closely related to the analysis period chosen in economic appraisal guidelines. Accordingly, the analysis period is set equal to the lifespan of the infrastructure, which is 20 years in our main scenario. The Nova model applies 17 years.

In project cost analysis, we are interested in the cash flows including investments and not depreciations. Furthermore, we do not apply discounting, as we are interested in the actual budget impacts over time. This approach is common practice in the Norwegian quality assurance scheme for major investment projects. Although project cost analysis is less common in Sweden, the choice is confirmed by the Swedish expertise.

2.2.3.1 *Productivity Growth and Real Wage Growth*

While the Nova model ignores growth in real wages for project staff and permanent staff, we assume that their wages follow the real wage growth in the rest of society. Both in Norway and Sweden, the convention up to now has been to assume that real wage growth follows labor productivity growth.

Annual forecasts for key features of the Swedish economy are provided in the Swedish Government Official Report (e.g., Almerud et al. 2015 and Aggeborn et al. 2019). In Aggeborn et al. (2019), the annual productivity growth from 2019 to 2035 is predicted to be 1.6 percent, down from 1.7 percent in Almerud et al. (2015).

However, the most recent report was published before both the corona pandemic and the changes in the security and energy supply situation following the Russian invasion of Ukraine, so that the growth rate should be expected to decrease as a consequence. For comparison, the Norwegian Ministry of Finance downscaled the predicted labor productivity growth in Mainland Norway towards 2060 from 1.8 percent in 2013 to 1.5 percent in 2017 and further to 1.3 percent in 2021 (Finansdepartementet 2013, 2017 and 2021a). In its World Economic Outlook Database as of October 2022, the International Monetary Fund predicts an annual growth in the Swedish labor productivity from 2023 to 2027 of 1.27 percent.

In conversation with Swedish economic experts, we were told that the estimates for labor productivity in the upcoming Swedish Government Official Report on economic forecasts would downscale the annual Swedish growth estimate for labor productivity to 1.3 percent. Furthermore, we were informed that the annual real wage growth rate was partly decoupled from the annual labor productivity rate, as one expects a worsening in the Swedish terms of trade. Thus, the real wage growth rate was set to 1.15 percent, which also is the rate assumed for project staff and permanent staff in our baseline model.

2.2.3.2 *Employment and Population Development*

The Nova model does not assume any population growth that would affect the number of users of Rakel G2. In our analysis, we assume that the Swedish population will grow by 0.4 percent annually in line with the latest forecasts of Statistics Sweden. This assumption is quality assured with economic expertise through interviews. The user basis of Rakel G2 is assumed to grow annually by the same rate beyond the growth associated with rollout among target user groups. This assumption is quality assured by Swedish economic experts through interviews.

We have not made any assumptions that are dependent on the size of the labor force relative to the population size. There is no such assumption in the Nova model either.

2.2.3.3 *Inflation and Monetary Valuation*

In Sweden, it is common to use the Swedish central bank's inflation target of 2 percent annually as the basis for inflation forecasts. The Nova model operates with fixed prices and so do we. Implicitly, this implies an assumption of symmetric inflation over time. In our baseline estimation, we also implicitly assume future annual core inflation of 2 percent, but we make two exceptions.

First, we assume that the future construction prices grow by 1 percentage point more annually than the core inflation. This is based on the observation that the Swedish construction sector has had an annual price growth of 2.8 to 2.9 percent since the turn of the millennium. As fewer migrant workers and some convergence between Western and Eastern European countries are expected in the coming years, it seems likely that the wedge in price developments will continue in the future. In Norway, misjudgment of cost developments related to construction was identified as the key error in cost analysis related to the quality assurance scheme for large national government investment projects (Ulstein et al. 2015).

Second, we assume that the future annual energy inflation is at 2 percent in addition to core inflation. According to Statistics Sweden, consumer prices related to electricity and gas grew by 4 percent annually between 2000 and 2021. A similar development in energy prices is reported by inter alia the International Monetary Fund. Considering the increased focus on climate preservation and adaptation measures and the new European security measures with less access to Russian energy resources, energy prices will likely continue to rise relatively sharply in the medium term.

We have also considered the price development in technical equipment and information and communication technology services. The relevant price index reported by Statistics Sweden implies a relatively weak positive or even negative price growth for these products. However, the indexes adjust for quality improvements, whereas we are interested in the price development where the standard quality improvements are included. The price index for technical equipment and information and communication technology services is generally more complex, as they involve quality improvements in addition to price development for a given quality. In the case of technological components, the Rakel G2 project also faces few suppliers and to some extent becomes dependent on the chosen supplier early in the project. This further complicates the pricing of technical equipment. Overall, we have decided to assume the same inflation for these components as the core inflation.

In our interviews with economic experts, we discussed the price assumption on the basis of the guidelines provided in Trafikverket (2020) and the upcoming revisions. It becomes clear that current appraisal guidelines allow for the inclusion of additional price growth in energy prices, but not in construction prices. However, our respondents informed us that they intend to open up for an additional price increase in construction prices in the upcoming revision. Furthermore, they thought it would be advisable to assume additional price growth related to construction costs in our case. The reference group also argued that heterogenous price developments were important to consider.

As the Nova model originally was developed with 2021 as the first model year, values in the Nova model are generally reported in 2021 prices, but in 2022 prices for towers and technical huts. Based on prognoses for price growth up to September 2022 and forecasts up to 2025, we approximate the price growth from 2021 to 2024 to be 115.16 percent and the price growth from 2022 to 2024 to 106.69 percent. The annual growth figures are reported quarterly but *recalculated to yearly averages.*

All prices in the cost analysis exclude value added tax, which is common practice in both project cost analysis and cost-benefit analysis.

2.3 Cost and Revenue Components

2.3.1 Base Stations

The table below shows investment costs associated with base stations, types of base stations and associated costs in different outcomes for both the Nova Model and the PBE. The investment cost per base station and operating expenditure per base station will increase slightly throughout the period in the PBE due to the additional inflation in both electricity and construction prices.

Table 2.2: Investment costs of base stations

Type of site	Cost per base station Nova Model (SEK)	Cost per base station PBE (SEK)
New greenfield site, rooftop	570,000	656,420
New greenfield site, rural	3,500,000	4,030,647
New leased sites	570,000	656,420
New leased sites, upgrade needed	1,280,000	1,474,065
Existing sites (MSB and TrV)	500,000	575,807
Special object	500,000	575,807

The number and type of base stations are usually the most important cost component in a mobile network, and it is also the largest cost component in the Nova Model. Investments related to base stations stand for 76 percent of all investments and 35 percent of all recurring costs in the Nova Model. The total investments in base stations are MSEK 6,930, the recurring costs are MSEK 6,225 and the reinvestment costs are MSEK 2,031.

The Nova Model has a high share of commercially leased sites (48 percent of total sites), as can be seen from Table 2.3. The most expensive site type is new greenfield sites in rural areas. Nova plans to deploy 400 such sites with an estimated deployment cost of MSEK 3.5 per site. The PBE maintains the same number and distribution of base stations as the Nova model. We note, however, that there is uncertainty related to the high number of base stations that will be placed in commercial towers. The question is whether there is enough space in the towers for the antennas and radio equipment of Rakel G2. On the other hand, experts we have interviewed have pointed out that existing 3G equipment will be removed in the coming years, which could free up space for Rakel G2. Other experts point out that there will be available space on the towers, but some will need upgrades to accommodate the added equipment for Rakel G2.

Table 2.3: Number and share of base stations in both models

Type of site	Number of sites	Share of sites
New greenfield site, rooftop	500	7 %
New greenfield site, rural	400	5 %
New leased sites	1,000	14 %
New leased sites, upgrade needed	2,500	34 %
Existing sites (MSB and TrV)	2,400	33 %
Special object	550	7 %
Sum	7,350	100 %

Table 2.4 shows the operating expenditure for the different types of base stations in both the Nova model and the PBE. The PBE uses the same costs as the Nova model, except for adjusting for the price inflation from 2021/2022 to 2024.

Table 2.4: Operating expenditure for base stations

Type of site	Cost per year per base station Nova Model (SEK)	Cost per year per base station PBE (SEK)
New greenfield site, rooftop	85,000	97,887
New greenfield site, rural	40,000	46,065
New leased sites	90,000	103,645
New leased sites, upgrade needed	90,000	103,645
Existing sites	40,833	47,024
Special object	15,000	17,274

The PBE deviates from the Nova Model on two points related to base station costs:

1. As for all cost components in the Nova Model, costs have been adjusted from 2021/2022 to 2024 prices.
2. An additional inflation of 1 percent for construction costs and 2 percent for energy prices has been added to the general inflation. This adjustment affects both investment cost (construction) and recurring costs (electricity).

These changes result in MSEK 950 higher investment costs (given 20 years' analysis period and life span), MSEK 3,075 higher recurring costs and MSEK 298 higher reinvestment costs related to base stations in the PBE.

The antennas and base stations need to be installed by competent personnel. The Nova Model includes SEK 100,000 as installation cost and SEK 50,000 for installation of radio links for the access network. Based on interviews with experienced Swedish installers, we believe these costs are reasonable and possibly even a little high for the radio link installation. For these cost levels to be true, a few conditions must be in place:

- Most importantly, the network deployment plan must include long term time and volume commitments. Logistics and planning costs are important cost elements for the installation companies, and any "moves, adds or changes" will inevitably increase installation costs. This creates a dilemma for Rakel G2 since the project depends on yearly budget allocations.
- Secondly, the network deployment plan should be (geographic) area-based since this will reduce travel time and increase actual installation time. For a project of Rakel G2's scope, the installation companies are likely to mobilize several teams which are responsible for different geographic areas.
- Third, any security clearance requirements, such as a registry check ("registerkontroll" in Swedish), need to be handled within a reasonable amount of time. Most installers in Sweden are Swedish citizens where the processing time for registry check is three weeks. Based on this, we assess that a requirement for Swedish citizenship and/or security clearance will not increase costs significantly for the installation companies.

2.3.2 Access Network

The access network has a total cost of MSEK 3,065 in the Nova Model, where MSEK 1,290 is investments and MSEK 1,775 is recurring costs. The access network cost makes up 10 percent of the total cost, which is slightly higher than the transport network cost. The investments in the access network consist of investments in switches, CPEs, technical huts and radio links, where investments in radio links are the highest cost. The operating expenditure is calculated as 3 percent of the material cost for the investments mentioned above. In addition, there are operational expenditures related to rent of fiber of up to MSEK 100 yearly based on the completion of base stations. This cost reaches its maximum of MSEK 100 from 2033 and onwards, when all of the base stations have been built.

The QA-team has made one change to the model which affects the access network cost, and that is the adjustment from 2021 prices to 2024 prices. This change increases the cost of the access network by MSEK 909 or 30 percent to MSEK 3,974, but much of this increase is driven by the increase in recurring cost due to the increase to 20 years lifetime. We have also reviewed the costs in the access network by comparing the costs to the costs of similar components presented in the LRIC-model for calculation of costs in a mobile network by the Swedish Post and Telecom Authority (Post- och telestyrelsen 2016). The cost of a microwave ethernet varies from SEK 45,000 to 120,000 depending on the bandwidth of the radio links (10-1000 Mbit). These prices are fixed prices set to 2010, so it is reasonable to assume that the prices of 2024 will be higher. The Nova Model uses prices of SEK 30,000 and SEK 100,000 for their radio links, which seems to be consistent with the prices in the LRIC-model even though we do not have much information about the radio links Rakel G2 will use. The cost of the radio links is also considered reasonable because each base station will have a pair of these radio links in order to secure redundancy.

2.3.3 Transport Network

The total cost of the transport network is MSEK 2,198, which is 8 percent of the total cost in the Nova Model. Investments in the transport network are MSEK 170, the recurring costs are MSEK 2,029 and there are no reinvestment costs. The total investments in the transport networks used for Rakel G2 are higher than MSEK 170, but Nova has only a 34 percent share of these investment costs while the Swedish Transport Administration (TRV) is responsible for the remaining 66 percent. The investment costs consist of both material costs and installation costs in the national backbone, regional backbone and transport network in the municipalities. The components needed are for example switches, optical network components and new technical huts. The recurring costs consist of two parts. The first is operating expenditure for the transport network which is calculated as 3 percent of the material cost of the different components of the transport network. The second part is personnel costs related to transmission and includes for example a documentation group and another network operating center-team. The plan is to have 63 employees working with the transport network. The recurring costs increase throughout the period as more and more of the transport network is being built.

We have made three changes which affect the transport network cost. The first is related to a bug in the calculation of the operating expenditure for the national and regional backbone. The bug affects the year 2026 and onwards, where the calculations do not consider that all the national and regional backbone will be built by the end of 2025. This makes the recurring cost very low from 2026 and onwards. The second change is that all the prices for the transmission network are increased from 2021 prices to 2024 prices. The last change is that we have decreased all of the transport network costs of the Nova Model by 25 percent, based on information from expert interviews that suggest that the transport network costs in Nova are too high. These changes in addition to the increase of lifetime to 20 years increase the total cost for the transport network by MSEK 516 or 23 percent.

2.3.4 Core Network, Service Platform and Multi-Operator Core Networks

Investments related to the core network, service platform, and access to commercial radio networks using multi-operator core networks (MOCN) together make up 5 percent of all investments and 19 percent of all recurring costs in the Nova Model. Over the calculation period the Nova Model has a total cost of MSEK 1,774 related to the core network and service platform, and a total cost of MSEK 2,100 for access to commercial radio networks.

The costs related to the core network consist of recurring costs of MSEK 1,264, investments of MSEK 479 and reinvestment costs of MSEK 31 for the entire period. The investment costs in the core network consist of 5G core, a technical solution to connect Rakel G1 users to G2 users, the Mission Critical service platform (MCX) and datacenter facilities for hosting these. These investments are planned to take place from 2024-2031. The costs related to MOCN are mainly recurring costs related to commercial RAN access.

There are significant uncertainties regarding the establishment of the core network and MOCN solution. The Nova project are still working on developing a high-level design for the seamless operations across dedicated and rented radio access networks. The complexity of the practical implementation of such a solution is significant. Factors driving uncertainty are interoperability issues between different system vendors, level of integration between dedicated radio network and commercial radio network and the required functionality of the solution. Much design work is still needed before the full cost picture can be reasonably estimated.

In spite of these uncertainties, we have not made any changes to the cost in the PBE. Instead, this uncertainty is discussed in the uncertainty analysis in chapter 3.3. The only change we have made which impacts the cost of the core network and MOCN in addition to the 20 years lifetime change is the adjustment from 2021 prices to 2024 prices. This increases the cost related to the core network and MOCN by MSEK 587, corresponding to 15 percent.

2.3.5 Organization

The personnel costs in the Nova Model are a big part of recurring costs. The project personnel costs and permanent personnel costs make up 26 percent of the total recurring costs in the Nova Model. To plan and build a new PPDR network requires lots of personnel, and to operate the network requires even more personnel. The NOVA model divides the personnel into project personnel and operations personnel, where the main costs are related to operations personnel. The project personnel is responsible for the planning and building of the PPDR network, while the operations personnel is responsible for the daily operation and supervision of the network. The table below shows the number of full time equivalents (FTEs) in project personnel and in operations, where we can see that the number of operations personnel increases until 2030 where it stabilizes at 143 FTEs until the end of the project period in 2040. The number of project personnel FTEs is at 62 the first three years, before it declines until 2033 when the project personnel is at 0.

Table 2.5: Number of FTEs

	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033-2040
FTEs project Nova & PBE	62	62	62	60	58	27	27	21	21	0
FTEs operations Nova	19	23	50	79	113	139	143	143	143	143
FTEs operations PBE	19	23	50	79	113	130	130	130	130	130

The Nova Model uses SEK 1,300,000 as annual wage costs including overhead per FTE. This is based on an annual monthly wage of SEK 50,000. The overhead is based on the current number of employees in Rakel. This wage is considered reasonable when looking at permanent staff but may be a bit low if lots of consultants are used. The Nova Model does not specify whether it is permanent staff or consultants which shall be used.

In addition to the recurring costs, the Nova Model has SEK 197,500,000 in personnel related investments, which is mainly related to offices, a security operations center and a network operating center. These investments represent a small part of the total investments in the cost model.

We have made three changes to the organization costs in the project base estimate:

1. Adjusted the wage by the real wage growth throughout the entire period and the personnel investments by the inflation from 2021 to 2024.
2. Separated the employees for the project organization into consultants and internal full-time employees, so that we could differentiate their wages. We estimate that 25 percent of the FTEs in the project organization will be consultants.
3. Implemented a yearly cost for FTE consultants at MSEK 2,160,000. This was seen as a reasonable wage for the consultants and calculated based on an estimate of 1,800 hours per consultant each year with an hourly wage of SEK 1,200. The cost of the consultants becomes higher than the cost of the internal full-time employees, which is as expected.
4. Reduced the number of full-time employees in the operations organization from 143 to 130 from the year 2029 onwards. We have reduced the FTEs in staff and overhead functions by a

total of 13 FTEs. We have kept operational employees and also 14 employees in the service development group. We do not believe there will be major service development work across time, but these employees will likely be useful in process development together with important user groups.

These changes in addition to the increase to a 20-year lifetime increase the total cost related to the organization by MSEK 1,966. Also, we note that the transport costs include 63 new employees. There may be some synergies between Rakel G2 and these employees.

In 2012, the Norwegian PPDR operator had 86 full time employees according to chapter 4.3 in their 2012 annual statement (Direktoratet for nødkommunikasjon 2013). We think it is reasonable to expect for Rakel G2 to have more employees since the Norwegian PPDR network has outsourced many NOC functions and Rakel G2 is a larger network with more services.

2.3.6 Revenues

The revenue in the Nova Model is divided into three types of subscriptions – the base subscription (including voice and messages), the data subscription and the internet of things (IoT) subscription. The price is SEK 950, SEK 240 and SEK 60 for the base subscription, the data subscription and the IoT subscription respectively. The number of subscribers is increasing throughout the period until 2037, when the maximum number of subscribers is reached. The QA-team has interviewed experts who indicate that the number of subscribers seems reasonable. It is likely that the number of subscribers will increase substantially over the years compared to Rakel G1. The total revenue in the Nova Model is MSEK 16,334. The revenue stream begins in 2025 and reaches its peak from 2037 onwards. The revenue from 2037 is estimated to be MSEK 1,376 each year.

We made two changes which affect the revenue in the Nova Model. It is worth noting that the prices of the different subscriptions were not adjusted by inflation from 2021 to 2024 like the costs in the model were.

1. Reduced the price of the data subscription from SEK 240 to SEK 150, because the data we have gathered indicates that the price of SEK 240 is too high. The price of SEK 150 is more appropriate for a data subscription in the Swedish market if we compare with the prices of other mobile operators in the market. It is important to consider the price sensitivity of the customers, and not overestimate their willingness to pay. The price sensitivity of the users constitutes an uncertainty of the model, which will be considered further in the uncertainty analysis.
2. We postponed the revenue of the data subscriptions from 2026 to 2032, as the QA-team received information from MSB and TrV that the data service of Rakel G2 would not be available to users until later in the project period. It may also be possible to launch a regular mobile broadband service before a Mission Critical data service which is likely to require significant time and development resources.

These two changes alone result in a decrease in revenue in the PBE by MSEK 991, which is a 6 percent reduction. The delayed data service causes 27 percent of this reduction in revenue, while the decrease in data subscription price causes the remaining 73 percent drop in revenue. The increase from 17 to 20 years lifetime causes an increase in revenue of MSEK 3,940, which results in a total increase in revenue in the PBE of MSEK 2,949 compared to the Nova Model.

2.4 Funding Options

2.4.1 Overall Assessment

Our main conclusions regarding funding options are as follows:

- The annual cashflow of Rakel G2 will be negative most years and will require financing
- Financing via annual grants from public budgets secures the lowest financial costs possible
- Negative cashflows throughout the 20 years' life of the project strongly suggests that bond or alternative financial market-based financing is not optimal from a cost and budgeting perspective
- Marked based project financing may mitigate the risk of lack of sufficient public financing in the critical initial investment phase

The cashflow from Rakel G2 is likely to be negative most years throughout the 20-year lifetime of the project. Naturally, the cashflow will be highly negative during the initial investment phase of the project. However, during the operation and maintenance phase income from users will hardly be large enough to match negative running and reinvestment cashflows. Most years the project needs public or market-based funding.

2.4.2 External Financing of Public Infrastructure Project

Large public infrastructure investment projects may seek funding in domestic and international financial markets, via bonds, bank loans and, to an increasing extent, from international equity investors. Such projects typically have an expected positive cashflow from user payments during the post-investment phase of the infrastructure project that supports down-payment and covers the costs related to the financing of construction. This is not the case here. An expected continuous negative cashflow for most of the project's lifetime suggests that there is no basis in the form of future revenue generation that can support financial market funding. Any external financing will depend on future grants from the parliament to cover down-payments and cost of financing.

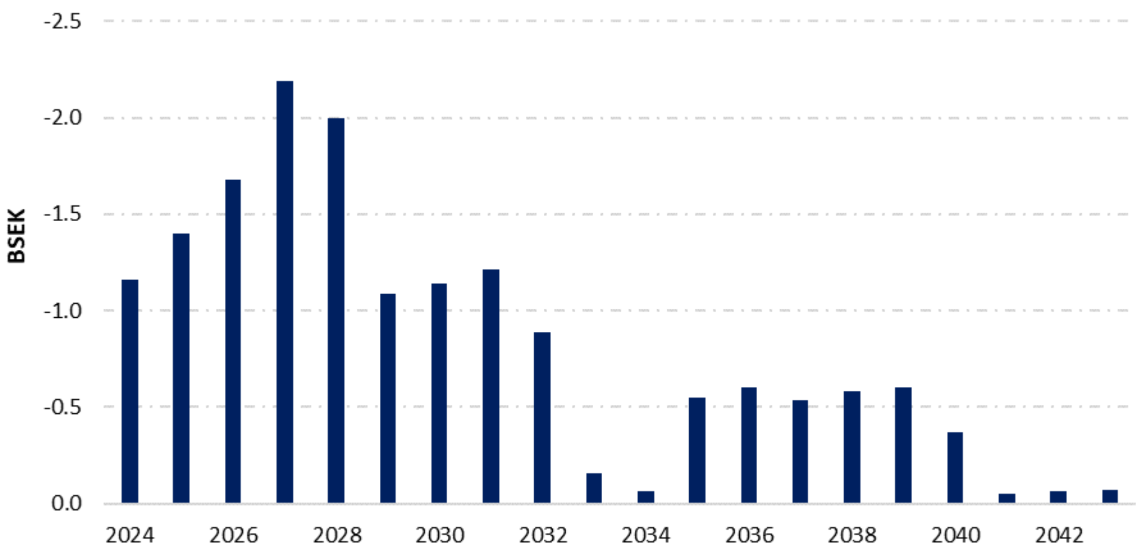


Figure 2.6: Cash flow establishing and running Rakel G2

2.4.3 The Cashflow of the Rakel G2 Project

As an illustration, we assume that the cashflow of the project is financed in the market at a low fixed interest rate (i.e., EIOPA = 3.45). During a 20-year period, total debt, including the financing of interest rate payments, will accumulate to about MSEK 16,200. Market financing of Rakel G2 implies a postponement of required public funding – for future generations to pay. That is, given the current income potential of Rakel G2, and the substantial investment costs, the first choice should be to fully fund the project via public grants – year-by-year. Annual grants will typically be in the range zero to approximately MSEK 2,200.

In case the project is fully funded every year by the Swedish government, finance costs of the project will be given by the Swedish government's funding costs in the international government bond market – reflecting the credit rating of the Kingdom of Sweden – which typically will represent the lowest funding cost available.

2.4.4 Arguments for External Financing of Rakel G2

Investments according to budget and a timely development of the system to match the requirement of end-users, are key to the success of Rakel G2. If, due to unexpected events, funding via public grants falls short of expectations and budget, this will delay the development of Rakel G2. This could jeopardize the project and delay future income from end-users. End-user related income short of budget can further add to the delay of the system.

In the initial investment phase, the risk of delayed public funding may be an argument for external financing in financial markets – based on guaranties related to end-user payments (e.g., based on regulations) and future public grants. However, it may be inconsistent to regard lack of funding during the initial investment phase as a real risk to the project – given that both the decision to develop Rakel G2 and the annual decision to fund the project is the Swedish parliament's to make.

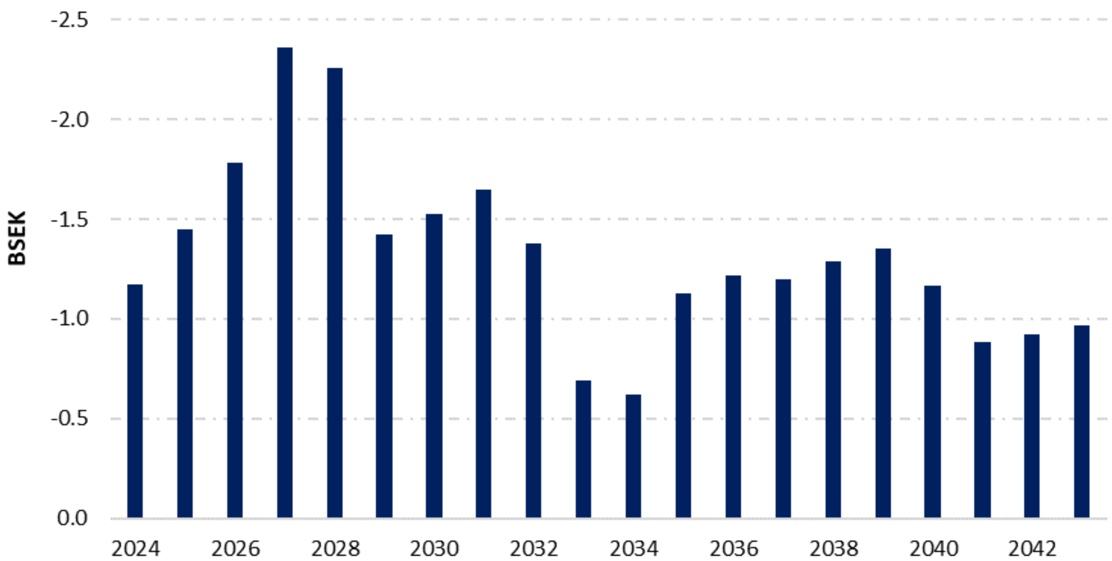


Figure 2.7: Cash flow establishing and running Rakel G2 – in the case of 100 percent debt financing

2.4.5 Interest Rate Uncertainty

In the cashflow analysis above a fixed and low EIOPA (European Insurance and Occupational Pensions Authority) interest rate is assumed. At present inflation is unusually high in Sweden and internationally and interest rates are trending upwards, as a part of central banks' attempt to control price growth. International interest rates trended downwards from the early 1980s until the financial crisis, and thereafter stayed at low levels until the end of the Covid-19 pandemic.

The international financial markets are in uncharted waters. Our base case is that the Swedish central bank (Riksbanken) and international central banks will succeed in stabilizing inflation shortly, which will support stable and low inflation and nominal interest rates during the lifetime of Rakel G2. However, there is a real risk of significantly higher interest rates going forward than the assumed EIOPA. In the case of external financing of the investment phase of Rakel G2, higher interest rates will weaken the project's cashflow and required public grants will increase accordingly.

Figure 2.8: Swedish 10-year government bond yield 1986 to 2022. Source: Federal Reserve Economic Data

3 Quality Assurance of the Uncertainty Analyses

3.1 Summary and Introduction for the Uncertainty Analyses

3.1.1 Introduction to the Uncertainty Analyses

As the Swedish government does not have a fixed scheme for quality assurance of large national government investment projects, the quality assurance (QA) of the Rakel G2 project is based on the requirements for QA of large public projects in Norway, as established by the Norwegian Ministry of Finance. One of the key requirements in such Norwegian QA processes is to undertake an independent uncertainty analysis of the project's investment cost estimate, prior to presentation of the project to the Norwegian government and parliament for investment decision.

This chapter describes the method and analysis results of the independent uncertainty analysis carried out by the QA team of the Rakel G2 base cost estimate, which includes the base investment cost estimate and the base estimate of recurring costs for the operational phase of Rakel G2. These estimates are described in detail in the cost analysis of this investigation. We have also included a brief comparison of methods and results between our uncertainty analysis (UA) of the investment cost estimate and the UA of investment cost established by MSB and TrV in May 2022 (cf. Erdalen 2022).

The uncertainty analysis has mainly been undertaken through a workshop with all key members from the QA group. In the workshop, characteristics of the project have been reviewed relative to their risk potential, and an uncertainty register has been established through brainstorming and review of the uncertainties identified in the UA workshop held by MSB and TrV in May 2022. These uncertainties have been grouped into nine uncertainty drivers. Further, estimate accuracy uncertainties have been reviewed. Three-point estimates, P10 (ten percent probability of being within this cost frame), most likely (ML) and P90 (90 percent probability to be within the cost frame), have been established for each uncertainty element to quantify the uncertainties relative to each base estimate, before Dovre Group's stochastic analytical model (AnRisk) has been used to calculate the results of the uncertainty analysis.

The cost uncertainty analysis is based on an assumption of no delays in project sanction (2024), and no delays in yearly budget approvals. Extreme events (with marginal probability and large consequences), as well as major changes to concept or project premises, are excluded from the analysis. The uncertainty analysis is carried out early in the project preparation phase, with limited documentation available on the project preparations. Hence it is assumed that the project will provide documentation that project preparations are acceptable, with reference to the Norwegian Ministry of Finance's requirements (Finansdepartementet 2019; see also Direktoratet for økonomistyring 2021). The cost uncertainty analysis should be updated and finalized, after the project has completed its documentation on project preparations.

Both the QA team's uncertainty analysis and the MSB and TrV uncertainty analysis are based on the successive method developed by Steen Lichtenberg (2000). However, comparison between the two uncertainty analyses is challenging due to differences in methodology and timing between the analyses. The main difference between the analyses is related to the methodology for the analysis. As opposed to the QA team analysis, the MSB and TrV analysis is not based on a deterministic base estimate, but on an estimate reconciled in a group process.

Based on the results from the uncertainty analysis the QA-team has also made a recommendation on risk reducing measures for each of the defined uncertainty drivers of the project. The most important risk reducing measure at this project planning stage, as assessed by the QA team, is to develop a clearer high-level project design for the Nova project. Such a plan document should describe the services that will be offered in Rakel G2, the time and order in which these services will be introduced, and a realization plan for the services.

The Norwegian quality assurance scheme for major public investments does not entail mandatory requirements for conducting uncertainty analysis of project schedules across time. Yet, uncertainty related to the project implementation over time is most often considerable. An uncertainty analysis of the time schedule for Rakel G2 was also carried out by MSB and TrV and documented in a project internal investigation report (Erdalen et al. 2022).

At the end of our review of uncertainty aspects, we have included an analysis of the method and process for this schedule uncertainty analysis, a comparison with the method and process used by Dovre, member of the QA group, and our recommendations for MSB and TrV's next schedule uncertainty analysis (Erdalen et al. 2022). Lastly, we provide a brief comparison of the schedule in the Rakel G2 Planning and Preparation Report (by Myndigheten för samhällsskydd och beredskap and Trafikverket 2021b, made public March 2023) and the results of MSB and TrV's 2022 schedule uncertainty analysis.

3.1.2 Main Results from the Uncertainty Analyses

The main results of the preliminary cost uncertainty analysis are shown in Table 3.1. Values are given as MSEK with cost level 2024. Recurring costs (i.e., costs related to operations) are limited to 20 years' duration. Reinvestments exclude investment in significant technology improvements and new technology. Recall that terminals and other user costs are not included in the PBE nor in the analysis, as it concerns users and not the infrastructure costs.

*Table 3.1: Uncertainty analysis results – preliminary. * Not comparable with sum of investments, recurring costs and reinvestments due to portfolio effects*

Parameter	Investments (MSEK)	Recurring costs (MSEK)	Reinvestments (MSEK)	Total (MSEK)
Base estimate	10,349	25,478	2,399	38,225
Contingency	1,467	242	143	1,853
Expected cost (P50)	11,816	25,720	2,542	40,078
Management reserve	2,502	3,467	1,110	4,440*
P85	14,318	29,187	3,652	44,518*
Relative contingency (%)	14%	1%	6%	5%
Relative standard deviation (%)	20%	13%	42%	11%

The uncertainty for (initial) **investment costs** is dominated by market uncertainty, site and transmission conditions and estimate accuracy uncertainty related to unit costs for equipment. The contingency of 14 percent to the PBE (for investments) and standard deviation of 20 percent of the expected cost are within the normal range for a project at this development stage.

The uncertainty for **recurring costs** is dominated by uncertainty related to the operating organization's capability for successfully undertaking the operation and supervision of the network, by estimate accuracy uncertainty related to the number of personnel needed for the operating organization, and by estimate accuracy related to unit costs for the operation scope, that is annual OPEX costs (operating expenditure, i.e., recurring cost for the operational phase). The overall contingency of 1 percent to the PBE (for recurring costs) indicates the base estimate is on a probable level. The QA group has identified the cost estimate for recurring costs based on documented and plausible reference data with low uncertainty. Further, most of the uncertainty elements are assessed with symmetric uncertainty spans. The aggregated uncertainty range represented by one standard deviation of 13 percent of the expected cost is somewhat low, but this must be seen in relation to the quality of the reference data.

The uncertainty for **reinvestment costs** is dominated by estimate accuracy uncertainty related to the percentage used to calculate reinvestment needs, by market uncertainty and by site and transmission conditions. The overall contingency of 6 percent to the PBE (for reinvestments) is low. Yet, it is mainly caused by reinvestments being far in the future, leading to many of the uncertainty elements being symmetrically quantified. The low contingency should also be seen in context with the very wide uncertainty span from the analysis, represented by one standard deviation of 42 percent of the expected cost. This is due to the fact that several uncertainty drivers are quantified with wide uncertainty spans, including the above-mentioned estimate accuracy uncertainty related to reinvestment needs.

Recurring costs amount to approximately two-thirds of the total costs, both in terms of PBE and in terms of expected costs. Accordingly, the analysis results for recurring costs have a profound impact on the overall contingency and relative standard deviation for the total project costs. The overall uncertainty in the project is dominated by uncertainty related to the organization and management, dominant for both the investment phase, the operation phase and for reinvestments. Further, the cost uncertainty is highly affected by market uncertainty and by estimate accuracy uncertainties for recurring costs.

We do not conduct an uncertainty analysis of the time schedule anchored in the project cost analysis, as we deem the affiliated documentation insufficient in our quality assurance of the project preparations. For the same reasons, we have not performed a quality assurance of the project's plans and durations, as no current sufficiently detailed schedule exists. Furthermore, the existing schedules from MSB and TrV's project report for planning and preparation of the further development and establishment of Rakel G2 (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021) was compared to the project internal uncertainty investigation in Erdalen et al. (2022). Both have been prepared in an early planning phase. Besides, both are at a very general level with a very limited number of activities, and where the logic and durations of the two existing schedules differ considerably.

Instead, we have carried out a comparative analysis of the method and process of MSB and TrV's schedule uncertainty analysis (Erdalen et al. 2022). As the analysis was done in the early planning phase, few strategies and details were in place. Except for general uncertainties, the study contains no documentation data used nor any description of the reasoning behind durations and uncertainty quantifications. Furthermore, the impact of general uncertainties is only shown for the total project duration and not allocated to the relevant activities and their cost effects. Thus, there is a high likelihood for overlaps in quantifications of activity uncertainties and quantification of general uncertainties. By the same token, MSB and TrV's project internal report breaks down the project into seven high level activities only, leaving subactivities and their dependencies undefined and untreated. In addition, limited identification of a network of processes and dependencies, long activity durations could give a wrong analysis result (ibid.).

Based on our concerns and our impression of changed planning assumptions since May 2022 (when MSB and TrV's internal uncertainty investigation was carried out), we support the Nova project's plans for a new uncertainty analysis on the time schedule in the second half of 2023. Our recommendations for a next schedule uncertainty analysis chiefly concern prerequisites, planning and execution of the analysis and execution plan finalization.

With regard to prerequisites, we recommend the establishment of a high-level project design with an affiliated execution strategy and a detailed draft execution schedule. On planning, preparations and execution, we recommend establishment of a more detailed planning network for the uncertainty analysis, quantification of general uncertainties before estimate accuracy uncertainties, quantification of the uncertainty drivers on activity level rather than overall project level, and documentation of all experience data applied by the workshop participants. In finalization of the execution schedule, we recommend that the project considers how the results from the uncertainty analysis and likely effects of risk reducing measures may warrant changes to the detailed execution plan and that a concise management plan should be prepared.

3.2 Method and Assumptions for the Uncertainty Analyses

3.2.1 Method and Assumptions for the Uncertainty Analysis for Project Costs

In the following, we document our method and assumptions for the uncertainty analysis for project costs. Then, we turn to our methodological approach for quality assurance of the project internal uncertainty analysis of the time schedule.

3.2.1.1 Methodology for the Uncertainty Analysis for Project Costs

The uncertainty analysis process for the project cost uncertainty analysis is shown in Figure 3.1 below.

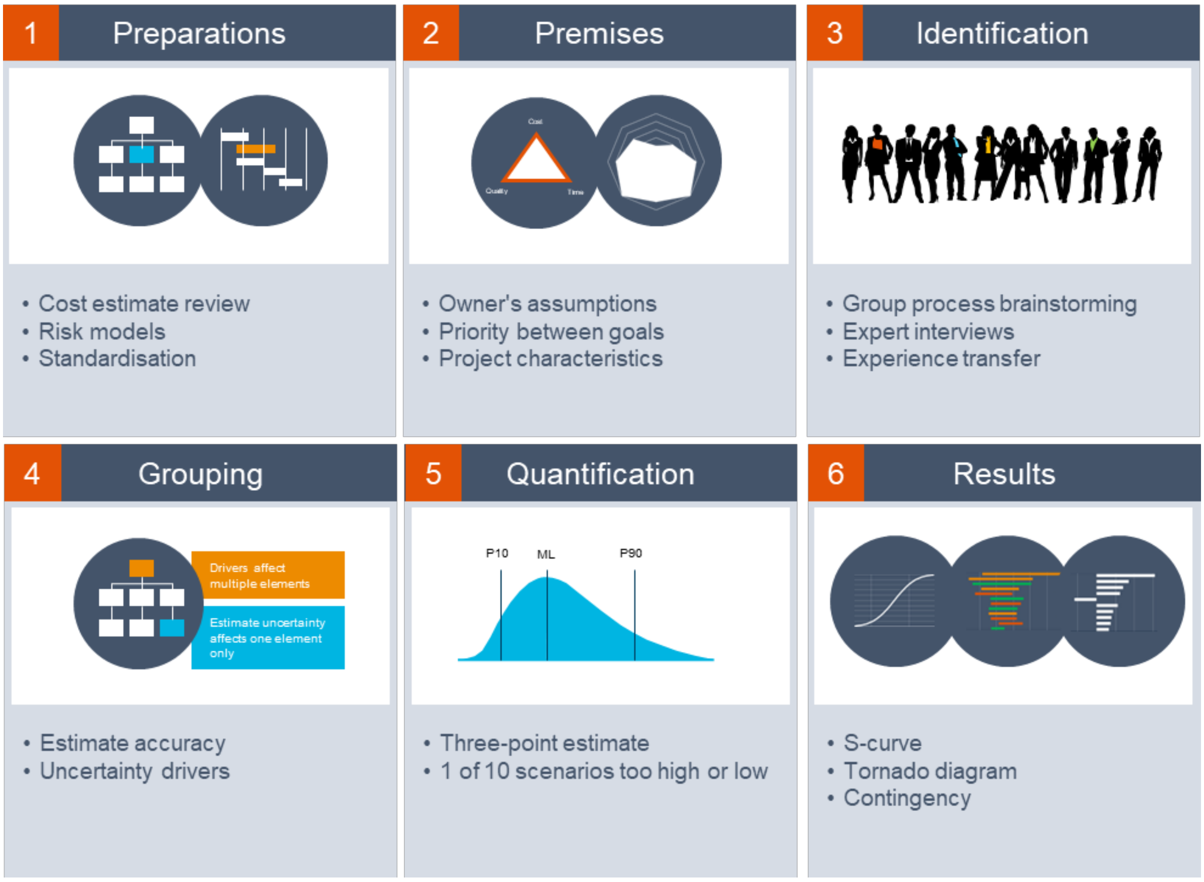


Figure 3.1: Cost uncertainty analysis process

The QA-team's independent uncertainty analysis methodology is based on Lichtenberg's successive method, see for example Lichtenberg's (2000) book "Proactive Management of Uncertainty using the Successive principle". It should be noted that this approach has been undertaken in QA of large Norwegian public projects. The Norwegian Ministry of Finance's requirements for such uncertainty analyses of cost estimates are described in enclosure 1 to its frame agreements for quality assurance of large national government investment projects (cf. Finansdepartementet 2019; see also Direktoratet for økonomistyring 2021).

An outline of the specific process used in the QA-assignment is described below:

- Detailed base estimates, for investments, OPEX and reinvestments, were available at the start of the QA-team's UA workshop. The base estimates are presented in chapter 2.
- All key members from TØI, Analysys Mason and Dovre Group in the QA group participated in the workshop.
- The QA group reviewed characteristics of the project relative to their risk potential.
- An uncertainty register was established in the workshop, through brainstorming and review of the uncertainties identified in the UA workshop held by MSB and TrV in May 2022.
- The uncertainties were grouped into nine uncertainty drivers.
- Three-point estimates, P10, ML and P90, to quantify the uncertainties relative to each base estimate, were discussed and established by the QA group for each uncertainty driver. P10 indicates the optimistic cost effect assessed by the QA group for a given uncertainty driver, thus referring to how low the cost effect may be in one out of ten instances. ML indicates the most likely cost effect for the uncertainty driver as assessed by the QA group. P90 indicates

the pessimistic cost effect assessed by the QA group, thus referring to how high the cost effect may be in one out of ten instances. Quantifications and uncertainty driver mapping (description of cause and effect) are presented in subappendix B.1.

- Three-point estimates – P10, most likely (ML) and P90 – are utilized to quantify estimate accuracy uncertainty. These were discussed and established by the QA group. Estimate accuracy covers uncertainty related to reference data, quantities, unit costs, percentages and more used to produce the cost estimate, assuming all other premises and constraints behind the cost estimate are kept constant. Quantifications and estimate accuracy uncertainty mapping (i.e., description of cause and effect) are presented in subappendix B.1.
- Dovre Group's stochastic analytical model (AnRisk) has been used to calculate the results of the uncertainty analysis. Dovre Group's methodology for uncertainty analyses is described in more detail in subappendix B.2.
- Based on a review in a separate workshop of the risks comprised by the nine uncertainty drivers, the QA-group made a proposal of several risk reducing measures for each uncertainty driver.

Note that information from the QA expert interviews has been used as a foundation for both quantitative and qualitative risk assessments in the above-mentioned workshop (cf. subsection A.1.1 for interview guides and subsection A.2.3 for list of interviews). Furthermore, we obtained feedback on our uncertainty considerations from the project's key personnel at MSB and TrV, the project council (known as the Nova council) and the reference group (see appendix section A.2.1 and A.2.2, respectively).

TrV also presented the previous uncertainty analysis for the project group (see appendix section A.2.1). The main difference between the QA-team's independent uncertainty analysis and the MSB and TrV analysis is related to part of the methodology. As opposed to the QA team analysis, the MSB and TrV analysis is not based on a deterministic base estimate. In the MSB and TrV analysis, the estimate was developed in a group process. We refer to the project internal uncertainty analysis (Erdalen et al. 2022) and Erdalen and Lillskogen (2021) for more information on the methodology utilized in the MSB and TrV analysis.

3.2.1.2 Uncertainty Elements Concerning Project Costs

The uncertainty drivers affecting Rakel G2 are listed below.

Market uncertainty comprises uncertainty in the market for contractors for upgrading and establishment of sites, including opportunities for the project to utilize TrV's existing frame agreements. Other market uncertainties included are uncertainty in the market for suppliers of telecom systems, uncertainty regarding the market for hire of space in commercial towers, uncertainty regarding TrV's attractiveness as a client, and uncertainty related to the attractiveness of the project and its contract to the contractor and supplier market.

Design development, maturity and system integration comprises uncertainty in the concept and technical basis for the project, uncertainty regarding the maturity of the project and uncertainty regarding the integration of the MOCN solution and other main elements in the system.

Project organization and management comprises uncertainty related to the project organization's competence, capacity and continuity, as well as stakeholder management capability. Further, the uncertainty driver covers uncertainty related to interface coordination, procurement strategies, management and coordination between MSB and TrV, change management, risk management and project control activities.

Project owners' governance and management comprises uncertainty related to management and governance of the project, both within relevant ministries and government functions, as well as at higher levels in MSB and TrV. Further, the uncertainty driver comprises uncertainty related to changes and additional demands from project owners and delays in political decisions.

Authorities comprises uncertainty related to changes in project requirements due to changes in relevant laws, regulations, rules, and standards, as well as changes in how these are practiced.

User influence and demand comprises uncertainty related to user-initiated changes to project solutions, project requirements and operational requirements, as well as uncertainty related to number of subscribers and types of subscriptions.

Interfaces and other stakeholders comprise uncertainty related to interfaces with commercial network operators.

Suppliers' capability comprises uncertainty related to suppliers' capacity, competence and overall capability for successful project execution. Competence and overall capacity inter alia involve the suppliers' ability to handle interfaces, their ability to effectively cooperate with MSB or TrV, supplier prioritization, continuity of key supplier personnel, experience with similar projects and abilities for follow-up of subsuppliers.

Site and transmission conditions comprises uncertainty related to local conditions at the sites, including conditions of existing constructions and equipment, below ground conditions, site access conditions, weather conditions and restrictions in the project execution phase.

Estimate accuracy uncertainties covers uncertainty related to the accuracy of the current base estimate, assuming constraints and premises behind the estimate are kept constant. The estimate accuracy covers uncertainty in available reference data, which in turn leads to uncertainty in quantities, unit costs, percentages and so forth. Estimate accuracy has been assessed for the following:

- Number of sites – TrV and MSB
- Number of sites – commercial sites
- Number of sites – new greenfield sites
- Unit costs (assessed separately for investments and recurring costs)
- Personnel costs (assessed separately for investments, recurring costs and reinvestments)
- Personnel quantities (assessed separately for investments, recurring costs and reinvestments)
- Reinvestment needs (reinvestments calculated as percentage of investment costs)
- Inflation adjustments (uncertainty in future inflation adjustments of the estimate)

Uncertainty quantifications, assessments and scenarios are documented in Appendix B.

3.2.1.3 Assumptions in the Uncertainty Analysis for Project Costs

The QA team's assumptions and exclusions for the independent uncertainty analysis are listed below:

- QA team's preliminary project base estimate (PBE) from 31.01.2023, which includes adjustments relative to MSB and TrV's cost estimate (Nova Model) from 25.11.2022. The estimate is detailed and calculated through estimated quantities and unit cost elements. However, the estimate also includes substantial rounded values for certain cost elements, without further break-down explanation or explanation of how these rounded values have been established.

- Reinvestments are calculated as percentage parts of the cost elements in the estimate for initial investments.
- No benchmarking data such as actual cost for similar items has been provided by MSB and TrV.
- Cost level is SEK 2024 in the PBE.
- Recurring cost (operations) is limited to 20 years' duration.
- Reinvestments exclude investment in significant technology improvements and new technology.
- Terminals and integration costs are not included in either of the models.
- No delays in project sanction (2024), no delays in yearly budget approvals. This is a standard assumption made in uncertainty analyses of public investment projects in Norway. Furthermore, the QA-team lacks experience on government budget processes in Sweden.
- Extreme events (marginal probability and large consequences) are excluded from the analysis.
- Major changes to the concept are excluded from the analysis.
- It is assumed that the QA-team in subsequent phases of this QA-assignment will receive sufficient documentation from the project-on-project preparations in accordance with the Norwegian Ministry of Finance's requirement of late-stage quality assurance (see Finansdepartementet (2019a and 2019b). We also assume that the QA-team will be able to verify that the project preparations are acceptable in accordance with these requirements.

3.2.2 Methodological Approach for Quality Assurance of the Project Internal Uncertainty Analysis of the Time Schedule

As accounted for in chapter 4, we have not found the project documents on governance and time schedule mature enough to conduct our own uncertainty analysis on the time schedule. Instead, we assess the uncertainty analysis on the time schedule carried out by MSB and TrV (Erdalen et al. 2022). First, we consider the methodology for uncertainty analysis on time applied by MSB and TrV and compare it with the methodology applied by the quality assurance team in other instances. Then, we compare the time schedule applied for the MSB and TrV uncertainty analysis with MSB and TrV's time schedule for the planning and preparation report of the further development and establishment of Rachel G2 to Government (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021). Based on our assessment, we draw our conclusions and provide our recommendations on the uncertainty analysis on the time schedule.

3.3 Uncertainty Analysis for Project Costs

3.3.1 Project Characteristics

Rakel 2 is a large project, with a significant duration of the project execution phase and a 20 years' operations phase, and which is partly overlapping with the execution phase. We consider this type of project as quite special in the TrV project portfolio. Further, we consider the project unique within MSB today, as roll-out of the first version of Rakel was completed in 2010, more than 12 years ago. The project below illustrates our characteristic of eight key project factors.

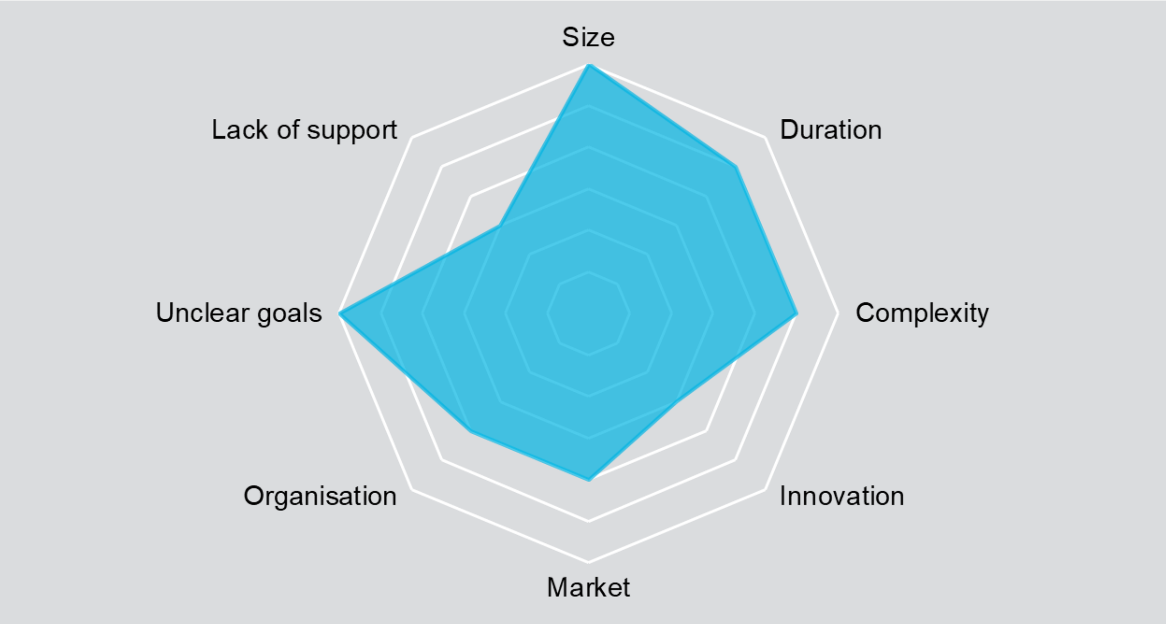


Figure 3.2: QA team's evaluation of degree of risk for 8 key project factors, on a scale from 1 (insignificant risk) to 6 (very high risk)

The project is considered to have above average risk on four factors – project size, duration, complexity and project goals.

Megaprojects are often defined as projects with investment costs above about MSEK 10,000. TrV has significant experience from very large transportation projects. However, the size of this telecommunication project, with more than MSEK 10,000 in initial investments, is very large compared with MSB's and TrV's experiences from this type of project in the recent past.

The ten years' duration of the initial project execution period means increased risk for changes initiated by authorities, users or other stakeholders. Additionally, such a duration increases the risk for discontinuity of personnel both in the project team and at the project owners. Furthermore, based on MSB and TRV's uncertainty analysis of the project schedule in May 2022, the schedule until 2030, when it is planned that all users have migrated to Rakel 2, is considered to be very tight.

The Complexity factor comprises technical, commercial and organizational complexity. Elements that contribute to significant complexity are the technical and commercial interfaces of the MOCN solution and the organizational interfaces between MSB and TrV.

At present, the goals of the project are seen as unclear and incomplete by the QA team. Precise project goals are not yet defined with respect to cost, time, quality and HSSE, with a defined prioritization between these goals. Also, measurable goals on the effects which the project shall deliver to the users and to the larger society are also lacking.

3.3.2 Results from the Uncertainty Analysis

Below, the uncertainty analysis results for investments, recurring costs and reinvestments are presented. The quantifications of all uncertainty elements are described in detail in subappendix B.1.

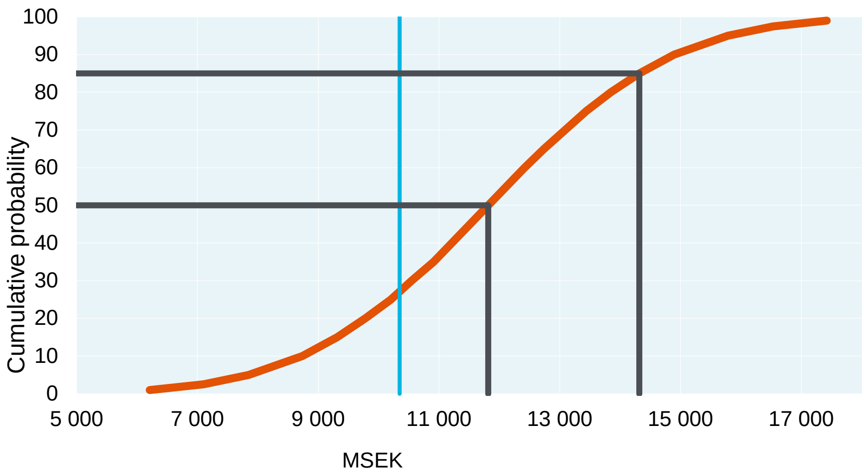
3.3.2.1 Investment Costs

The main results from the uncertainty analysis for (initial) investment costs show an accuracy range and expected value as listed in Table 3.2.

Table 3.2: Uncertainty analysis results – investment costs

Parameter	Rakel G2 investments (MSEK)
Base estimate	10,349
Contingency	1,467
Expected cost (P50)	11,816
Management reserve	2,502
P85	14,318
Relative contingency (%)	14 %
Relative standard deviation (%)	20 %

Figure 3.3 shows the cumulative distribution of investment costs.



P	MSEK
P95	15,786
P90	14,896
P80	13,849
P70	13,089
P60	12,418
P50	11,816
P40	11,215
P30	10,544
P20	9,784
P10	8,737
P05	7,847

Figure 3.3: S-curve showing the distribution of investment costs. The cumulative distribution function describes the probability (on the y-axis) that the project cost will be lower than or equal to the corresponding cost on the x-axis. The blue vertical line is the base estimate.

In Figure 3.4, the main uncertainty elements that affect the cost uncertainty for investments are illustrated in a tornado diagram.

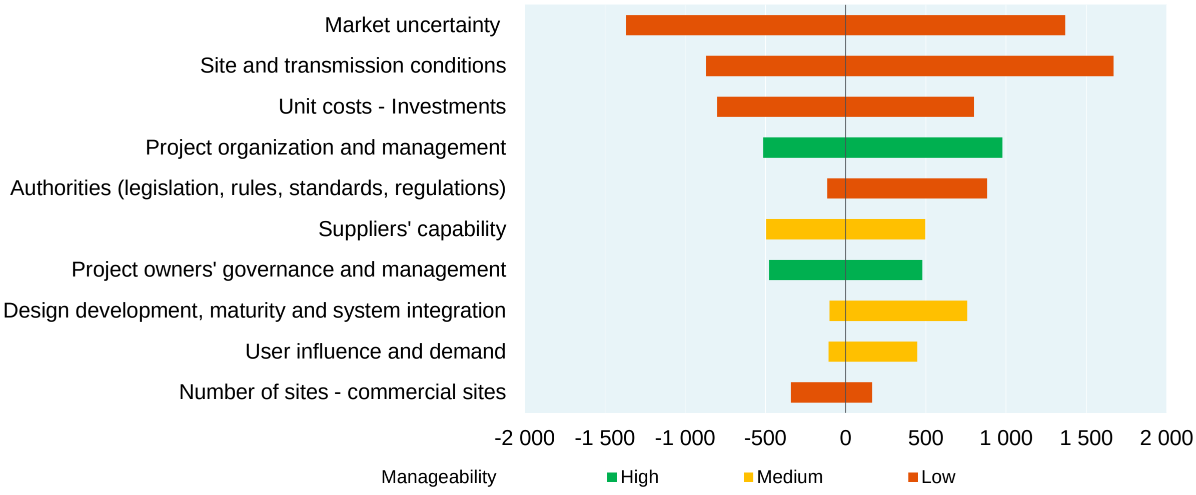


Figure 3.4: Tornado diagram showing the main uncertainty elements that affect the investment costs. The uncertainty element with the highest impact is shown on top of the chart, followed by the other uncertainty elements in descending order of impact. The colors indicate the degree of manageability of the uncertainty element, where the colors red, yellow and green respectively represent low, medium and high manageability.

The analysis results, with an overall contingency of 14 percent to the PBE (for investments) and an aggregated uncertainty range represented by one standard deviation of 20 percent of the expected cost, are, compared with the QA team's past experiences, within the normal range for a project at this development stage.

Market uncertainty is the uncertainty driver contributing most to the overall uncertainty. The quantification of the uncertainty driver is based on empirical research conducted at the Concept research program, assessing market uncertainty for a number of Norwegian construction projects. In order to account for both general and specific market uncertainty, the uncertainty span of the driver is wide. The uncertainty affects nearly all cost elements of investment costs. Market uncertainty is generally an important uncertainty driver for investment costs in all projects that have not been contracted.

Site and transmission conditions has the second largest impact on the overall uncertainty for investment costs. Base stations will be established at a number of sites, both at greenfield sites in rural and urban (rooftop) areas, at leased sites and at existing TrV and MSB sites with costs highly affected by actual and local conditions. Furthermore, access networks and transport networks are affected by local conditions (e.g., in terms of conditions at technical huts and actual transmission conditions). The cost for base stations, access networks and transmission have been estimated based on a number of assumptions on local conditions, with high uncertainty as to the validity of the assumptions.

Unit costs for investments covers uncertainty in the estimate accuracy for the investment scope, that is all physical scope to be constructed in the investment phase of the project. The unit costs utilized in the PBE are derived from the Nova Model. This model is based on several reference data, which may or may not be fully valid and relevant for the scope to be constructed for the Rakel G2 project. The estimate accuracy uncertainty affects all physical cost elements.

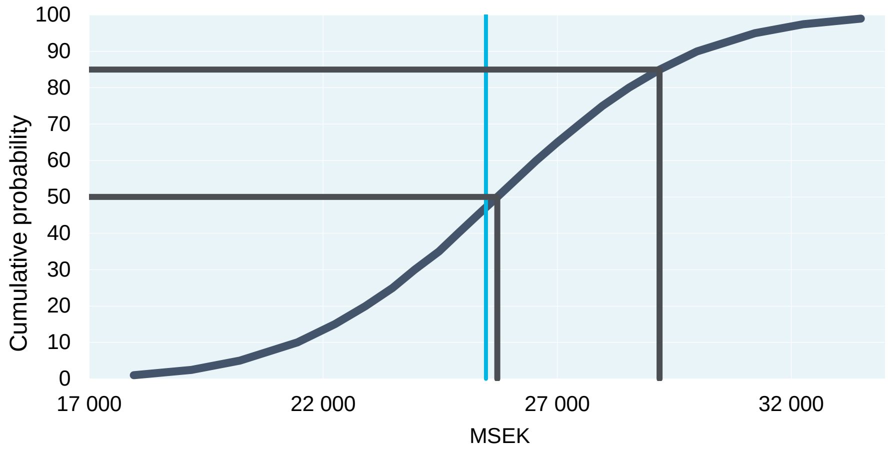
3.3.2.2 Recurring Costs

The main results from the uncertainty analysis for recurring costs show an accuracy range and expected value as listed in Table 3.3 below.

Table 3.3: Uncertainty analysis results – recurring costs

Parameter	Rakel G2 recurring costs (MSEK)
Base estimate	25,478
Contingency	242
Expected cost (P50)	25,720
Management reserve	3,467
P85	29,187
Relative contingency (%)	1 %
Relative standard deviation (%)	13 %

Figure 3.5 shows the cumulative distribution of recurring costs.



P	MSEK
P95	31,220
P90	29,987
P80	28,537
P70	27,483
P60	26,553
P50	25,720
P40	24,887
P30	23,957
P20	22,903
P10	21,453
P05	20,220

Figure 3.5: S-curve showing the distribution of recurring costs. The cumulative distribution function describes the probability (on the y-axis) that the project cost will be lower than or equal to the corresponding cost on the x-axis. The blue vertical line is the base estimate.

In Figure 3.6 the main uncertainty elements that affect the cost uncertainty for recurring costs are presented in a tornado diagram.

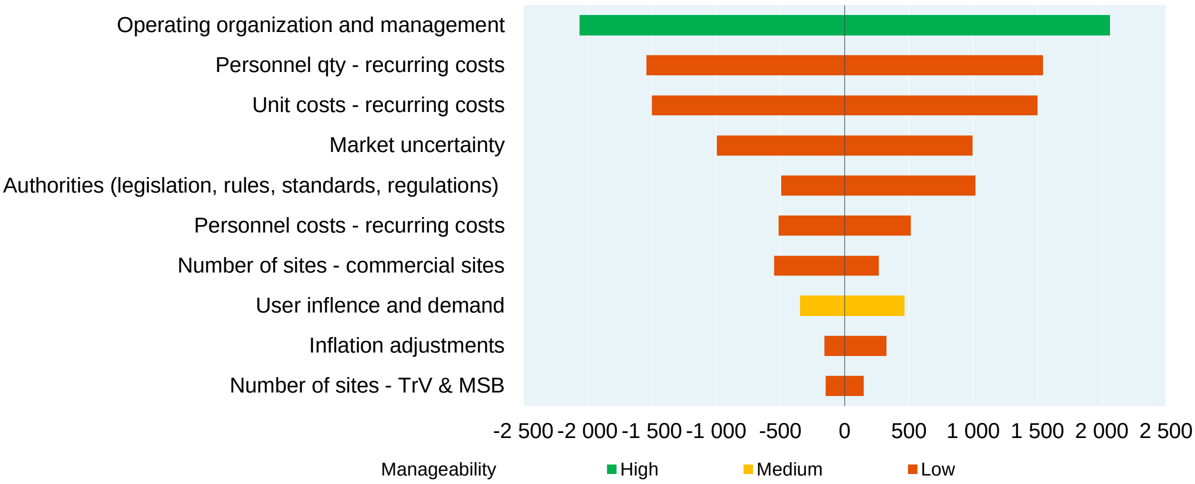


Figure 3.6: Tornado diagram showing the main uncertainty elements that affect the recurring costs. The uncertainty element with the highest impact is shown on top of the chart, followed by the other uncertainty elements in descending order of impact. The colors indicate the degree of manageability of the uncertainty element, where the colors red, yellow and green respectively represent low, medium and high manageability.

The overall contingency of one percent to the PBE (for recurring costs) indicates the base estimate is on a probable level. The QA group has identified the cost estimate for recurring costs are based on documented and plausible reference data with relatively low uncertainty. Further, most of the uncertainty elements are assessed with symmetric uncertainty spans, as shown in the figure above. The aggregated uncertainty range represented by one standard deviation of 13 percent of the expected cost is, seen in isolation, somewhat low compared with the QA team's previous experiences from similar projects. However, the low value must be seen in relation to the quality of the reference data, such as benchmarking data and information obtained in the expert interviews.

Operating organization and management is the uncertainty driver contributing most to the overall uncertainty. The uncertainty driver comprises uncertainty related to the operating organization's capability for successfully undertaking the operation and supervision of the network. The operating organization's capacity concerns competence, capacity and continuity, customer relations and other stakeholder management in the operation phase, management and coordination between MSB and TrV and change management. The size and duration of the project adds uncertainty to the organization's management of the operations.

Personnel quantity for recurring costs covers uncertainty in the estimate accuracy for the operating organization. This regards the number of full-time equivalents (FTEs) needed to manage the operating phase of the project given all other factors and premises held constant. As shown in section 2.3.5, personnel costs account for a large share of the recurring costs. As also indicated in this section, the QA group has assumed that the network may be operated through a lower number of FTEs than in the Nova Model. Yet, there is still uncertainty as to whether this estimate is sufficient and realistic.

Unit costs for recurring cost covers uncertainty in the estimate accuracy for the operation scope, i.e., annual OPEX costs for operation of the project scope. The annual costs utilized in the base estimate are derived from the Nova Model. As for unit costs for investments, the reference data on which the estimate is based may or may not be fully valid and relevant for the Rakel G2 project.

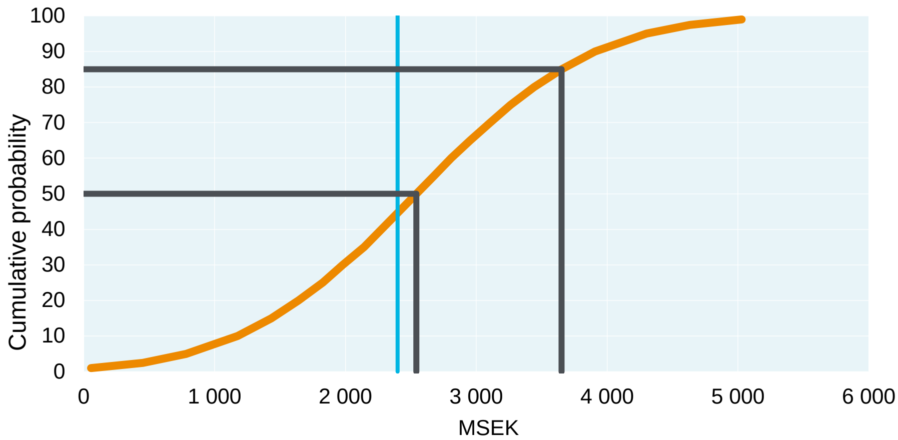
3.3.2.3 Reinvestment Costs

The main results from the uncertainty analysis for reinvestment costs show an accuracy range and expected value as listed in Table 3.4 below.

Table 3.4: Uncertainty analysis results – reinvestment costs

Parameter	Rakel G2 reinvestments (MSEK)
Base estimate	2,399
Contingency	143
Expected cost (P50)	2,542
Management reserve	1,110
P85	3,652
Relative contingency (%)	6 %
Relative standard deviation (%)	42 %

Figure 3.7 shows the cumulative distribution of reinvestment costs.



P	MSEK
P95	4,303
P90	3,908
P80	3,444
P70	3,106
P60	2,809
P50	2,542
P40	2,275
P30	1,978
P20	1,640
P10	1,176
P05	781

Figure 3.7: S-curve showing the distribution of reinvestment costs. The cumulative distribution function describes the probability (on the y-axis) that the project cost will be lower than or equal to the corresponding cost on the x-axis. The blue vertical line is the base estimate.

In Figure 3.8 the main uncertainty elements that affect the cost uncertainty for reinvestments are presented in a tornado diagram.

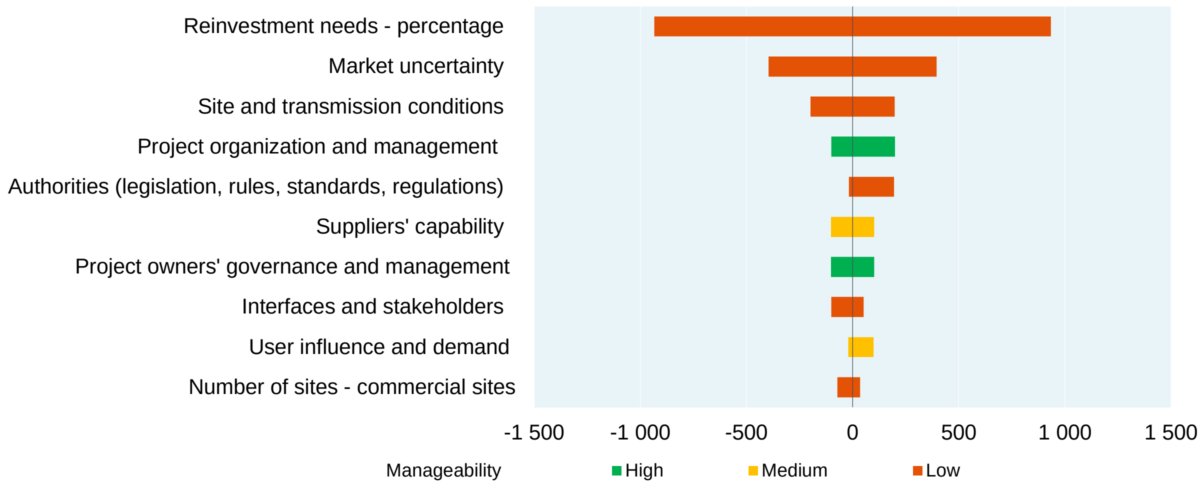


Figure 3.8: Tornado diagram showing the main uncertainty elements that affect the reinvestment costs. The uncertainty element with the highest impact is shown on top of the chart, followed by the other uncertainty elements in descending order of impact. The colors indicate the degree of manageability of the uncertainty element, where the colors red, yellow and green respectively represent low, medium and high manageability.

The overall contingency of 6 percent to the PBE (for reinvestments) is low. Yet, when interpreting these results, it should be noted that the reinvestments are far into the future, and thus many of the uncertainty elements are symmetrically quantified. The low contingency should also be seen in context with the very wide uncertainty span from the analysis, again due to the fact that these costs are expected far into the future, represented by one standard deviation of 42 percent of the expected cost.

The main reason for the wide uncertainty span comes from the uncertainty driver *reinvestment needs – percentage.* Future reinvestments have been calculated as percentages of investment costs. However, there is significant uncertainty as to how large reinvestments are necessary during the operation phase of the project, leading to this uncertainty driver being quantified with a wide and symmetrical span.

Market uncertainty has the second highest contribution to overall uncertainty. With procurement processes for reinvestments starting from 2035, the uncertainty driver has a wider quantification than the equivalent driver from the investment cost analysis. Nevertheless, market uncertainty is still far lower than uncertainty related to reinvestment needs.

Site and transmission conditions have the third largest impact on the overall uncertainty for investment costs. Reinvestment costs are assumed to be subject to variations in site conditions, as discussed for investment costs. However, the uncertainty span concerned with site and transmission conditions for reinvestments are assessed to be symmetric, as opposed to the equivalent driver for investment costs.

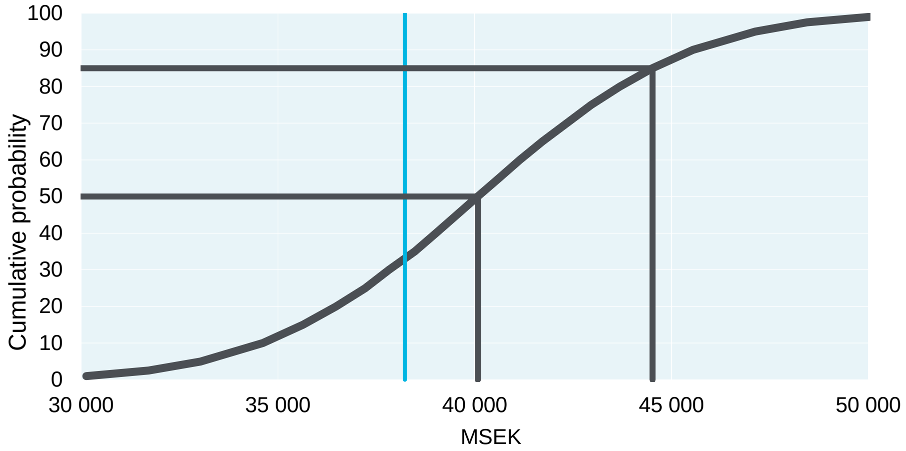
3.3.2.4 Total Project Costs

The aggregated results from the uncertainty analysis for the total of investment costs, recurring costs and reinvestment costs have an accuracy range and expected value as listed in Table 3.5 below. The values for base estimate, contingency and expected costs equal the sum of the equivalent values in subsections 3.3.2.1 to 3.3.2.3. However, portfolio effects affect the values of the management reserve, P85, and the relative standard deviation for the total project. This means these values differ from the sums of the equivalent values in subsections 3.3.2.1 to 3.3.2.3.

Table 3.5: Uncertainty analysis results – total costs

Parameter	Rakel G2 (MSEK)
Base estimate	38,225
Contingency	1,853
Expected cost (P50)	40,078
Management reserve	4,440
P85	44,518
Relative contingency (%)	5 %
Relative standard deviation (%)	11 %

Figure 3.9 shows the cumulative distribution of total Rakel G2 costs.



P	MSEK
P95	47,122
P90	45,543
P80	43,686
P70	42,337
P60	41,146
P50	40,078
P40	39,011
P30	37,820
P20	36,471
P10	34,614
P05	33,035

Figure 3.9: S-curve showing the distribution of total project costs. The cumulative distribution function describes the probability (on the y-axis) that the project cost will be lower than or equal to the corresponding cost on the x-axis. The blue vertical line is the base estimate.

In Figure 3.10 below, the main uncertainty elements that affect the cost uncertainty on aggregated project cost are presented in a tornado diagram.

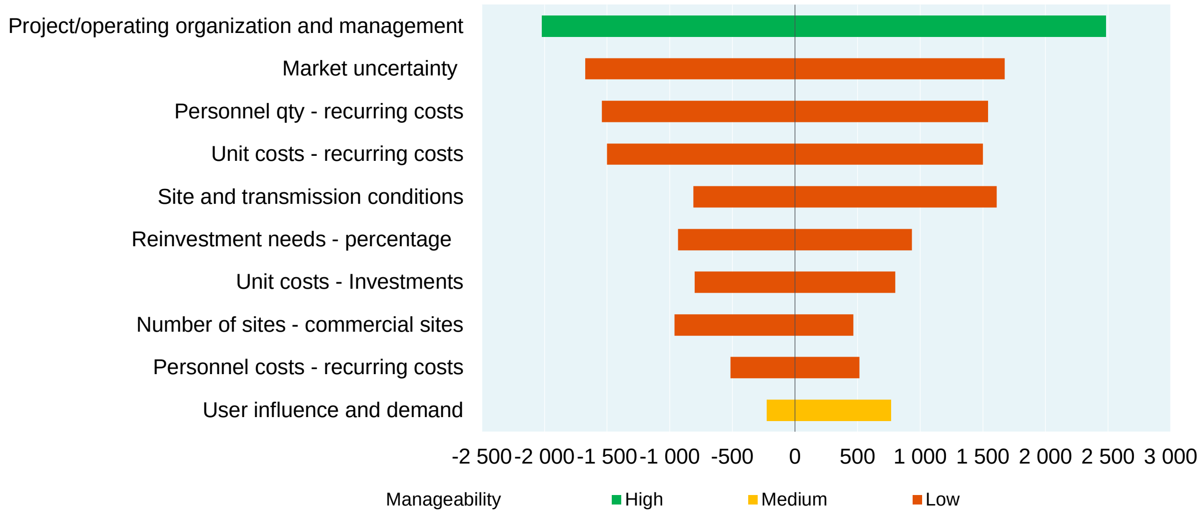


Figure 3.10: Tornado diagram showing the main uncertainty elements that affect the total project costs. The uncertainty element with the highest impact is shown on top of the chart, followed by the other uncertainty elements in descending order of impact. The colors indicate the degree of manageability of the uncertainty element, where the colors red, yellow and green, respectively represent low, medium and high manageability.

Recurring costs constitute approximately two-thirds of the overall costs, both in terms of PBE and in terms of expected costs. Accordingly, the analysis results from subsection 3.3.2.2 are impacting both overall contingency and the total project's relative standard deviation the most.

The high share of total project cost from recurring costs is also evident in the tornado diagram. With uncertainty related to the organization and management dominant for both the investment phase, the operation phase and for reinvestments, the combined effect of these uncertainty drivers gives the highest overall impact on the total project uncertainty.

Market uncertainty has the second highest contribution to overall uncertainty. Market uncertainty is significant for all subproject uncertainty analyses, leading to the combined effect high in the total project tornado diagram.

Further, the overall uncertainty picture is affected by estimate accuracy uncertainties for recurring costs and uncertainty related to local conditions relevant for both investments and reinvestments.

3.3.3 Comparison with the MSB and TrV Uncertainty Analysis

The results from the uncertainty analysis for investment costs are compared in Table 3.6 below with results from MSB's and TrV's uncertainty analysis carried out in May 2022. MSB and TrV have not yet carried out uncertainty analyses of recurring cost (OPEX) and reinvestment cost.

Table 3.6: Comparison between the QA uncertainty analysis and MSB's and TrV's uncertainty analysis. Base estimate and contingency in the MSB and TrV analysis are derived from sum of probable costs.

Parameter	QA team (Jan. 2023)	MSB and TrV (May 2022)
Cost level – year	2024	2021
Base estimate	10,349	7,400
Contingency	1,467	700
Expected cost (P50)	11,816	8,100
Management reserve	2,502	2,000

P85	14,318	10,100
Relative contingency (%)	14 %	9%
Relative standard deviation (%)	20 %	24%

A comparison between the two uncertainty analyses is challenging due to differences in methodlogy and timing between the analyses. The MSB and TrV analysis was carried out almost one year earlier than the QA team analysis, with a certain maturation of the project between these analyses. While cost level is set at 2021 for the MSB and TrV analysis, costs are inflated to 2024 values in the QA team analysis.

The main differences between the analyses are, however, related to methodology. As opposed to the QA team analysis, the MSB and TrV analysis is not based on a deterministic base estimate. In the MSB and TrV analysis, the estimate was developed in a group process, with limited documentation as to how costs are calculated. In the MSB and TrV analysis, contingencies arise from estimate uncertainties, (i.e., basic items or "*Grundposter*" in Swedish), with limited documentation of assessments behind the quantifications. Uncertainty drivers contribute with a negative contingency of -4 percent of the expected (P50) investment cost. From the QA team's experience, this indicates there is a high likelihood of uncertainty factors affecting several cost elements being included in the quantifications of estimate uncertainties. Accordingly, major effects of risks described under uncertainty drivers are potentially "double counted" in several estimate uncertainties. In the QA team's uncertainty analysis, the main focus has been on uncertainty drivers, which are contributing with almost all contingency, which constitutes about 14 percent of the expected (P50) investment cost.

The uncertainty drivers used by the QA team and the uncertainty drivers used by MSB and TrV are shown in Figure 3.11.

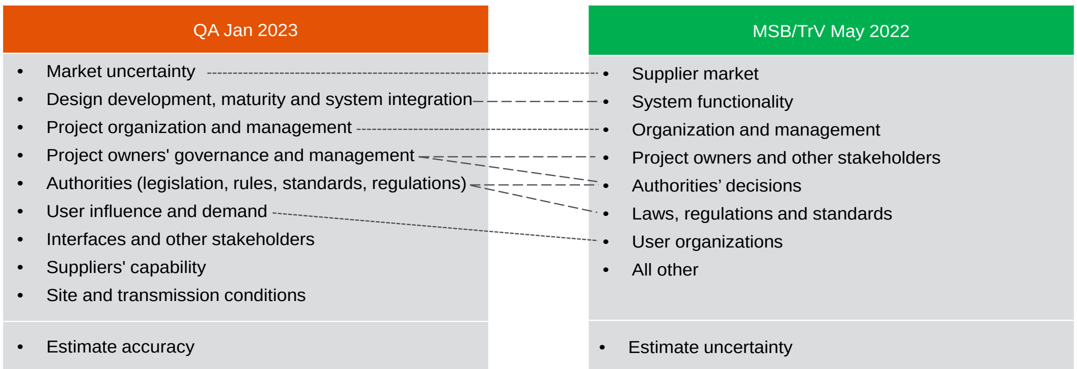


Figure 3.11: Uncertainty drivers used in the QA team analysis and the uncertainty drivers used in the MSB and TrV analysis. A dotted line indicates a high degree of similarity between a QA team uncertainty driver and an MSB and TrV uncertainty driver. Dashed lines indicate some degree of similarity between uncertainty drivers used in the two analyses.

As can be seen from the figure, there is a high degree of overlap between the uncertainty drivers related to the supplier market, organization and management, and user influence and organization. Some similarities can be found between the drivers related to design development and system functionality. The uncertainties related to project owners are included in one driver in the QA team analysis, but they are divided on two drivers in the MSB and TrV analysis. Similarly, also uncertainties related to authorities in the QA team analysis are divided into two drivers in the MSB and TrV analysis.

Uncertainties related to supplier market, establishment of sites and transmission have the highest impact on uncertainty in both analyses, even though the methodology between analyses is different. The uncertainty related to organization and management has a wide and right-skewed impact on the QA team results, while the specified impact in the MSB and TrV analysis is low. Further, uncertainties related to system functionality, design development, maturity and system integration have significantly higher impact in the QA team analysis than the specified impact in the MSB and TrV analysis. Lastly, uncertainty related to interfaces with commercial network operators, uncertainty related to local conditions for sites and transmission networks, and uncertainty related to capability for the suppliers are included in the QA team analysis. Such uncertainties are not specified in the MRB and TrV analysis.

3.3.4 Issues which Are Relevant for Further Review Prior to Update of the Uncertainty Analysis

The elements and issues discussed in subsections 3.3.4.1 and 3.3.4.2 below require further review by the QA group. The cost uncertainty analysis should be updated when the uncertainties related to these issues have been evaluated by the group.

3.3.4.1 Comments from the Reference Group

The results of the preliminary cost uncertainty analysis have been presented to the QA assignments reference group, which has been appointed by MSB and TrV. The following issues of relevance for the UA of the cost estimate were raised by the reference group when discussing the uncertainty analysis in the reference group meeting on February 10 2023:

1. Technology development throughout the lifetime of the project
2. Uncertainty related to schedule, e.g., related to migration from Rakel G1 to Rakel G2, including establishment of bridging solution between G1 and G2, and subsequent cost effect
3. Uncertainty related to schedule for development of the IT part of this ICT project, and subsequent cost effect
4. Potentially replacing or supplementing the Rakel G2 system with more use of commercial networks and/or sites towards the end of the project execution period. Implementation of such measures also may save costs.

These issues have been reviewed by the QA group. Our responses are stated below:

5. We state in chapter 2 that reinvestments exclude investment in significant technology improvements and new technologies. We believe that implementing Rakel G2 should be based on currently available technologies, in order to have a firm basis for the investment decision. A potential later implementation of new technology should be subject to a management of change process. Such a management of change process should require separate decisions by the project owners to implement any new technologies, based on an evaluation both of benefits and of effects on investments, OPEX, schedule and other consequences.
6. A detailed time schedule for the project will be provided by MSB and TrV during further project planning and preparations. The QA team will review the detailed schedule, including the migration phase from G1 and G2, as part of the delivery on "Quality Assurance of Organization and Governance" (confer chapter 3). An independent uncertainty analysis of the schedule should be considered as part of this QA review.
7. MSB and TrV confirmed in a meeting on March 17 2023 that establishing or updating IT-systems to enable efficient usage of the telecom system is included in the Rakel G2 scope of

work and cost estimate. However, updating or establishing IT-systems on the user side is not included. Schedule and cost consequences for Rakel G2 due to potential delays in development of the IT-systems have not yet been evaluated. We will review this uncertainty when further documentation has been received from MSB and TrV on project preparations. The project's detailed time schedule and the project's descriptions of its technical, commercial and organizational interfaces are of particular relevance for this issue.

8. The existing plan for Rakel G2 is based on a hybrid model with a dedicated radio network combined with the use of public mobile networks through a MOCN solution. A successful implementation of MOCN early in the establishment phase will be important for delivering early user benefit before a dedicated radio network is fully established. A working MOCN solution will establish a partial service level and reduce risk associated with user and service migration to Rakel G2. Good experiences with this solution can potentially reduce the need for a dedicated radio network in some areas, and therefore reduce cost.

3.3.4.2 Project Preparations related to Cost Uncertainty

The uncertainty analysis for costs was carried out early in the project preparations phase, with limited documentation available on the project's preparations. Hence, it is an assumption for the preliminary uncertainty analysis that the project at a later stage will provide documentation that project preparations are acceptable with reference to the Norwegian Ministry of Finance's requirements (see Finansdepartementet 2019a and 2019b).

Based on the information on specific project preparations included in the documentation received so far, the QA group considers the further documentation for project preparations incomplete. We refer to chapter 5 for details in this regard.

From our point of view, the cost uncertainty analysis should be updated and finalized after receipt of further documentation on project preparations. Therefore, we are content to learn that a new uncertainty analysis carried out by MSB and TrV is planned in the second half of 2023 and that the documentation on project preparations will be extended by this time, confer subchapter 3.3.4.

3.4 Risk Reducing Measures

In TrV and MSB's internal uncertainty analysis (Erdalen et al. 2022), several risk reducing measures are presented, relevant for the most dominant uncertainties related to time, to activities on critical path, and for cost uncertainties. In the uncertainty analysis report, approximately 30 risk reducing measures are described, of which a significant share is related to organization and management of the project. Although some of the risk reducing measures are generic in nature, the majority of the stated risk reducing measures are sufficiently project specific. As assessed by the QA team, the stated risk reducing measures are considered a good basis for future work with detailing risk reducing measures in the project. However, the project organization should in the future work with evaluating and implementing risk reducing measures and strive to further concretize measures.

As a part of the quality assurance process, the QA team have independently assessed important risk reducing measures. Important risk reducing measures are presented in Table 3.7.

The single most important risk reducing measure as assessed by the QA team is to develop a clearer high-level project design for the Nova project. Such a plan should describe the services that will be offered in Rakel G2, the time and order in which these services will be introduced, and the realization plan for the services. The existing high-level plan is unclear on several of these aspects.

Regarding services, issues that should be clarified in the plan include: whether mobile data will be a part of the initial service offering in Rakel G2, to what extent these data services will replace the use of data services in public mobile networks, whether MC video solutions will be a native service in the network, and the type of functionality that will be offered to call external users. Regarding implementation, it is not clear how the dedicated radio network will work together with one (or more) MOCN partners' networks to offer a seamless user experience that can exploit the coverage and capacity in both networks.

These are examples of central questions that will shape the implementation plan and have a significant impact on the timeline of the establishment phase. In the absence of a clear high-level design that is sanctioned by user groups and important partners, the project runs a significant risk of delayed migration with associated cost impacts. For example, migration of users could be delayed by two years because important services are missing or the MOCN solution does not work as expected. In such a case, this would result in 10 percent reduction of Rakel G2 lifetime (and thus user benefit), while the cost of the project would remain the same or even increase.

Table 3.7: Uncertainty drivers from the independent uncertainty analysis, identified key uncertainties related to each driver, and important risk reducing measures as assessed by the QA team

Uncertainty driver	Key uncertainties	Risk reducing measures
Design development, maturity and system integration	- Further detailing of the project leads to cost increases and more expensive solutions. - The project to date is less detailed than assumed, leading to higher need for estimate allowances. - System integration is more challenging and time consuming than estimated, with substantial need for use of supplier personnel.	- Establish high level design, with further detailing of which services are to be delivered to the users, and when, potentially through dialogue with service providers or commercial operators. - Establish system design.
Market uncertainty	- Low attractivity. - High competition for resources.	- Prepare the market for coming tenders, after further detailing the project (with reference to above mentioned risk reducing measure). - Exploit supplier capacity and ask for supplier feedback in further detailing of the project. - Consider a high-level design reducing risks of monopoly situations.
Site and transmission conditions	- Conditions at site (ground conditions, existing infrastructure condition). - Lack of space on commercial towers, leading to increased need for use of own sites.	- At a later stage further define which sites to use, establish radio plan. - Clarify space on commercial towers. - Prioritize MOCN in high level design, and through this make the project less vulnerable to unfavorable site conditions. - Consider use of commercial transport incl. satellite system.
Project/operating organization and management	- Risk of discontinuity in the organization. - Project strategies not adapted to the project characteristics. - Lack of project definition and subsequent lack of quality of planning and strategies resulting in cost overruns and delays.	- Collect competence and experiences from commercial operators. - Investigate and implement measures to reduce risk of discontinuity. - Clear definition of leadership and organizational roles. - Rig the project organization in a way which reduces dependency on individuals. - Systematically follow up recommendations from the QA process.

Uncertainty driver	Key uncertainties	Risk reducing measures
Project owner's governance and management	- Delays in decisions and budget allocations. - New requirements from owners.	- Early definition of decision basis and documentation requirements with project owners. - Provide project owners with credible schedule, to highlight importance of timely decisions. - Consider external loan financing. - Anchor high-level design and schedule with important user organizations.
Suppliers' capability	- Lack of capacity at suppliers. - Quality of suppliers' execution and management of the scope. - Ability to deliver important equipment, especially terminals and bridge solution.	- Prepare contract strategies which increase likelihood of awarding contracts to suppliers of high quality. - Cooperation with other PPDR organizations to achieve economies of scale. - Staged roll-outs of Rakel G2 on a region-by-region basis.
Authorities (legislation, rules, standards and regulations)	- Changes in security requirements. - Delays in zoning processes.	- Analyze probable future development of security requirements. - Clarify legal position in terms of possibilities to establish sites in national parks et cetera. - Steer away from suppliers which may represent a security risk – verify that the public procurement regulations include the necessary mandates on this issue
User influence and demand	- Resistance from users in migrating to the new system. - New requirements from users.	- Provide users with clear definition of what is to be delivered and when. - Clarify relations between Rakel G2 and commercial offers towards users. - Clear delimitation and clarification of expectations between MSB and TrV and development projects at user organizations. - Clarify requirements from all users, including military.
Interfaces and other stakeholders	- Opportunity: Reduced need for radio link investments due to increased use of commercial solutions. - Opportunity: Functioning MOCN solution based on commercial solution leading to reduced need for new sites in the later stage of investment period.	- Clarify actual commercial use of current MSB masts.

We advise the project organization to further define and concretize the risk reducing measures, as the project is further defined and detailed. We further advise that responsibilities for assessing and implementing these measures are assigned to roles most capable of handling the issues.

3.5 Quality Assurance of the Project Internal Uncertainty Analysis of the Time Schedule

The quality assurance (QA) group has reviewed the method and process used for the uncertainty analysis done by MSB and TrV in May 2022 regarding the time schedule for planning and execution of Rakel 2. This uncertainty analysis is documented in MSB and TrV's analysis report (Erdalen et al. 2022). The QA group's review includes a comparison with the QA group's recommended methodlogy for such analyses. Quality assurance of the project's schedule should take place in the second half of 2023, when a more detailed execution schedule has been completed by the project.

3.5.1 Method and Process Applied in the Project Internal Time Schedule

The project internal uncertainty analysis on the time schedule was carried out May 2022 (Erdalen et al. 2022).

As for the cost uncertainty analysis, the schedule uncertainty analysis is in accordance with the principles developed by Steen Lichtenberg (2000). Both the cost uncertainty analysis and the schedule uncertainty analysis were done in the same process. The same risks and the same uncertainty drivers (i.e., basis items) were used in both analyses. For the schedule uncertainty analysis, seven comprehensive activities were identified and included in a network as part of the preparations for the uncertainty analysis workshop. No project schedule was available, the activities and the network were established in a dialogue between the project and the facilitators for the analysis. The network and its seven activities are shown in Figure 3.12.

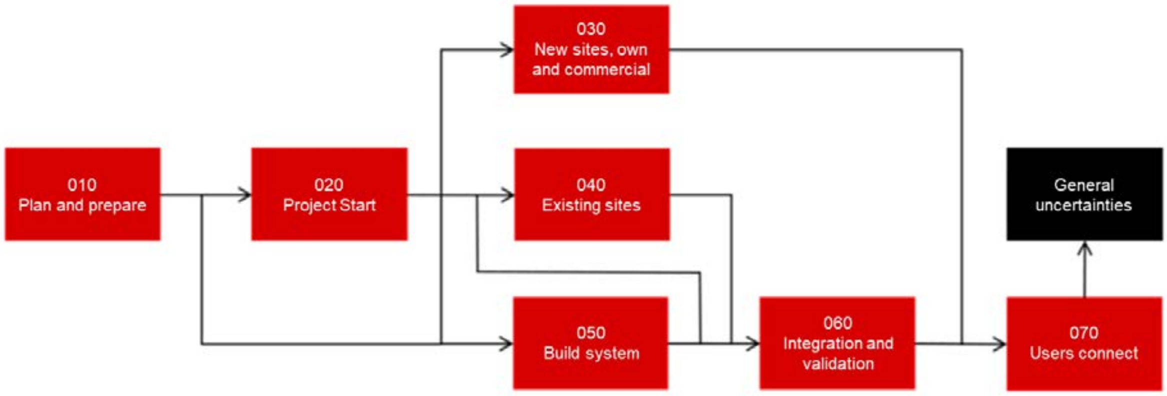


Figure 3.12: MSB and TrV's activity network at overall level, as reported in MSB and TrV's internal uncertainty analysis report (Erdalen et al. 2022)

Quantifications of Min, Most Likely and Max activity durations were made as individual assessments by the participants in the analysis workshop. Quantification of dependencies on preceding activities were made as group assessments. Quantifications of minimum, most likely and maximum activity duration effects of each of the uncertainty drivers were also made.

Documentation or information is not available either on experience data used nor on reasoning behind the quantified uncertainty durations for the activities and their dependencies. However, the scenarios used as basis for quantification of the uncertainty drivers are documented.

3.5.2 Assessment of MSB and TrV's Method and Process

The method used, that is Lichtenberg's successive method, is well recognized. The process has been comprehensive and well prepared. Furthermore, a comprehensive group of 19 people participated in the uncertainty workshop. Several of the participants from MSB and TrV were not Rakel project members. Their participation contributed to a balanced outsiders' view in the quantifications and discussions.

The uncertainty analysis was conducted in an early planning phase of the project. We consider key project elements such as scope of work, design, strategies, plans and organization as underdeveloped at that stage. Thus, the level of detail in the analysis was low, with only seven, comprehensive activities included in the network. Hence, neither key subactivities nor dependencies between such subactivities were defined and therefore not part of the analysis.

The timing of the analysis and the low level of detail have resulted in significant uncertainty spans for the total project duration, as documented in the uncertainty analysis report. High uncertainty restricts the potential for use of the results in further planning of the project and as a basis for major project decisions. The limited network of seven activities only, whereof six with very long durations, could result in unprecise or wrong analysis results. This would be the result of uncertainties and dependencies linked to essential subactivities not being identified, and hence their effect not being assessed in any detail.

The lack of documentation and information on experience data used and reasoning behind the quantified uncertainty durations and dependencies would also restrict use of the analysis results in further project planning, and in verification of the analysis and its results by others.

Our understanding is that there was an implicit assumption in the analysis that all new sites need to be established and all existing sites need to be upgraded prior to the start of user migration from Rakel G1 to Rakel G2. We suggest that this assumption is reconsidered by the project, as Rakel G2 could start functioning with a less complete network of sites.

In the workshop the quantification of each activity's duration uncertainty was done prior to quantification of uncertainty due to uncertainty drivers. Based on our experience from quality assurance of uncertainty analyses using the same sequencing in Norwegian projects, this could result in overlaps between the quantifications. In such a case the risks may be quantified twice, "double counted", leading to analysis results with overstated uncertainty spans.

3.5.3 QA Group's Method and Process for Schedule Uncertainty Analysis

Within the QA team, Dovre Group has extensive experience with schedule uncertainty analyses for large, complex projects. The same process as used in the QA group's independent cost uncertainty analysis is used in schedule uncertainty analyses, preferably in a joint process with cost. The process used for the cost uncertainty analysis is shown in Figure 3.12. For cost uncertainty analyses, the preparation starts with a review of the project's latest deterministic cost estimate. Similarly, the schedule uncertainty analysis starts with a review of the project's latest deterministic project execution schedule, and analysis of the schedule's uncertainties in a workshop. The same uncertainty drivers as in the cost uncertainty analysis will normally be used also in the schedule risk analysis. Each uncertainty driver is mapped towards relevant activities, thus ensuring that only affected activities are subject to the uncertainty quantification for each uncertainty driver.

Dovre utilizes Safran Risk as the analytical model in the schedule risk analyses. The model uses Monte Carlo simulations with 10,000 iterations to calculate the uncertainty effects on schedule. The model produces tables and graphs which illustrate key results, such as the expected duration for each activity in the network, expected dates for schedule milestones and the effect on results of each uncertainty driver.

3.5.4 Comparison of QA Group and MSB and TrV's Processes and Methods for Schedule Uncertainty Analyses

Table 3.8 shows a comparison of topics related to the process and the method utilized in schedule uncertainty analyses done by Dovre Group (part of the QA group) and by TrV (as utilized in the MSB and TrV Rakel 2 schedule uncertainty analysis). The table shows a summary of the comparison, which is described in more detail in the text below the table.

Table 3.8: Comparison of QA group, and MSB and TrV's process and method for schedule uncertainty analyses

Assessments	Dovre / Safran Risk	MSB /TrV / Futura Nova
Method	Lichtenberg successive method	Lichtenberg's successive method, adjusted
Project phase	End of project planning and preparations phase	Early planning phase
Schedule based on	Medium network (preferably 15-20 activities)	Small network (7 activities)
Establish deterministic (base) schedule	Before session (planning specialists, experience data)	No
Logic network	Set before group session	
Activity durations	Included in the schedule before group session	Quantifications in the group session
Uncertainty of duration estimate	Quantifications of estimate accuracy in the group session, linked to activities	Part of the duration quantifications, linked to activities
Uncertainty drivers	Quantifications in the group session, linked to activities	Quantifications in the group session, separate from the activities
Analysis of interim goals	Yes	No

Uncertainty analyses done by both Dovre and TrV are based on Steen Lichtenberg's successive method. Some adjustments to Lichtenberg's original method are made in the method used by Dovre, in line with the method utilized for cost uncertainty analysis of large national government investment projects in Norway. These include that a deterministic schedule prepared by the project is a starting point for the analysis, quantification of P10 and P90 uncertainty span durations instead of P1 and P99, and group discussion and assessment of these quantifications instead of individual assessment by each participant in the analysis.

The MSB and TrV uncertainty analysis was done in a very early planning phase of the project, with immature definitions of key project elements such as scope of work, design, strategies, plans and organization. In Norway, uncertainty analysis of schedule normally is carried out at the end of planning phases when these elements are more matured and documented. Such documentation will include a detailed deterministic project schedule, prepared by planning specialists utilizing experience data from previous similar projects. This practice allows for establishing a much more detailed network (high number of activities and dependencies) compared to the practice for the MSB and TrV Rakel 2 analysis.

Both Dovre and TrV establish in advance the planning network which will be reviewed and assessed in the group session. In the uncertainty workshop Dovre can utilize the activity durations from the detailed schedule as a starting point for assessment of the uncertainties' effects on schedule. In comparison, TrV's practice is to have all input on activity durations in the group session.

Quantification of uncertainty drivers differs between Dovre and TrV. With the model used by Dovre, Safran Risk, the effect of each driver is linked to activities, hence all resulting expected durations can be broken down to activity level. The TrV model seems to lack this functionality, which means that all effects can be shown at total project level only. Due to this difference in functionality, it is possible to analyze results for interim goals and milestones in Safran Risk. Such analyses would at best be unprecise in the model used by TrV as the effects of the uncertainty drivers on interim milestones and goals are lacking.

3.5.5 Comparison between the Results from the MSB and TrV Uncertainty Analysis and the Rakel G2 Planning and Preparation Report

The results from MSB and TrV's uncertainty analysis on the time schedule (cf. Erdalen et al. 2022) can be seen in Figure 3.13.

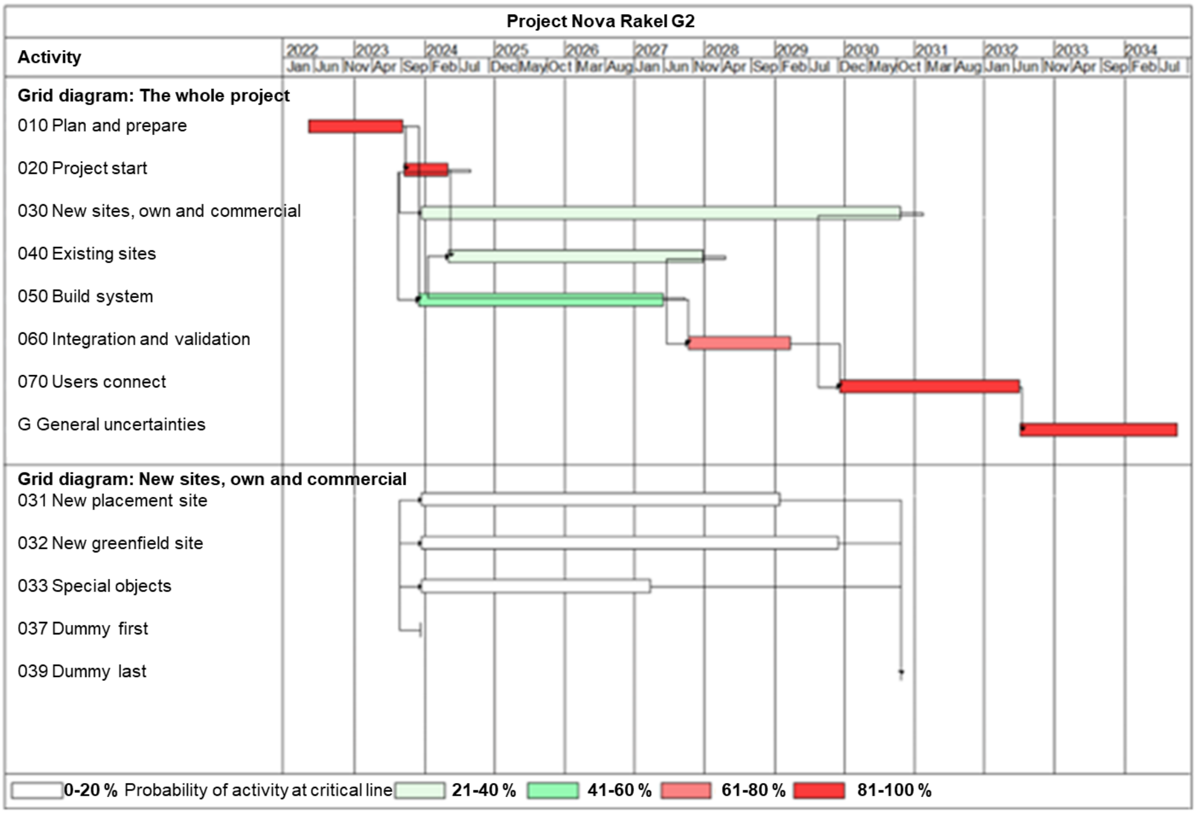


Figure 3.13: Schedule for establishment of Rakel G2 with elaboration on project activities for the whole project and related to new sites, as reported in MSB and TrV's internal uncertainty analysis report (Erdalen et al. 2022)

As can be seen from the figure, expected start of migration of users to Rakel G2 is in late 2029, with reference to activity 070 "users connect". However, any effects on this activity due to the uncertainty drivers, named activity G, "general uncertainties" in the figure, cannot be assessed from the uncertainty analysis report. These uncertainty drivers contribute to a delay of approximately 27 months to the total project duration. How this time element affects the migration cannot be determined from the analysis results, but it would not be unreasonable to assume that the effects of the uncertainty drivers would push start of migration well into 2030 or even 2031.

Figure 3.14 shows the overall time schedule for Rakel G2 included in MSB and TrV's project report for planning and preparation of the further development and establishment of Rakel G2 to Government (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021). This report was made public in March 2023.

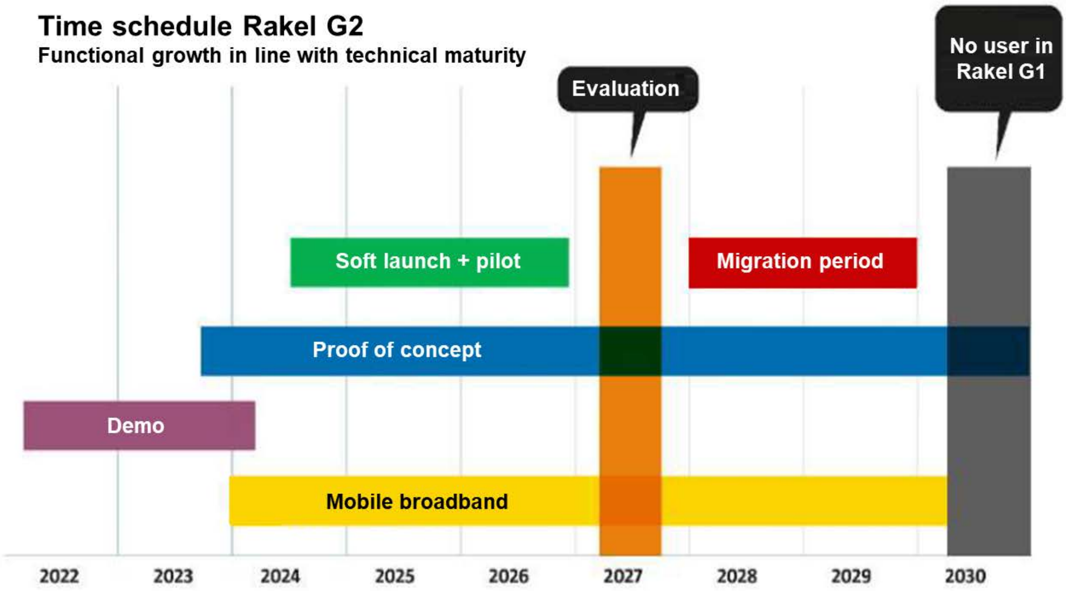


Figure 3.14: Time schedule for establishment of Rakel G2 with elaboration in functional growth in line with technical maturity, as reported by Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b)

This time schedule by Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b) shows that migration to Rakel G2 starts in 2028, i.e., two years earlier than the expected date in the uncertainty analysis report. Taking the effect of uncertainty drivers into account, the planned start may be 3 years or more earlier than the expected migration start date that can be derived from the uncertainty analysis report. Based on this comparison, the planning in Myndigheten för samhälls-skydd och beredskap and Trafikverket (2021b) seems optimistic.

The Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b) report also includes Figure 3.15, which shows the execution schedule for Rakel G2 in another format.

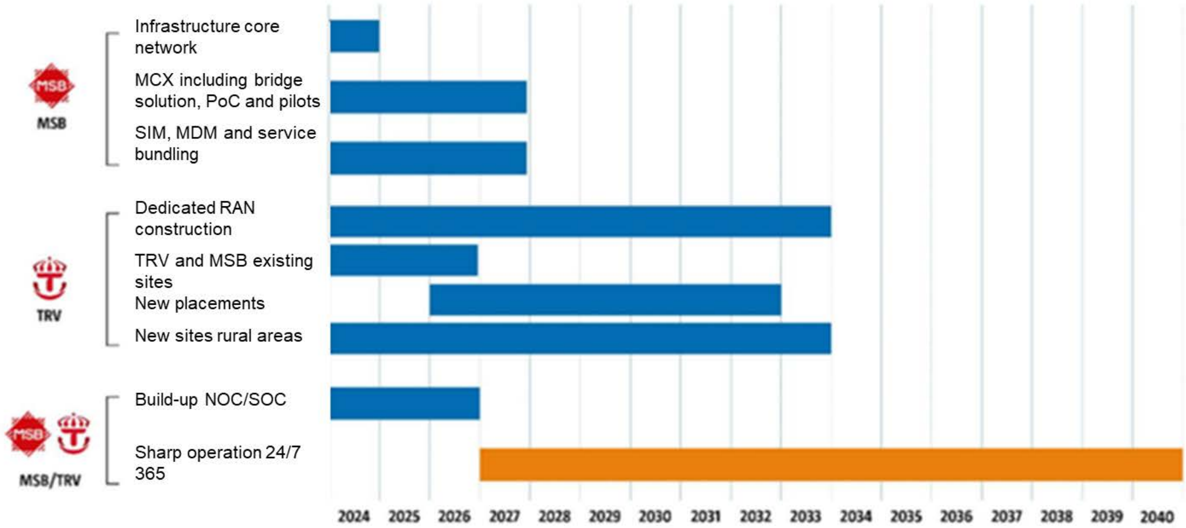


Figure 3.15: Plan for expansion of Rakel G2, as reported by Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b)

The figure shows the start of Rakel G2 operations in 2027, confirming the plan of starting migration to the new system well ahead of the expected migration start date from the uncertainty analysis. This seems to be due to a change in the network planning logic from Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b)'s execution schedule to the planning network prepared for the May 2022 uncertainty analysis. In the 2021 schedule, Rakel G2 operations commence just after the existing sites have been upgraded, but several years before the new sites have been established. We recommend that the project reconsider this change in logic. The project should rely on the existing sites and the commercial network only, in order to accelerate the migration launch.

Still, based on the uncertainty analysis results, the schedule in Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b) seems optimistic. This schedule shows expected finish of upgrading of existing sites to be end of 2026 and the systems completed end of 2027, without taking effects of uncertainty drivers (also known as general uncertainties) and estimate accuracy uncertainty into account. The effects of the uncertainty drivers would likely extend the expected finish date of this activity well into 2028, or longer. This is at least one year later, or more, than shown in the new 2021 plan.

It should be noted that Myndigheten för samhällsskydd och beredskap and Trafikverket (2021b) refers to uncertainty in cost estimates and in the number of subscribers to Rakel G2, but we have not noted any reference to schedule uncertainty.

3.5.6 Conclusions and Recommendations on the Uncertainty Analysis on the Time Schedule

Uncertainty analysis of project schedules across time is not part of the requirements for mandatory external quality assurance of large public projects in Norway. However, Rakel 2 QA group members have extensive experience from uncertainty analyses of project execution schedules. The May 2022 Rakel 2 schedule uncertainty analysis has resulted in an estimate of the expected duration of the project. Based on our experience from uncertainty analyses of other projects, we question the usefulness of the May 2022 analysis for execution planning of Rakel 2. Our concerns, as discussed earlier, can be summarized as listed below:

- The analysis was done in the early planning phase when few strategies and details were in place.
- No documentation is available either on experience data used nor reasoning behind durations and uncertainty quantifications, except for the general uncertainties.
- The effects of the uncertainty drivers (i.e., general uncertainties) are not allocated to the relevant activities. Their effects are shown for the total project duration only.
- Overlaps in quantifications of activity uncertainties and quantification of general uncertainties cannot be ruled out.
- Break-down of the project into seven high level activities only, hence critical subactivities and their dependencies are not defined and not part of the analysis.
- With a limited network and limited dependencies identified, the long activity durations may give wrong analysis result.

Based on these concerns, and our impression that planning assumptions have changed since May 2022, we support the project's plans for a new uncertainty analysis on schedule later in 2023. Our recommendations for a next schedule uncertainty analysis are provided in the following.

3.5.6.1 Prerequisites for the Schedule Uncertainty Analysis

On prerequisites, we have three recommendations for the next uncertainty analysis on the time schedule:

a. The project should establish a "high-level project design". Such a document should describe the services that will be offered in Rakel G2, the time and order in which these services will be introduced, and a realization plan for the services. The need for such a document is discussed in section 3.4 on risk reducing measures.
b. The project should establish an execution strategy, which reflects the "high-level project design". The project's sequence for establishing new sites and upgrading existing sites, and the intensity of these activities, should be part of this strategy.
c. A draft execution schedule, reflecting the execution strategy, should be established. Format and level of detail of this schedule should reflect MSB and TrV's requirements for management of Rakel 2 project during execution, to ensure timely implementation of activities and for monitoring and follow-up of progress of the project's defined activities.

3.5.6.2 Planning, Preparations and Execution of the Schedule Uncertainty Analysis

On planning, preparations and execution, we have four recommendations for the next uncertainty analysis on the time schedule:

a. The project should establish a planning network for the uncertainty analysis, based on the detailed execution schedule.
b. For quantification of the uncertainties (i.e., minimum, most likely and maximum of quantification of durations), we recommend that the uncertainty drivers (general uncertainties) are quantified first in the uncertainty analysis workshop, and that estimate uncertainty of durations is quantified thereafter. By using this sequence any tendency for overlap of quantifications should be reduced.
c. The model used in the analysis should allow for quantification of the uncertainty drivers on activity level, instead of and not on overall project level.
d. All experience data used by the workshop participants in quantification of the uncertainties should be documented. Also, the reasoning behind all quantifications should be described, for example by use of scenario descriptions.

3.5.6.3 Finalization of the Schedule Uncertainty Analysis

We have three recommendations related to the finalization of the execution schedule:

a. As quality assurance of the execution schedule established by the project, it should be considered if an independent schedule uncertainty analysis should be effected.
b. When the results from the uncertainty analysis (and possibly the results of additional quality assurance activities) are available, the project should consider if the results warrant a revision of the execution schedule established in item c. Expected activity durations from the uncertainty analysis results should be analyzed, together with estimated effects of risk reduction measures.
c. We recommend that a short and to-the-point management plan is established, derived from the execution schedule and the uncertainty analysis. This plan should reflect the overall work breakdown structure-picture of the project, as well as critical and/or major activities, delivery milestones and dependencies.

3.5.7 Reference Group's Comments to the Project Internal Uncertainty Analysis of the Time Schedule

Our quality assurance of the method and process applied in MSB and TrV's schedule uncertainty analysis has been presented to the reference group for this QA assignment. The reference group's main comments relate to the activities to ensure smooth interfaces between Rakel G2's and the users' systems and organization during both preparing for operations and for user migration to Rakel G2 and the actual operations. The group considers that it is essential that the project and its operating organization understand and prepare for all aspects of being a service provider to the users. Furthermore, that it is a key success factor for Rakel G2 that the project actively supports all internal projects established by the users in preparing for their migration to Rakel G2.

3.6 Comments from the Facilitators of the Project Internal Uncertainty Analysis

The QA group has discussed the difference in method and process with TrV's facilitators of MSB and TrV's uncertainty analysis of cost and time. We have also received written comments from the facilitators on a draft version of this report. TrV's main comments are all linked to the fact that facilitators and the QA team have different views on the process and methods for uncertainty analyses. TrV's methods and process are fully in line with the Successive Principle developed by Lichtenberg (2000). The QA team's method and process are based on a modified version of Lichtenberg's methodology in line with the requirements of the Norwegian Ministry of Finance for quality assurance of large public projects.

Lichtenberg refers to the experience from the Norwegian "quality audits based on the Successive Principle" as a case example in his article "Successful Control of Major Project Budgets" (Lichtenberg 2016). Experience from this quality assurance program is well documented in reports from the Concept Research Program. In an investigation report by Concept, Welde et al. (2019) analyses and compares the actual cost of more than 80 finalized Norwegian national government investment projects with the cost estimates established in the projects' QA reviews. Dovre and TØI did the QA review for 19 of these projects. The report documents that 16 percent ended up with final cost below P10 (10 percent probability of being within this cost frame). Furthermore, 57 percent of the projects ended up below ML (most likely, corresponding to P50), while 95 percent of the projects ended up below P90 (90 percent probability of being within the cost frame). 79 percent had a final cost within an 80 percent prediction interval (80 percent probability for final cost between the P10 and P90 values). Even if the number of projects is relatively small, the statistical results of the Concept analysis show that the estimated cost uncertainty from the Dovre and TØI QA reviews correlates well with actual cost uncertainty.

It should be noted that The Norwegian Public Roads Administration ("*Statens vegvesen*" in Norwegian) uses a similar methodical approach (Statens vegvesen 2021) to TrV's method. However, in the SVV method the parameters for maximum and minimum uncertainty quantifications (P10 and P90, respectively) and the use of group discussions on such quantifications differ from those used by TrV. A work group led by the Norwegian Ministry of Transport has made several additional recommendations (Samferdselsdepartementet 2016) on how the SVV method should be further adapted to align it with the Norwegian QA-requirements.

Based on the comments from TrV's uncertainty experts, we have made some clarifications to the draft text of this chapter. Note that our QA-team's mandate has been to perform the quality assurance of the Rakel G2 project in accordance with the Norwegian KS2-requirements. Based on these requirements and our experience from KS2 QA of about 80 large government investment projects in Norway, we maintain our conclusions and recommendations regarding the project's uncertainty analyses.

4 Quality Assurance of Project Preparations

4.1 Summary and Introduction for the Quality Assurance of Project Preparations

4.1.1 Introduction to Quality Assurance of Project Preparations

In the 1980s and the 1990s, Norway experienced significant cost overruns on several large public projects. Consequently, from the year 2000 onwards the Ministry of Finance introduced mandatory governance arrangements for major government funded public projects, including requirements for independent external quality assurance of the project management documentation (project preparations) and the project's cost estimate (KS2). Dovre Group has held frame agreements with the Ministry of Finance since the year 2000 for quality assurance assignments, from 2005 in a consortium with TØI, up to today. Since the year 2000, Dovre and TØI have undertaken quality assurance of project preparations and cost estimates for close to 80 projects. The Ministry's associated quality assurance requirements and guidelines have later been revised and further elaborated (Finansdepartementet 2008, 2019a, 2019b and 2020 and Direktoratet for økonomistyring 2021). Quality assurance of project preparations is not needed for parliamentary approval in Sweden, but we still consider quality assurance of the project preparations as highly advantageous also in a Swedish context, in order to reduce risks for cost overruns and project delays.

The quality assurance of project preparations investigates the project documentation within three main topics – the project's overall framework, project strategy and project control basis. Each of the main topics includes four to six subtopics, such as the project's identification of its critical success factors, interfaces, strategy descriptions, project ownership and project execution organization, quality of the cost estimate and of the project schedule. The Norwegian requirements for project preparations are in accordance with sound project practice, and similar requirements can be found in many large international corporations which regularly implement large investment projects, such as energy projects. Furthermore, the consistency between the topics is also reviewed in the quality assurance process, such as consistency between the work break-down structure (WBS), estimate, project time schedule and organization structure.

In the Norwegian quality assurance scheme for major public investments, for projects where the managing documents are found insufficient and the project is deemed immature, the quality assurer will call for more documentation before national government and parliamentary approval. Such a requirement does not exist in Sweden, but to minimize the risk of budget overruns and ensure predictability of the project, it is still recommendable to have thoroughly processed documents for project organization and governance setup.

4.1.2 Summary and Recommendation on Documentation Needs Concerning Project Preparations

Overall, our review of decision preparation documents on project organization and implementation shows a considerable amount of missing documentation. This holds for all key aspects of the affiliated documentation, including the project's overall framework, strategy project and control basis. Moreover, none of the topics assessed in the Norwegian quality assurance scheme for large national government investments were considered having complete documentation, as depicted in Table 4.1.

For the overall framework, the documentation on purpose, requirements and main concept, and critical success factors, would have met the minimum requirement for quality assurance by the Norwegian quality assurance scheme, despite some weaknesses. The documentation for the other topics would have been considered insufficient to move forward for parliamentary approval in Norway, either due to decisive deficiencies in the documentation (i.e., project framework and project objectives) or non-existing documentation (i.e., interfaces).

For the project strategy, none of the topics met the documentation requirements set by the QA team. The documentation was deemed to involve decisive deficiencies for the execution strategy and the organization and management, while no documentation was found for the strategies on risk management and contract design.

For the project control basis, work breakdown structure and cost estimate, as well as budget and phasing, there was sufficient documentation to move forward in the Norwegian quality assurance scheme, despite some weaknesses. Yet, other documentation would have been deemed insufficient by the Norwegian scheme due to decisive deficiencies (i.e., project schedule and scope of work, including management of change) and non-existing documentation (i.e., benefits realization plan and quality assurance and control).

The quality assurance group was asked to do the quality assurance of the project preparations on project management, governance and organization at a point in time when the project preparations still were not complete. Before the project launch, we strongly recommend that the MSB and TrV prioritize to improve the project preparations and its documentation on project preparations, similar to the Norwegian requirements. We also encourage quality assurance of these documents. However, we acknowledge that the requirements for quality assurance set by the Norwegian quality assurance scheme for large national government investments do not apply to Sweden. Accordingly, the project may have more flexibility with regard to documentation than major Norwegian investment projects.

Table 4.1: Assessment of missing project preparations – overall framework. Green color: Sufficient documentation. Yellow color: Documentation with some weaknesses. Orange/red color: Documentation with decisive deficiencies. Dark red color: No documentation

Main topic	Subtopic	Missing descriptions / documents	Status
Overall framework	Purpose, requirements and main concept	Purpose described in Government assignment. Precise descriptions of concept, requirements and expected performance missing	Yellow
	Project objectives	Objectives included in UA document neither complete, measurable nor prioritized	Orange/red
	Critical success factors	Not specifically described, but several measures included in UA report can be regarded as success factors	Yellow
	Project framework	Descriptions on TrV / MSB's project planning / execution framework, as well as laws and regulations missing	Orange/red
	Interfaces	No descriptions (technical, organizational, commercial interfaces)	Dark red
Project strategy	Risk management strategy	Not described in documents received to date	Dark red
	Execution strategy	Brief description only in the Rakel G2 Planning and Preparation Report (Myndigheten för samhällsskydd och beredskap and Trafikverket 2021)	Orange/red
	Contracts strategy	Not described in documents received to date	Dark red
	Organization and management	Division of roles/duties between MSB and TrV is described. Other information on how project is organized and managed is missing	Orange/red
Project control basis	Scope of work, including management of change	Detailed descriptions of project scope are missing, but quantities are given in the project's cost estimate. No information on change management.	Orange/red
	Work breakdown structure	Described in UA report from May 2022, but need information/confirmation on final structure	Yellow
	Cost estimate, budget and phasing	Detailed estimate received, but overview and verifiability are challenging. Investment estimate not structured in accordance with WBS.	Yellow
	Benefits realization plan	Not yet received	Dark red
	Project schedule	Brief description only in project's final report	Orange/red
	Quality assurance and control	Overview of QA/QC procedures and requirements for the project not yet received.	Dark red

4.2 Method and Assumptions

In our quality assurance assessment of project organization and governance setup, we follow the methodology applied in the Norwegian scheme for quality assurance of large national government investments (Finansdepartementet 2008, 2019a and 2019b and Direktoratet for økonomistyring 2021). Our baseline would be the necessary information and documents, which should be prepared by the project and made available for quality assurance, in order to meet the requirements of the Norwegian Ministry of Finance. When establishing the strategies for execution and contract, the quality assurance QA group should consider certain key factors, as listed in Table 4.2.

In the QA group's assessment of the degree of completeness of the Rakel 2 documentation, we apply color codes. Here dark red means that no information has been received or observed on the subject, orange/red indicates that the documentation has decisive deficiencies and yellow means that the documentation has some weaknesses. Note that only one shade of red is used in the Norwegian quality assurance scheme. In this assessment, we have nevertheless found it useful to distinguish between topics with documentation suffering from decisive deficiencies and topics with no documentation.

Table 4.2: Key factors when establishing the execution strategy and the contract strategy

Establishment of the execution strategy	Establishment of the contract strategy
Project's purpose, project framework, critical success factors and major uncertainties, and stakeholders concerns and interests.	Project's purpose, objectives and framework, magnitude, complexity and criticality, market uncertainty and competitive situation, project owners' and supplier markets' competence and capacity, parties' ability to handle risks and interfaces

Throughout the quality assurance, the NOVA council (i.e., the investment project's council) and key personnel at MSB, the reference group and key personnel at TrV have provided us with valuable input to our quality assurance of the project organization and governance setup. Although their feedback has not affecting our conclusions and recommendations in our quality assurance task substantially, it has provided us with valuable supplementary information that has strengthened our analysis.

4.3 Assessment of Missing Project Preparation on Project Organization and Governance Setup

In this section, we consider the missing project preparations on project organization and governance setup in more detail. We start by considering the overall framework, before we turn to the project strategy and the project control basis.

4.3.1 Overall Framework

In Table 4.3, we sum up our assessment of missing project preparations for the overall project framework. 'On none of the topics, documentation can be considered fully satisfactory, but the documenttation related to purpose, requirements and main concept, and critical success factors would have been sufficient for further quality assurance investigations under the Norwegian quality assurance scheme for large national government investments (yellow color). Project objectives and project framework also involve some documentation, but with decisive deficiencies (orange/red color). We have not received or come across any documentation on the handling of interfaces (dark red color).

Table 4.3: Assessment of missing project preparations – overall framework. Green color: Sufficient documentation. Yellow color: Documentation with some weaknesses. Orange/red color: Documentation with decisive deficiencies. Dark red color: No documentation

Topic	Missing descriptions / documents	Status
Purpose, requirements and main concept	- Main stakeholders' expectations of the project. - Main requirements which project needs to fulfill, in order to deliver on the purpose of the project. - Overall description of the project's concept: expected performance/quality, subprojects, main numbers and quantities. - How the project is delimited from MSB and TrV's other activities, and from activities undertaken and paid for by customers and other stakeholders.	Yellow
Project objectives	- Objectives for the project at three levels: a. Objectives on effects for the society b. Objectives on effects for the users c. Objectives that describe what the project specifically shall achieve, including objectives on performance / quality, cost and time. - Objectives should be SMART (Specific, Measurable, Accepted, Realistic and Time-limited). - Prioritization between the objectives needs to be stated. Such prioritization should be adhered to if project comes into a situation where it is impossible to meet all the objectives.	Orange/red
Critical success factors	- Description of elements which the project needs to succeed with in order to meet the project objectives (Several measures included in the May 2022 UA report can be regarded as success factors. These should be reviewed and considered for inclusion when compiling the complete list.) - Success factors should be project specific (generic success factors applicable for most projects should not be included)	Yellow
Project framework	- TrV and MSB's project planning / execution framework which the project must adhere to - The laws and regulations which are most relevant for the project	Orange/red
Interfaces	- Technical interfaces (between suppliers, between subprojects) - Organizational interfaces (between units in the project organization, between MSB and TrV, between units within MSB and/or TrV, between project and operating organization) - Commercial interfaces (between project and suppliers, between MSB and TrV, between project and other government agencies)	Dark red

4.3.2 Project Strategy

Our assessment of the missing project preparations regarding the project strategy is provided in Table 4.4. None of the topics would have been deemed satisfactory for further quality assurance investigations under the Norwegian quality assurance scheme for large national government investments without more documentation. For the execution strategy and organization and management, the documentation has decisive deficiencies (orange/red color). For the strategies for contract design and risk management, we are not aware of any relevant documentation (dark red color).

Table 4.4: Assessment of missing project preparations – project strategy. Green color: Sufficient documentation. Yellow color: Documentation with some weaknesses. Orange/red color: Documentation with decisive deficiencies. Dark red color: No documentation

Topic	Missing descriptions / documents	Status
Risk management strategy	- Most critical uncertainties, including risk reducing measures - Project's risk management procedures	
Execution strategy	- Description of, and rationale for, the chosen strategy for execution of the project, relative to criticality and degree of uncertainty related to: o Scope of work o Execution plan o Organization and management o Stakeholder relations	
Contract strategy	- Evaluation of two principally different contract strategies. For the project in total and each separate contract. Required topics: o Enterprise / contracts structure o Split of responsibilities. Guarantees. o Compensation format, including incentives / penalties o Level of detailing in specifications, specifications of requirements, change procedure o Tender processes and procedures, qualification requirements o Evaluation criteria for the tender competitions - Recommendation on choice of strategy, with rationale.	
Organization and management	- Overview of the project organization, which shows: o Project's internal organization o Project's relationship to superior organization units in MSB and TrV o Relationship between MSB and TrV o Relationship to the relevant ministries involved o Relationship to other government agencies involved - Descriptions of decision authorities and areas of responsibility for the key positions in the project - Reporting procedures/routines	

4.3.3 Project Control Basis

In Table 4.5, we assess the missing project preparations associated with the project control basis. Here, documentation is found to be incomplete for all topics. We find that despite some weaknesses, the documentation of project preparations concerning work breakdown structure and cost estimate, budget and phasing would have been sufficient for further quality assurance in the Norwegian quality assurance scheme (yellow color). For the remaining factors, we consider the documentation insufficient as a project control basis. For scope of work, including management of change, and project schedule, the documentation involves decisive deficiencies from our point of view (red/orange color). Regarding benefits realization plan and quality assurance and control, we have not found or received any relevant documentation (dark red color).

Table 4.5: Assessment of missing project preparations – project control basis. Green color: Sufficient documentation. Yellow color: Documentation with some weaknesses. Orange/red color: Documentation with decisive deficiencies. Dark red color: No documentation

Topic	Missing descriptions / documents	Status
Scope of work, including management of change	- Precise description of scope of work, with specification of quantities. (Quantities are included in the project's November 2022 estimate, but the specification needs to be updated with any changes since November 2022.) - Description of the project's management of change system (MoC), i.e., requirements and routines for deciding and implementing changes to the above specified scope of work during project execution	Orange/red
Work breakdown structure	- How the scope of work is divided into manageable packages. (A WBS was included the project's May 2022 UA report, but information/confirmation on final structure is needed.)	Yellow
Cost estimate, budget and phasing	- Detailed base estimate received, but overview and verifiability are challenging. Not structured in accordance with WBS. Base estimate may need updating for any changes since November 2022. - Updated uncertainty analysis based on the final base cost estimate. - Potential for further simplifications and reductions of the project's scope of work, with estimates on cost reduction potential. - If a Norwegian project: Recommended investment budget for MSB and TrV (P50 estimate). Recommended investment budget for the relevant ministries (P85 estimate).	Yellow
Benefits realization plan	- Project's operative plan to achieve the desired effects, cf. project's objectives, from the project. o Type and magnitude of benefit (effect) o Responsible person for obtaining each benefit o Indicators which will prove that the benefit has been achieved o The stakeholders that will receive the benefit o When the benefits are expected to be realized o Required measures to achieve the benefits	Dark red
Project schedule	- Detailed schedule for the total project including detailed schedule for each of the main activities shown in Figures 1 and 5 in the project final report (received February 2. 2023). - The schedule must contain the entire scope of work, highlight dependencies between the activities, delivery milestones and tender processes, as well as activities towards authorities and stakeholders. - Critical line should appear in the schedule and highlight which activities should be in focus of project's management.	Orange/red
Quality assurance and control	- Overview of cost control, progress control and QA/QC procedures and requirements and for the project	Dark red

4.4 Process for Establishing Documentation on Project Organization and Governance Setup

The QA group's view on the current status of project preparations, as accounted for in this chapter, was made clear in March 2023. In a meeting between the QA group, MSB and TrV on March 17. 2023, the QA group substantiated its assessment on the current status of project preparations. In a further meeting on March 24. 2023, MSB and TrV asked the QA group to document the weaknesses related to the documentation on project organization and governance setup. Some additional documentation has been received since then with slight improvements in the evaluation scores for certain topics, but the main content and conclusions of the assessment remain the same. Towards the end of March, it became clear that much of the documentation needed for better evaluation on topics of the project organization and governance setup would not be ready before the second half of 2023, that is after we have delivered our assignment. Hopefully, our analysis has helped to shed light on the needs for documentation in this regard. During the first half of 2023, MSB and TrV have been fully occupied with other Rakel G2 activities which they consider more urgent.

The QA group strongly recommends that MSB and TrV prioritize improving the documentation on project organization and governance setup prior to the project launch, preferably during the second half of 2023. The main purpose of these preparations is to reduce the risk of cost overrun and delay. Furthermore, we encourage quality assurance of these documents when ready. At the same time, we acknowledge that the requirements for quality assurance set by the Norwegian quality assurance scheme large government investment projects do not apply for Sweden.

5 Analyses of Impacts External to the Infrastructure Project

5.1 Summary and Introduction of the Analyses of Impacts External to the Infrastructure Project

5.1.1 Introduction and Motivation for Investigation of Impacts External to the Infrastructure Project

In this chapter, we analyze impacts of Rakel G2 that are external to the Nova project. These impacts are in some way assessed at the first stage of the Norwegian quality assurance system (KS1). In addition, except for the user cost analysis, we evaluate the impacts of Rakel G2 against a reference scenario, where Rakel G1 is gradually phased out and replaced by uncoordinated use of mobile network services for public protection and disaster relief (PPDR) purposes. The five impact analyses carried out in this chapter are listed in the following:

- **Direct user impacts**: When focusing solely on the cost side of infrastructure projects, there will always be a danger that one disregards the user benefits, which constitute the motivation for the project solution in the first place. Here, we will explore the user benefits applying a multi-criteria analysis for various stakeholders, reflecting direct beneficial effects of the quality of the mobile network.
- **Gross user costs:** While infrastructure project analysis typically constitutes the core of the appraisal in public infrastructure investment projects, user costs are often ignored, even though they may be substantial. We estimate the gross user costs associated with the whole system integration project, where the term "gross" reflects that the alternative user costs have not been assessed.
- **Indirect impact:** Much of the attention in public debate on public emergency networks is directed towards indirect impacts, which are typically non-monetized. In our investigation, we provide a qualitive overview of indirect impacts, including impacts on aspects of spectrum utilization, cooperation, production economy, knowledge generation, security and environmental issues.
- **Marginal costs of public funds:** In both Norwegian and Swedish methodology for cost-benefit analysis from a society point of view, marginal costs of public funds usually constitute a considerable component of the total net and gross costs. In this investigation, we estimate the net marginal costs of public funds of infrastructure cost and the gross marginal costs of public funds of user costs, as well as assessing tax distortions originating from non-monetized impacts qualitatively.
- **Distributional considerations:** Public decision-makers should not and do not only care about the net benefit of a project, but also about distributional aspects. Towards the end of the project, we have assessed the distribution impacts of the infrastructure project, concerning various stakeholders (i.e., the horizontal dimension), groups with various socio-economic backgrounds (i.e., the vertical dimension), various geographical locations (i.e., the spatial dimension) and across time (i.e., the intergenerational dimension).

5.1.2 Summary of the Analyses of Impacts External to the Infrastructure Project

Public safety users need modern communication services that are reliable, secure and easy to use wherever they operate and in all situations. Based on interviews with several Rakel users, we assess that robustness is the most important user priority, followed by functionality, user experience and coverage. Interoperability and security are also important, while capacity was rated least important.

We have compared the current Rakel G2 setup with a reference scenario, where Rakel G1 is kept alive as long as possible and mobile data to PPDR users is delivered over regular commercial networks.

As the ultimate benefits of increased service quality caused by Rakel G2 are hard to address accurately, we proxy these impacts by addressing direct user benefits for the emergency services. Table 5.1Table S.1.3 shows a relative comparison of the project's assessment of expected user benefits in the Rakel G2 scenario and the reference scenario. Interoperability is the attribute with the highest expected improvement from the reference scenario to Rakel G2. Also, we expect improvements in robustness, user experience, coverage, security and capacity with Rakel G2 compared to the reference scenario. In terms of capacity, it is important to note that it will likely be possible to get priority in commercial mobile networks, which is an advantage with Rakel G2. The anticipated improvements in robustness and capacity both require a seamless multi-operator core network (MOCN) solution. The only attribute where we do not expect an improvement compared to the reference scenario is functionality.

Table 5.1: User benefits in Rakel G2 versus reference scenario

Benefit	Weight	Rakel G2 scenario
Robustness	23	+
Functionality	21	0
User experience	20	+
Coverage	20	+
Interoperability	18	++
Security	17	+
Capacity	14	+

In addition to subscription fees, Rakel G2 users will incur other direct costs. First, they will have to pay for terminals and in some cases the installation of terminals. In addition, there will be costs for integrating Rakel G2 services with the users' applications and IT systems. We estimate initial terminal and integration costs to be around BSEK 1. This estimate does not include VAT, procurement or training costs. Annual costs are around MSEK 125per year or BSEK 2.5over a 20- year span. This means that total estimated user costs are BSEK 3.5when both initial and recurring costs are included. Please note that these are the gross user costs of Rakel G2. The net user costs excluding the subscription fees will be lower, as there will be user costs in the reference scenario as well.

Nevertheless, the network subscription costs will most likely be higher than the additional subscription costs associated with Rakel G1 and private subscriptions in the reference scenario. Thus, we expect considerable net user costs associated with subscription fees, which should have been subtracted from the subscription revenues for the infrastructure project in a cost-benefit analysis.

Furthermore, implementation of Rakel G2 induces a wide range of indirect impacts. A brief overview is provided in Table 5.2.

Table 5.2: Overview of Indirect impacts

Indirect Impact Group	Description
Impacts on radio spectrum utilization	• Reduced spectrum availability for public mobile networks • Improved coverage in rural areas • Indirect spectrum impacts caused by competition impacts
Cooperation	• Interagency cooperation between the emergency services • Cooperation with others across networks
Economic	• Potential comparative advantage for Telia from the MOCN solution • Important assignment for the chosen system supplier • Available capacity and healthy competition prevent distortions within construction
Knowledge generation	• Learning outcomes on integration between civil and PPDR networks • Technology-specific training costs and learning outcomes
Security	• National security, network ownership and protection against hacking • Emergency preparedness for the civil emergency agencies • Personal security and privacy • Perceived security
Environmental	• Construction affects landscape value at sites • Daily operations indirectly involve climate through the energy consumption

First, the spectrum utilization is affected by fewer frequencies available for auctions, additional construction of mobile coverage in rural areas and indirect influences through competition impacts. Second, Rakel G2 will affect cooperation between the emergency services and their interaction with other partners applying another network. Third, Rakel G2 will affect competition and economic capacity in several markets, providing Telia and possibly systems suppliers (e.g., Ericsson) with competitive advantages in the market for telecommunication services and manufacturing, respectively. Competition in the market for telecommunication construction is on the other hand likely to be less affected due to available capacity and healthy competition.

Fourth, Rakel G2 will generate new knowledge on integration between civil and PPDR networks, as well as on technology-specific training costs and learning outcomes. Fifth, Rakel G2 will influence PPDR security, mostly in terms of improvements such as network ownership and protection against hacking, and emergency preparedness for the civil emergency agencies. In addition, the network may enhance personal security and privacy, and contribute to higher perceived security. Last, the project will also entail some environmental impacts such as effects on landscape values at sites in connection with construction and greenhouse gas emissions through energy consumption related to daily operation.

As realization of Rakel G2 calls for tax funding and comes at the expense of tax cuts and welfare arrangements, it will involve distortion in the tax system. We estimate the net marginal costs of public funds for the infrastructure project to BSEK 3.84. Furthermore, we estimate the gross marginal costs of public funds related to the user costs to BSEK 1.05, where user costs in the alternative scenario are left unaccounted for. In addition, Rakel G2 will involve indirect tax distortion, especially in connection with the loss of public revenues from spectrum auctions.

Rakel G2 also involves considerable distributional impacts. Some of these are connected to tax funding, including infrastructure costs and user costs of the project, as well as the induced distortion in the tax system. Other distributional impacts relate to user benefits and indirect impacts, building further on the related non-monetized analyses.

Overall, the infrastructure project involves a redistribution to actual and potential users of emergency and preparedness services from taxpayers and receivers of welfare arrangements that alternatively would have been funded. Furthermore, Rakel G2 may contribute to improved mobile coverage in rural areas. If the project is funded by loans rather than grants, it will imply a redistribution to the current population from the future population.

Methodology and Interviewees

5.1.3 Reference Scenario

We compare the expected user benefit in Rakel G2 to the expected user benefit in a reference scenario. The reference scenario is a hypothetical scenario where no investments are made in a modernized network for public safety workers. In the reference scenario, emergency organizations are instead left to purchase communication services from public network providers in an uncoordinated fashion. Over time, this approach will make it harder to maintain a common operating model and common services across emergency organizations.

We have illustrated the reference scenario in Figure 5.1. A further description of the Rakel G2 and reference scenarios in connection to user benefit is given in subchapter 5.2.

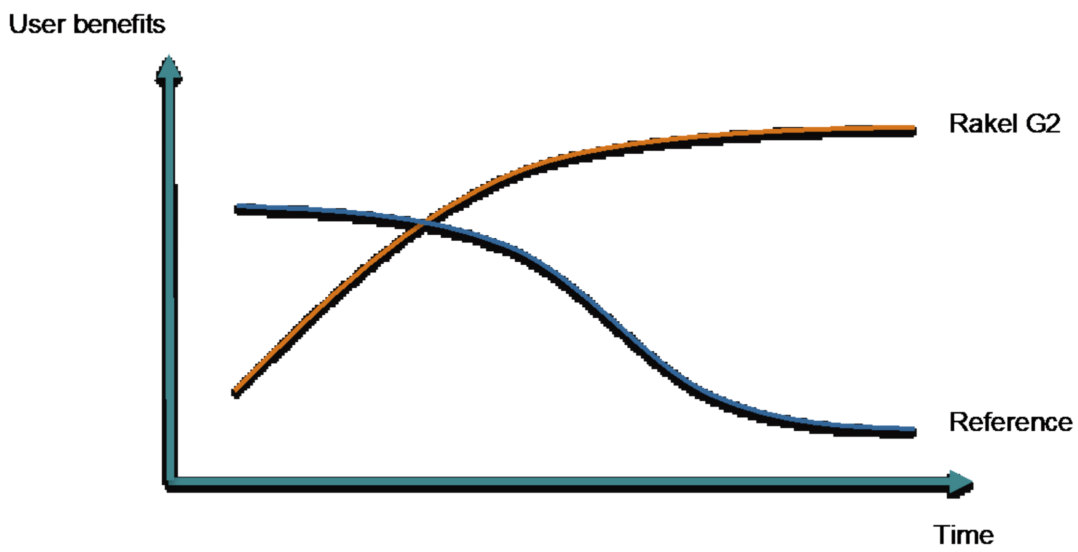


Figure 5.1: Rakel G2 and reference scenario comparison

5.1.4 Information Collection on Impacts External to the Infrastructure Project

Information sources in our study of impacts external to Rakel G2 are interviews and the reference group, in addition to investigation reports and public appraisal methodology.

5.1.4.1 *Interviews*

Our interview guidance is reported in appendix section A.1.2, while our informants are listed in appendix section 0. This includes interviews with future users of Rakel G2 and experts on PPDR networks' social significance.

5.1.4.2 *Investigation Reports*

We have reviewed other investigation reports on construction of PPDR networks, particularly Kvalbein, Lie and Holmen (2017) and Agenda Kaupang (2021).

5.1.4.3 *Reference Group*

A reference group was held in relation to this subproject with three Norwegian participants and one Swedish participant (cf. appendix section A.2.2). We also received feedback from the council responsible for the investment project (cf. appendix section A.2.1). For more details, we refer to subsection 2.2.2.5 and subsection 2.2.2.4, respectively.

5.1.4.4 *Public Appraisal Methodology*

We utilize public appraisal methodology in each of the analyses with some adaptions. Relevant documents include project cost methodology in the user cost analysis (Finansdepartementet 2019b) and non-monetized appraisal methodology in the assessment of user benefits and indirect impacts (Direktoratet for økonomistyring 2021), as well as methodology for appraisal of marginal costs of public funds (Trafikverket 2021 and Wangsness, Holmen and Hansen 2022) and distributional impacts (Transport and Infrastructure Council 2016, Department for Transport 2020, Direktoratet for økonomistyring 2021, Trafikverket 2021 and Wangsness, Holmen and Hansen 2022).

5.1.5 Direct Non-Monetized User Impacts

In our analysis of user benefits of Rakel G2, we focus on direct user benefits for providers of emergency services (e.g., ambulance services, fire services, sea rescue services and the police) rather than addressing the benefits of increased quality of their services directly. Obviously, the direct user benefits for these services are not important in a vacuum, but because they affect their ability to serve (i.e. private persons, public institutions, businesses and nonprofits). Yet, as these causal linkages are complex and opaque, we will focus on the direct user attributes as proxies for the ultimate benefits of increased service quality.

User impacts beyond costs are non-monetized. In our assessment of non-monetized user impacts, we make use of multi-criteria analysis. This method corresponds to ranking of aspects of user benefits for four user groups along an ordinal scale, known as Likert's scale. These groups are police, fire and ambulance services, SAR including coast guard, and the defense forces. Next, these aspects are weighted in accordance with these users' preferences. We also depict the resulting score if we apply a subjective weighting of each group of informants with double weight on the police compared to the three other groups due to a considerably higher number of users. The exact weighting can still be considered somewhat arbitrary, but it allows us to make a rough comparison of the overall importance of the user benefit.

We have compared the user impacts of Rakel G2 to a reference scenario. Based on our assessment, we have evaluated each of the user aspects between the scenarios. This type of relative multi-criteria analysis is known as the plus/minus method (see section 3.4.8 in Direktoratet for økonomistyring 2021).

Interviews with key stakeholders in Rakel G2 have been used to assess the direct non-monetized user impacts. In addition, we have benchmarked our results to similar mappings (Kvalbein, Lie and Holmen 2017 and Agenda Kaupang 2021).

The intention behind the user interviews was to get a better understanding of what is important to the different stakeholders regarding Rakel G2, and especially how the different users of Rakel prioritize the different benefits of a second generation PPDR network. We asked the interviewees to rate the importance of different benefits of Rakel G2, using a Likert scale. We apply the Likert scale with a range from one to five, where one represents a benefit that is not important and five represents a very important benefit. It is worth noting that it was challenging for many of the interviewees to quantify the importance of the different benefits, but they were nevertheless able to communicate important priorities.

5.1.6 User Costs

Our user costs analysis is a "gross" analysis, in the sense that we do not consider the reference scenario. Beyond this, we follow standard methodology for project cost analysis (Finansdepartementet 2019a and 2019b). User cost analysis is not a mandatory part of the Norwegian quality assurance scheme, but it is implicitly handled in the cost-benefit analysis associated with the early quality assurance stage (KS1).

The analysis of user costs in chapter 5.3 is based on three data sources. First, we pulled the number of subscribers from the Nova project model and allocated subscriptions to terminal types. Second, we discussed the topic with suppliers of PPDR terminals to obtain a better understanding of price levels for different terminals. Third, we discussed integration costs with user experts, where SOS Alarm was especially useful. In addition, we account for the subscription costs, which constitute income in the project cost model.

5.1.7 Indirect Non-Monetized Impacts

Indirect non-monetized impacts of Rakel G2 are considered qualitatively against a reference scenario. Again, we lean on the guidance from Direktoratet for økonomistyring (2021). The indirect impacts concern spectrum utilization, cooperation facilitation of the production economy, knowledge generation, security and environmental challenges. In the following, we provide an overview of the indirect and non-monetized impacts of Rakel G2.

Interviews with experts on the importance of PPDR networks have provided us with valuable input. We have also considered similar analyses in other investigations reports (see subchapter 7.2 in Kvalbein, Lie and Holmen 2017 and subchapter 10.4 in Agenda Kaupang 2021).

5.1.8 Marginal Costs of Public Funds

Marginal costs of public funds constitute distortive efficiency costs related to tax funding, reflecting that production is reallocated in a way that counteracts the populations' preferences. Marginal costs of public funds reflect that a negative impact on public funds induces a reduction in welfare provision or an increase in taxes in the short or the long run.

Estimates for marginal costs of public funds vary considerably across countries (cf. Holmen and Hansen 2023). In Sweden, the marginal costs of public funds are estimated to 30 percent of public funds (Trafikverket 2021), contra 20 percent in Norway (Finansdepartementet 2021b) and 10 percent in Denmark (Transportministeriet 2015), while there is no monetization due to parameter uncertainty in Australia, the Netherlands, New Zealand and the United Kingdom (Wangsness, Holmen and Hansen 2022). In this study, we will stick with the Swedish methodology and be content with pointing out the uncertainty regarding the magnitude of these costs.

In case of Rakel G2, we will estimate the net marginal costs of public funds related to funding of the infrastructure project, as well as the gross marginal costs of public funds related to the user costs (where we do not consider user costs in the reference scenario).

In addition, we discuss efficiency costs related to public funding related to non-monetized impacts. This includes loss of income from spectrum auctions for the frequencies applied for Rakel G2, but also other distortions induced by other indirect impacts.

5.1.9 Distributional Considerations

In addition to efficiency impacts on social welfare, construction of Rakel G2 affects the distribution between groups in society. Distribution effects regard the distribution of gains and costs derived from a project's direct gains and cost allocations. Metaphorically speaking, one may say that while efficiency impacts concern the size of the value cake, distributional impacts concern the distribution of the value cake slices.

Distributional impact analysis constitutes a standard part of economic appraisal. Most countries with somewhat developed appraisal practices at national or sectorial level have some sort of framework for distributional analysis. Yet, these frameworks are less harmonized and complete than the framework for cost-benefit analysis (Wangsness, Holmen and Hansen 2022). The Australian and British appraisal guidelines stand out as relatively advanced on distributional analysis (cf., Transport and Infrastructure Council 2016 and Department for Transport 2020, respectively). In our analysis, we have also considered the Norwegian and Swedish guidelines (cf., subchapter 3.7 in Direktoratet for økonomistyring 2021 and chapter 17 in Trafikverket 2021, respectively).

Essential in all the mentioned appraisal guidelines is to assess who is likely to be affected by each cost, benefit and other transaction element that the intervention generates. All the guidelines recommend doing a separate analysis of distribution effects, rather than integrating it with a given weight in the calculation of cost-benefit analysis. Moreover, distributional weights would make the analysis less transparent and comparable, as well as involving political judgement. The assessment of distribution effects will be closely related to the main analysis. One will examine the distribution effects of the benefits and costs identified there.

Furthermore, to determine essential distribution effects, all guidelines suggest two initial steps: (1) **What** – identifying what types of impact have distribution effects and (2) **Who** – essential affected groups.

To discuss how these impacts affect distribution across groups, the analysis is structured as recommended by the Australian guidelines – with four dimensions. These four dimensions are illustrated in Figure 5.2 and consist of the horizontal dimension (i.e., impacts on different groups of stakeholders), the vertical dimension (i.e., redistribution between weaker groups), the spatial dimension (i.e., uneven distributional impacts over space) and the generational dimension (i.e., timing of the financial burden). The results will be compared to the reference scenario and not to the status quo.

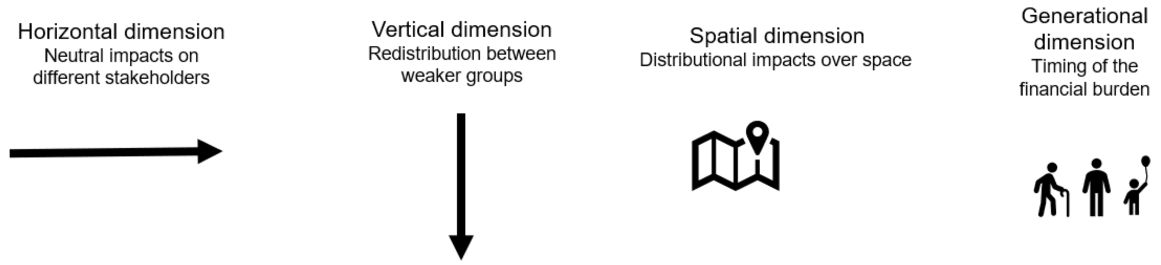


Figure 5.2: Discussion categories for distributional effects

The interviews have provided valuable input to our assessment of distributional impacts. In addition, we have considered distributional analysis in earlier assessments of PPDR networks (see in particular chapter 9 in Kvalbein, Lie, Holmen 2017).

In our assessment, we provide a brief, systematic overview of the distributional impacts. On the one hand, distributional impacts associated with the infrastructure and user costs associated with Rakel G2 relate to our monetized assessment and tax funding. On the other hand, distributional impacts associated with user benefits and indirect impacts of Rakel G2 will build further on the non-monetized analyses.

5.2 Direct Non-Monetized User Impacts

Public safety users need modern communication services that are reliable, secure and easy to use wherever they operate and in all situations. In this section, we break these user requirements down into different aspects of user benefits. We describe how we believe these aspects will differ in the Rakel G2 scenario versus the reference scenario. We then use insights from interviews with different user groups to describe how Rakel users prioritize these benefits. Finally, we describe relative differences in user benefits in the two scenarios.

5.2.1 Aspects of User Benefits

The utility of a communication system is a function of many different properties. These can be technical properties of the communication network, or organizational properties such as limitations to the number of users. Here, we break down user benefit in seven different system properties where we believe there are significant differences between the Rakel G2 scenario and the reference scenario. These properties are described in Table 5.3.

Table 5.3: Properties of a communication system

Benefit	Description
Coverage	Radio network coverage including indoor coverage and coverage in remote areas
Robustness	The ability to maintain a functional service in the face of external stress, failures or unforeseen events
Security	The ability to maintain the availability, integrity and confidentiality of system information, user data, and metadata
Capacity	Total network capacity available for PPDR end users, which may depend on priority in public mobile network
Interoperability	The ability to seamlessly communicate and collaborate with Rakel users in other organizations, as well as with the general public
Functionality	Broadband data and special functions required by PPDR users, including MC push-to-talk / MC video Direct Mode Operations / 5G side link Access to OTT services including Internet-based services
User experience	Sound quality, terminals, ease of use

While the properties above are all tied to the technical implementation of Rakel G2, we also note that some of them have dependencies to systems discussed in section 5.3 that are not included in the Nova cost model. In particular, functionality in Rakel G2 will depend on the availability of terminal support. Also the user experience is not only dependent on the Rakel G2 network, but also on terminals and the overall collaboration platform that is built on top of the network, as illustrated in Figure 5.3.

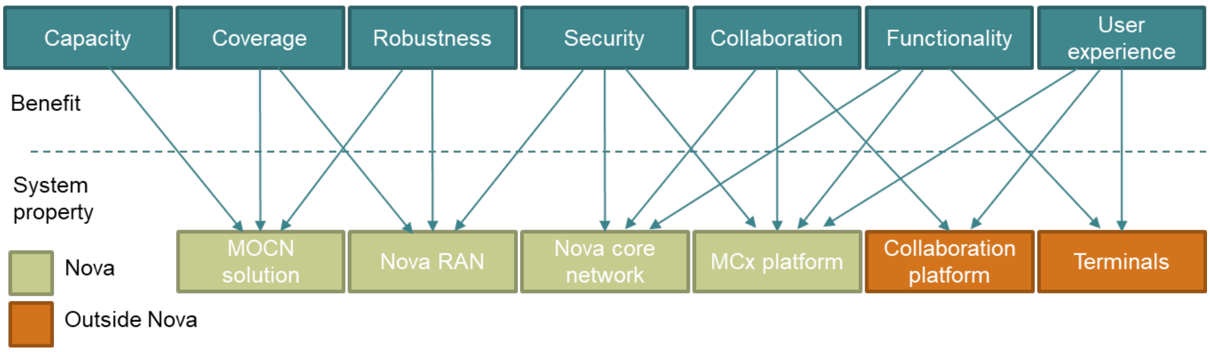


Figure 5.3: Rakel benefits and system properties

5.2.2 User Benefits in Rakel G2 and Reference Scenarios

Rakel G2 is still in a planning stage, and several aspects related to the services that will be available, and the timing of these, are still unclear. When evaluating and comparing user benefits in the two scenarios, we must make several assumptions about network and system properties. Table 5.4 below describes the most important assumptions we make for the comparison.

Table 5.4: Rakel G2 and reference scenario assumptions

Property	Rakel G2 scenario assumptions	Reference scenario assumptions
Network use and MOCN	MOCN solution with seamless handover established before first users are migrated Rules in place that make commercial capacity available in a seamless manner	Rakel G1 will be used for voice beyond 2030 Maintenance increasingly difficult Users make separate agreements for mobile broadband.
Coverage	Nova RAN gradually established Improved coverage beyond existing commercial coverage	Rakel G1 coverage as today Mobile broadband coverage driven by competition between MNOs Coverage gaps remain in remote areas.
Robustness	Improved backup power and backhaul in Nova Parallel use of Nova RAN and commercial RAN	Robustness in mobile broadband driven by competition and regulatory requirements, no national roaming.
Security	Use of commercial network capacity for Rakel G2 users with an acceptable security level	Security regulated through SLA Special requests may be costly or difficult
Capacity	Seamless use of Nova + MOCN capacity Priority in MOCN partner network	Access to full public network capacity Priority may be an option
Interoperability	MSB takes a coordinating role to implement common support systems and operational procedures that enable inter-organizational collaboration over Rakel G2.	Rakel G1 gives interoperability for voice early, but over time extra investments are needed Inter-organizational collaboration based on mobile data implemented as a third-party application.
Functionality	MCPTT and later mobile data is implemented as services in Rakel G2 early in the build phase.	PTT only available through Rakel G1 Missing support for DMO, functionality evolves
User experience	Common implementation of voice Common terminal approval process	UX decided by individual agreements

5.2.3 Respondent Weighting of Benefits

Table 5.5 below shows the weighting of Rakel G2 benefits on a Likert scale of 1 to 5. We underline that the interviews were qualitative and that the final scores have been set by the project team based on our overall assessment of the input. Both the police and the fire/ambulance services named robustness and functionality as very important benefits of Rakel G2. Battery time, MOCN and DMO functionality were named as their highest priorities. Both of these user groups also mentioned the importance of coverage, but coverage was not as important for these groups as for search and rescue (SAR) users. The SAR users including the coast guard emphasized that many of their operations happen in remote areas and often far out at sea, and consequently good coverage is the most important attribute for these users. A concern which was raised by SAR was that the coverage of Rakel G2 could be inferior to Rakel G1 as higher frequency bands may be used.

It is worth noting that SAR users do not mention security among their highest priorities. Several respondents say that they do not transmit very sensitive data or have very sensitive conversations over the Rakel network. Security was a bigger concern for the three other user groups, especially for the police and defense, as they more often communicate sensitive information.

Interoperability, meaning the ability to use Rakel G2 together with other systems and to communicate across different user groups, was of great importance to many of the user groups. The reasoning behind this was the fact that many of the users have common operations where it is often important to be able to communicate with users of Rakel in other organizations. An example of this is the police and ambulance service needing to communicate on many occasions, such as for example during traffic accidents.

Table 5.5: Respondent weighting of benefits

Benefit	Police	Fire and ambulance	SAR including coast guard	Defense
Coverage	4	4	5	3
Robustness	5	5	4	4
Security	4	3	2	4
Capacity	3	3	3	2
Interoperability	4	4	3	3
Functionality	5	5	4	2
User experience	4	4	4	4

Table 5.6 below shows that robustness is the overall most important attribute of Rakel G2, based on the respondents weighting of benefits, where the police's weighting counts double. Many of the interviewees mentioned that robustness is so important because they have to trust that the network is always working, and that downtime is as low as possible. It is for example crucial that the mobile network is working when there is a large crisis. Many of the users mentioned that the robustness of todays' Rakel network is good, and that it is very important that Rakel G2 is just as robust.

Functionality and user experience constitute the second and third most important attributes. The functionality attribute includes functions such as DMO and video, which many users emphasize the importance of. User experience is closely related to these functions, as it is important that all these kinds of functions are easy and intuitive to use. It is also important for many users to have easy-to-use terminals.

Security and capacity have the overall lowest score. The reasoning behind security scoring low is largely because many of the users do not communicate sensitive information as already discussed. Capacity has the lowest overall score, but some users note that capacity can be important during large events where many Rakel users are using the network at the same time. Capacity could become a bigger problem in Rakel G2 than in Rakel G1, as more videos and pictures are expected.

Table 5.6: Weighted sums of respondents' benefits

Benefit	Weighted sum	Comment
Robustness	23	Scores high with all user groups, availability during crises, impacts operational models
Functionality	21	DMO, video, calling, collaboration
User experience	20	Voice quality, terminal ecosystem
Coverage	20	Rural including sea coverage, indoor, relay extensions
Interoperability	18	Common platform increases quality
Security	17	Diverse requirements
Capacity	14	Required for large events, may require priority

5.2.4 User Benefits in Rakel G2 versus Reference Scenario

Table 5.7 shows a relative comparison of the project's assessment of expected user benefits in the Rakel G2 and reference scenarios. We use a scale from '--' to '++', where '--' indicates a strong reduction in benefit and '++' indicates a strong increase in benefit. We argue that interoperability is the attribute with the highest expected improvement from the reference scenario to Rakel G2. Improved interoperability is a main benefit of a common network platform and was also highlighted as a main benefit in an evaluation of the Norwegian emergency network (Agenda Kaupang 2021).

Without a common network solution, emergency organizations are likely to select different technical solutions, which over time will limit the ability to communicate seamlessly and develop common operational procedures. This assessment assumes common platforms and coordination of operational procedures across user organizations, which go beyond the implementation of the network itself.

We expect there to be improvements in the robustness, user experience, coverage, security and capacity of Rakel G2 compared to the reference scenario. In terms of capacity, it is important to note that it will likely be possible to get priority in commercial mobile networks. This constitutes an advantage with Rakel G2. The improvements in robustness and capacity both require a seamless MOCN solution. The only attribute where we do not expect an improvement compared to the reference scenario is functionality. On the one hand, a common network may make it easier to create a handset standard that supports DMO, but on the other hand, a dedicated Rakel G2 network may not have the agility and resources to develop new services at the same pace as commercial mobile networks.

Table 5.7: User benefits in Rakel G2 versus reference scenario

Benefit	Weight	Reference scenario	Rakel G2 scenario	Description
Robustness	23	0	+	Strong dependence on seamless MOCN solution
Functionality	21	0	0	DMO, calling, general service development in MNO
User experience	20	0	+	Coordination across user organizations
Coverage	20	0	+	Assumes priority of network build-out in uncovered regions
Interoperability	18	0	++	Assumes common operational model, common security framework, common service platform and applications
Security	17	0	+	Infrastructure control, common framework, operations
Capacity	14	0	+	Assumes priority + seamless MOCN solution

5.3 User Cost Analysis

From a user perspective, subscription fees are the most important cost element associated with Rakel G2, and the Project Base Estimate includes BSEK 19.2 in subscription revenue over 20 years (measured in fixed 2024-prices).

However, Rakel G2 users will incur other costs in addition to subscription fees. First, Rakel G2 users will have to pay for terminals and in some cases the installation of terminals. Second, there will be costs for integrating Rakel G2 services with the users' applications and IT systems. This chapter estimates terminal and integration costs for Rakel G2 users.

5.3.1 Terminals

In total, the Nova Model has ca. 365,000 subscriptions split between Base, Data (Mobile Broadband) and internet of things (IoT) subscriptions. Figure 5.*4* shows our estimate for initial costs of terminals associated with these subscriptions.

Base subscriptions include two main types of terminals – regular handsets and mounted terminals in vehicles, vessels and aircraft. We are confident that most Base subscribers will use a regular handset and estimate a cost of SEK 6,000 excluding VAT per handset. In addition, there are about 2,600 police vehicles and approximately 1,550 ambulances in Sweden. We have included 5,000 mounted terminals among base subscribers for a cost of SEK 16,000, which includes installation.

For Data/Mobile Broadband usage, we believe that most subscribers will use the service on their regular handset, but we have included 5,000 dedicated broadband modems at a price of SEK 2,000 each.

With regards to IoT devices, the main cost issue is whether the device has a camera or not. We believe that most devices will be low-cost devices without a camera, but we have included 10,000 camera devices at a cost of SEK 2,800 each.

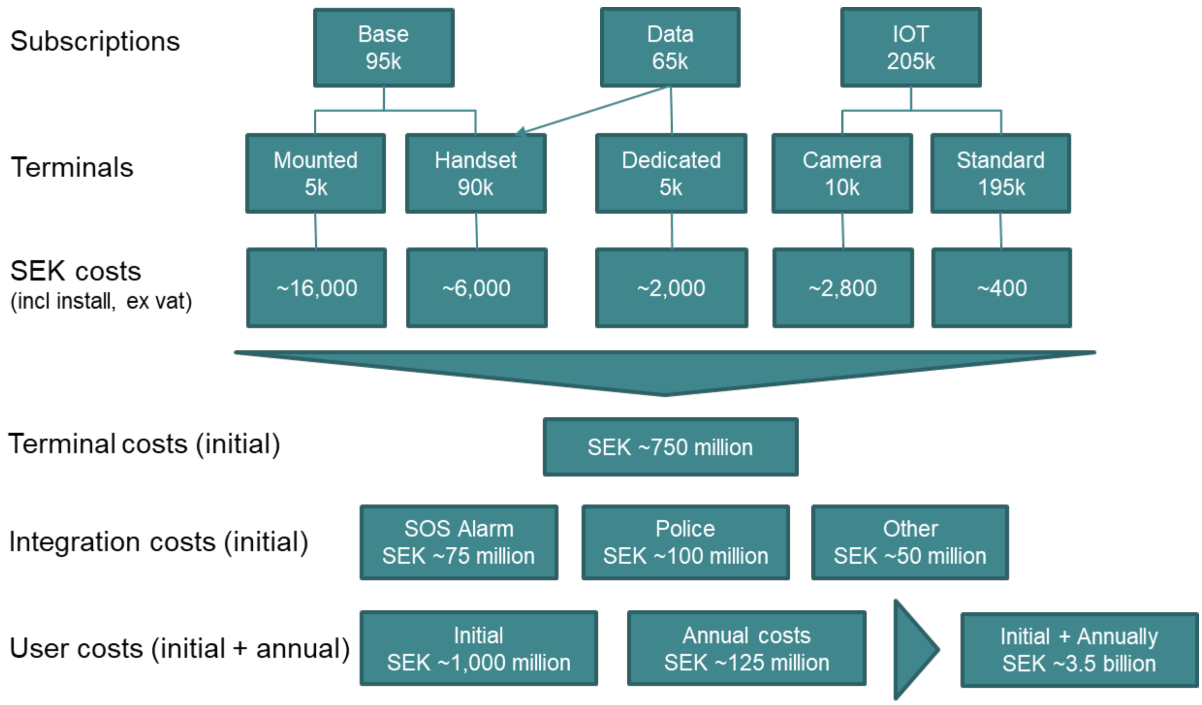


Figure 5.4: Terminal costs and integration costs

In total, we estimate initial terminal costs to be around MSEK 750. There will be additional terminal costs due to losses, new requirements and general wear and tear. We have used an average terminal lifetime of 7.5 years, which means that around 15 percent of terminals will be replaced each year for an annual cost of around MSEK 100.

5.3.2 Integration Costs

Many users will integrate Rakel G2 services with their own systems and applications. We interviewed experts at SOS Alarm that operates the emergency number 112 on behalf of Swedish municipalities and regions. They estimated their own integration costs for Rakel G2 to be between MSEK 50 and 100, which underlines the importance of enough time to plan and execute the implementation.

We do not have similar estimates from other user groups, but we know that the Swedish police have important IT systems that need Rakel G2 integration. We estimate an integration cost of roughly MSEK 100for the police, MSEK 75 for SOS Alarm and MSEK 50for other users, Thus, the total initial integration cost amounts to about MSEK 225. Also, we have included recurring integration costs at 10 percent of initial costs which adds up to MSEK 22.5 per year. We assume that a device management system is included in the Nova project cost model. Hence, we have not included this in the user cost estimate.

5.3.3 Lifetime Costs

In total, we estimate initial terminal and integration costs to be around BSEK 1 . This estimate does not include VAT, procurement or training costs. Annual costs are around MSEK 125 per year or BSEK 2.5 over a 20-year span. This means that estimated user costs are BSEK 3.5when both initial and recurring costs are included.

Please note that this is the gross user costs of Rakel G2. The net user costs will be lower, as there also will be some user costs in the reference scenario.

5.3.4 User Subscription Costs

In addition to the user costs accounted for above, the users will have a total gross subscription cost of BSEK 16.334, confer section 2.3.6. There will also be subscription costs in an alternative scenario in terms of commercial subscriptions and possibly longer Rakel G1 subscriptions. However, additional costs associated with private and Rakel G1 subscriptions in the reference scenario are likely to be somewhat lower than the subscription costs associated with Rakel G2, such that there is a net subscription user cost. Thus, we expect considerable net user costs associated with subscription fees, which should have been subtracted from the subscription revenues for the infrastructure project in a cost-benefit analysis.

5.4 Indirect Non-Monetized Impacts

Some of the impacts that receive most attention in the political debate on realization of the PPDR network are indirect impacts. Indirect impacts are typically non-monetized. These include impacts concerning spectrum utilization, cooperation facilitation of the production economy, knowledge generation, security and environmental challenges. In the following, we provide an overview of the indirect and non-monetized impacts of Rakel G2.

5.4.1 Impacts on Radio Spectrum Utilization

The realization of Rakel G2 will have several impacts on spectrum utilization. First and foremost, the frequencies reserved for Rakel G2 could alternatively have been used for commercial purposes. Moreover, the spectrum applied by Rakel G2 could have been sold to commercial infrastructure companies within telecommunication through auctions, reflecting its commercial value. This would have generated considerable public income with associated efficiency gains in the tax system. Some of our informants claim that the process towards the dedicated PPDR network of Rakel G2 has affected the Swedish commercial telecom industry negatively. We will not exaggerate this impact on the industry’s development, but it is at least clear that the frequencies dedicated to Rakel G2 entail a substantial alternative commercial value.

Rakel G2 will also affect the mobile coverage across Sweden. The Nova project will deploy 400 new mobile sites, which will be available for commercial networks. Over time, this is likely to increase commercial coverage in areas that are poorly served today, typically in rural areas.

Rakel G2 may also affect the spectrum utilization indirectly, by affecting the competition. If Rakel G2 strengthens Telia’s competitive advantage in relation to its competitors, so that the competition in the market for telecommunication infrastructure weakens, it may hamper spectrum utilization in the long run to some extent.

5.4.2 Cooperation Impacts

In general, Rakel G1 does to some extent facilitate cooperation benefits for emergency and preparedness organizations. Whereas such benefits will be enhanced by the new opportunity that follows with Rakel G2, they are likely to diminish if the PPDR communication gradually becomes uncoordinated in commercial networks with organization-specific solutions. Although cooperation may continue to function well in some instances, there will be a considerable risk communication becomes more exposed to frictions in others.

Realization of Rakel G2 can help foster an interagency culture that supports communication both internally and between emergency services in emergency incidents. A benefit of better communication and cooperation between the emergency services during emergency incidents through Rakel G2 would be an enhancement of interagency culture, which in turn can improve communication and cooperation in real life. The emergency services will become better at interacting in day-to-day situations. Such a development of an interagency culture will probably also strengthen the emergency agencies' abilities to coordinate when they need to handle extraordinary emergency situations such as natural disaster, major fire, terrorism or infrastructure-related accidents.

Unlike the situation in Finland, we are not aware of any plans for the Swedish Armed Forces to use Rakel G2. But Nordic Armed Forces are investigating and testing 5G networks that Rakel G2 will be based upon. As such, there may be opportunities for some cooperation and sharing of insights between civil PPDR authorities and the Armed Forces.

International cooperation constitutes another area where cooperative effects come into play. Facilitating international cooperation is important for dealing with larger incidents and incidents in border areas. Rakel G2 may facilitate communication and cooperation with Norwegian, Finnish and Danish emergency services. Thereby, the emergency services may collaborate more effectively when facing such incidents. These benefits do however depend on the PPDR solution chosen by the other countries and the development of technologies for seamless integration between dedicated PPDR networks and commercial networks.

In addition, realization of Rakel G2 will affect the cooperation between PPDR organizations and other actors handling emergencies. As long as the new Rakel G2 terminals are able to switch between Rakel G2 and commercial providers, they will also provide easy access to other relevant actors during emergencies. Providing such access will increase the number of resources available for handling emergencies and thus increase the emergency services' effectiveness in emergency incidents.

5.4.3 Economic Impacts

Many parts of the Swedish economy may be affected by the development and operation of Rakel G2. In the following, we will review impacts on the economy, in particular competition and industry building. The key markets affected by the infrastructure and the system integration project are the market for telecommunication services, the markets for telecommunication infrastructure and equipment, and the market for telecommunication construction.

Initially, Rakel G2 will provide substantial impulses in the market for telecommunication construction, as the demand from Rakel G2 for telecommunication construction will be substantial. The telecommunication construction market is to a large extent European, which probably will ensure ample supply during the construction phase. However, for the Rakel G2 development, construction workers are largely expected to be domestically recruited. Still, regarding site construction our informants expected no major capacity constraints.

The use of domestic firms and domestic labor may be favorable from a national security perspective. In the telecommunication construction market, no distortive competition impacts are expected as there are many suppliers available and work can easily be divided by regions and in time between suppliers.

Impacts on the market for telecommunication services occur once the project has reached the operational phase. When developed, Rakel G2 will operate in tandem with commercial networks. Rakel G2 will depend on the co-existence of commercial and PPDR networks – especially due to the Multi-Operator Core Networks (MOCN) solution. Leasing space in Rakel G2 towers can also affect local competitive conditions.

One commercial telecom operator will be awarded the responsibility for Rakel G2's utilization of electronic communication commercial infrastructure, when dedicated base stations are unavailable (i.e., the MOCN functionality is utilized). This operator may benefit from the integration of systems, both due to the technological advances of a successful MOCN development and during the operation phase. It is reasonable to assume that the PPDR's commercial partner will be a major national telecom operator (e.g., the national largest Swedish telecommunication operator, Telia). This implies a risk of an unfair competitive and technological advantage in favor of Telia versus competitors. An informant suggests that all or a high number of active commercial operators should be allowed to supply capacity to the PPDR as part of the MOCN solution – in order to secure fair competition and provide superior capacity.

A successful Rakel G2, with a significantly higher number of users than today's system, can to some degree erode the market for some commercial operators. In practice, this may happen when an extended part of the Swedish police, fire and ambulance services and other PPDR users will apply Rakel G2 instead of commercial operators in an increasingly digitalized environment.

Informants see security risks and vulnerabilities related to the merger of commercial networks and the PPDR (e.g., use of the MOCN solution). In this respect, it is paramount to choose commercial partners with a strong commitment to security. Contracts between the PPDR and commercial partners should pay attention to enforcement of contractual obligations and regulations. Hence, in the choice of commercial partners there seems to be a trade-off between reducing security risk and avoiding unfair competitive advantages.

Interviews with industry experts did not indicate any significant risk of severe resource shortages due to the development of Rakel G2, which could hamper the development of commercial telecom services during the construction phase of Rakel G2. However, it may be reasonable to expect some inflationary effects on domestic resources.

Informants argue that a dedicated network like Rakel G2 is inferior to solutions based on existing commercial networks. If this observation is correct, Rakel G2 represents a loss in terms of cost-benefit compared to an alternative optimal solution.

Another market impacted by the investment and operation phase of Rakel G2 is the market for telecommunication infrastructure and equipment. Economic literature supports the notion that subsidies and provision of advantages to local manufacturers may induce efficiency gains through economics of scale and scope, technology developments and agglomeration synergies (e.g., technological manufacturing in the Asian tigers and health technology in Switzerland). These arguments are, however, often criticized for exaggerating the gains from supporting local economic clusters and that the arguments are motivated by lobbyism from special interest groups (see for instance Krugman, Obstfeld and Melitz 2022).

Informants see Rakel G2 as a unique opportunity for the Swedish technology cluster to develop innovative concepts and technologies by merging the knowhow of the telecommunication industry and the “blue light” institutions. Swedish society at large – and the Swedish technology cluster in particular – may benefit from a formalization of knowledge exchange between commercial parties and “blue light” institutions. However, informants fear that international outsourcing and competetion law limitations will hamper domestic cooperation, limit knowledge spillovers and reduce knowledge accumulation.

Informants see an increased risk of failure of Rakel G2 if the project is too dependent on only a few suppliers.

5.4.4 Knowledge Generating Impacts

Per today, the technology for the integration of commercial telecommunication networks and PPDR networks is not fully developed. In the context of Rakel G2, such an integration is vital to get the MOCN functionality up and running (confer subsection 2.1.1.5). To achieve satisfactory network integration, the transition of traffic should be both frictionless and secure. Thus, many other national operators of PPDR networks, as well as other emergency networks, would be interested in learning outcomes on – and benefit from – an integration technology, developed in connection with Rakel G2. Moreover, a common Rakel G2-platform could help kick-start important developments in PPDR methodologies and new ways of working, especially with regards to data usage and inter-agency cooperation. Note that this impact largely takes place beyond the Swedish borders. It should therefore be left unaccounted for in a cost-benefit assessment that only applies to Sweden.

Use of Rakel G2 will also involve some technology-specific training costs and learning outcomes. Some of this learning will be transferable to other contexts. Moreover, it may to some extent improve the ability to adopt new technologies for the coworkers involved in the concerned entities and value chains.

5.4.5 Security Impacts

Several arguments have been proposed on security, largely in the sense that Rakel G2 provides higher security than a reference scenario, where the PPDR communication gradually mitigates from Rakel G1 to uncoordinated PPDR communication in commercial networks. These are presented in the following.

Some security advantages of Rakel G2 are related to public ownership. The Swedish government has chosen a model for Rakel G2 where the dedicated network will be owned by the government. One advantage of public ownership is that the government will be able to choose technical solutions. Thus, the government may choose solutions that reduce surfaces hackers can attack and gain access through. To some extent, the degree of security inter alia through the MOCN solution will come at the expense of other features of the network, such as functionality. A dedicated network may also be seen as beneficial from the Armed Forces’ point of view, although they are likely to investigate and use a number of different communications systems.

Another advantage of government ownership is that it reduces the risk of acquisition by a potentially hostile actor. Even if the authorities can stop acquisition of critical infrastructure of importance for national security and thereby impede majority purchase, government ownership will give more control and insights into implementation of the network technology. There will, however, always be a risk whenever Rakel G2 partly depends on national roaming with commercial providers.

Recently, geopolitical risks have increased. Rakel G2 may in the future, to a larger extent than originally planned, play a role for national security. The required reliability of a state of the art PPDR must be significantly higher than the reliability of commercial networks in order to play a role for national security. This suggests that domestic suppliers or allied suppliers (e.g., Ericsson) should be preferred to other foreign (e.g., Chinese) suppliers, despite the negative effect on the competitive environment and the cost of developing Rakel G2.

Protection against hacking is important both to protect sensitive information against intelligence gathering and snooping, and to protect control against takeover of ICT equipment such as phone and internet of things, and denial-of-service attacks. Deployment of a new national communication network for emergency services that is owned by the government provides the opportunity to make design choices that protect against hacking. A state operator can reduce the attack surfaces by offering fewer services than commercial providers. One challenge with the current Rakel network is the lack of sufficient control over membership in the different voice channels. Lack of control may also make it easier for personnel with access to the network to listen in on conversations they do not have any professional need to listen to. This may be improved in Rakel G2.

To some extent, there will be a trade-off between more public control and improved protection of personal security. Rakel G2 may also enhance public control of the emergency services. Privacy to increase personnel security is good, but privacy to avoid public control of the emergency services is not desirable. Before Rakel was deployed the media could listen in on the police radio and report what the police did in real time. Now, the media must wait until the police makes an operation public. This is negative for public control of the emergency services.

Personnel security may also be better protected through a dedicated PPDR network, such as Rakel G2. First, Rakel G2 will increase personnel security by protecting the integrity of information that is communicated through the network during an operation. It is especially important for the police that criminal elements do not have access to the communication during police operations. Second, increased user-friendliness of Rakel G2 will also make it easier for the emergency personnel to focus on the tasks and thus increase their personal security. Third and finally, a more secure network can increase privacy of the personnel involved in an operation. Police officers, for example, can be pursued by organized criminals after their participation in police operations against such organizations. Improved privacy would protect them against such persecution.

Rakel G2 may also affect the population's perceived security and feeling of safety. The general Swedish population has limited knowledge of Rakel. Hence, it is unrealistic that the deployment of Rakel G2 will directly influence perceived security among ordinary people. Rakel G2 should, however, increase the quality of emergency services by making it possible to deploy the right resources at the incident site more quickly. By increasing the quality of emergency services and the resulting positive media attention, perceived security among ordinary people may increase. However, large public procurements with budget overruns often generate negative media attention. Such negative media attention around the realization of the PPDR network may reduce perceived security in the general public.

5.4.6 Environmental Impacts

Overall, the environmental impact of Rakel G2 appears to be modest.

Much of the environmental impacts occur in relation to the infrastructure investments. In particular, environmental impacts, as part of the construction phase of Rakel 2, include negative landscape impacts (and to a lesser extent township impacts) near construction sites, particularly in rural and vulnerable areas (e.g., in national parks, including legal issues). Informants see a trade-off between installing new towers to increase coverage versus the preservation of landscapes in protected nature reserves.

Most infrastructure investments cause climate gas emissions issues – which is hard to mitigate. Rakel G2 is no exception. The development strategy of Rakel G2 should include plans to minimize climate gas emissions during the investment phase. Informants see limited impact in terms of local pollution (i.e., air, water and soil). Rakel G2 probably has only insignificant impacts on biodiversity and animal welfare.

The environmental impacts connected to running operations are primarily greenhouse gas emissions though energy consumption. Despite access to green energy and the EU's quota system, this energy consumption will imply some emissions on the margin. This is because alternatively, green energy could have displaced fossil energy sources elsewhere in the energy system, and because the European quota system is not free of energy trade to neighboring regions and sectors outside the system, nor does it entail a fixed emission cap in the long run.

Beyond climate gas emissions, the environmental impacts related to running operations will be negligible.

5.5 Marginal Costs of Public Funds

We will now turn to marginal costs of public funds, which represent the distortions through the tax system induced by changes in tax funding. This involves both monetized and non-monetized impact.

5.5.1 Monetized Marginal Costs of Public Funds

Our baseline estimate for the infrastructure project of Rakel G2 implies marginal costs of public funds of approximately BSEK 3.84, applying Swedish appraisal methodology (confer Trafikverket 2021). This corresponds to 30 percent of the revenue effect on public accounts. Note that the network subscription revenues are included in these figures.

By the same token, we approximate the gross taefficiency impact related to tax funding of user costs excluding user subscriptions costs to BSEK 1.05. Note that this is only a gross estimate, as there would also be similar cost items in a reference scenario with uncoordinated emergency communication in the commercial electronic communication networks. Thus, the net impact will be lower.

5.5.2 Non-Monetized Marginal Costs of Public Funds

There will also be non-monetized funding efficiency costs related to non-monetized impacts that affect public finances. The largest non-monetized distortion costs are likely to be related to loss of income from spectrum auctions and net user costs related to network subscription costs (as the project revenues are included in the project cost estimate).

Indirect impacts will also have indirect and somewhat complex and counteracting impacts on public funds. These will often be related to utilization of economic capacity and competition, as well as gains from improved mobile coverage and security.

5.6 Distributional Considerations

Implementation of Rakel G2 will imply distributional impacts associated with the infrastructure and the users with related funding. In addition, there will be distributional impacts associated with both user benefits and indirect impacts.

In the following, we will provide an overview of the distributional considerations regarding Rakel G2. In this regard, we will distinguish between horizontal, vertical, spatial and intergenerational distributional impacts (cf. section 5.1.9).

5.6.1 Horizontal Dimension

The horizontal dimension of distributional impacts concerns impacts on different stakeholders that deviate from impartial treatment.

In the realization of Rakel G2, users of the network will experience user benefits, as elaborated on in subchapter 5.2. These benefits will in turn transfer to the people or organizations that the agencies actually serve in terms of perceived and realized security. They will also be relatively beneficial for those who are actually exposed or relatively likely to be exposed to emergency incidents, and thereby likely to be in need of emergency services. On the one hand, to the extent that the cooperation between and the competence within the emergency and preparedness agencies and other users improves, the benefits are likely to transfer to their users in a similar fashion. On the other hand, taxpayers and stakeholders affected by cuts in alternative public spending at the expense of the infrastructure and user funding related to Rakel G2 will experience negative impacts.

In addition, indirect efficiency impacts of Rakel G2 will involve horizontal distributional impacts beyond security and funding. Some of these, like spectrum utilization and impacts on competition and economic capacity, will also affect taxpayers and impact markets associated with construction and operation of Rakel G2. Knowledge on integration between commercial and PPDR electronic communication networks, through the realization of the MOCN solution, may benefit operators of PPDR networks and other actors aiming to provide frictionless and secure network integration.

5.6.2 Vertical Dimension

The vertical dimension of distributional impacts concerns impacts on stakeholders with different socio-economic starting points.

In context of Rakel G2, weaker groups may in some ways benefit more from the emergency and preparedness network than other groups. For instance, weaker groups with illnesses and disabilities will often be more in need of health services, while people in socially burdened areas will typically be more inclined to seek law enforcement.

As the rich contribute more to tax funding than the poor, funding of Rakel G2 will also imply a redistribution that benefits poorer parts of the population. On the other hand, public expenses, which to a relatively large extent benefit weaker groups, will be in danger of being cut as the public budgets shrink.

5.6.3 Spatial Dimension

The spatial dimension of distributional impacts concerns redistribution of values across space.

In the case of Rakel G2, the network will provide improved mobile coverage and emergency communication in rural areas. This means that users or potential users of emergency services in rural areas will benefit more as the services are improved and available. Furthermore, esthetical landscape deterioration and local pollution will typically induce more severe impacts on the population in areas with vulnerable nature or high population density. Besides, spatial distributional impacts on the telecommunication value chain will to some extent follow where the associated activities are located.

Next, the implementation of Rakel G2 will induce spatial distributional impacts through the tax system. In some sense, the project implies redistribution from regions contributing relatively much to national government funds to regions contributing relatively little. In addition, some emergency services are funded by local authorities, such as ambulance and fire services. As such services tend to have somewhat larger employment shares in rural areas than in urban areas, the tax burden associated with extra purchase costs for user equipment may be larger in these areas. Differences in local financial situations and priorities will also lead to geographical differences in the local tax burden associated with extra purchase costs for user equipment.

5.6.4 Intergenerational Dimension

The intergenerational dimension of distributional impacts concerns redistribution of values across time and generations.

In the case of Rakel G2, the intergenerational dimension primarily reflects the selection of funding options through loans or direct grants. In this regard, loan funding may imply that the total cost will increase compared to direct grants. At the same time, the public cashflow will be distributed over time and shifted towards future generations.

Environmental issues may also have intergenerational distribution impacts. Moreover, today's impacts on biodiversity, landscape, local population and greenhouse gas emissions may not only imply a loss of environmental value today, but also in the future. Besides, potential future mitigation measures will also imply some mitigation costs.

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A. Appendix: Information Collection

A.1 Subappendix: Interview Guides

A.1.1 Interview Guides for the Project Cost Analysis and Uncertainty Analysis

In the following, we render the interview guides for the project cost analysis and uncertainty analysis in chapter 2 and chapter 3, respectively. These guidelines cover economic expertise, emergency network users, governmental telecommunication operators, telecommunication construction companies, telecommunication infrastructure companies and telecommunication operators.

A.1.1.1 Interview Guides for Economic Expertise

The Institute of Transport Economics (TØI), Dovre Group and Analysys Mason are conducting quality assurance of an ongoing project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV). In this project, we will quality assure project cost estimates and funding options, the uncertainty analysis, the organization and governance setup, and include an analysis of non-monetized impacts and distributional considerations.

Regarding cost analysis, insights on economic appraisal analysis in Sweden, especially defining project span and adjusting cost components, are of interest. In addition, knowledge of any existence of general guidelines across the sector. In Norway, such guidelines are provided by the Norwegian Ministry of Finance (2021) and the Norwegian Government Agency for Financial Management (2018 now and soon 2023), with further specifications in sectorial guidelines.

In Sweden, we know that the Swedish Transport Administration (2023) developed a public appraisal guideline for the transportation sector. Differences between Norwegian and Swedish appraisal practices for this sector are mapped in Wangsness, Holmen, and Hansen (2022).

1. *General guidelines:*
    a. What are the official guidelines for economic appraisal analysis applied across sectors?
    b. Which more specialized guidelines do you believe are relevant for the quality assurance of the Swedish emergency network?
    c. To what extent are the guidelines applied, and to what extent are there flexibilities in the Swedish appraisal methodology?
2. *Analysis period and annual weights.* We notice that the Swedish Transport Administration (2023) lists the expected life span of different infrastructures but that these are mainly related to transportation.
    a. How does one assess and decide upon a project's life span and infrastructure life span, possibly directly related to emergency and telecommunication?
    b. Are there any special considerations that will increase or decrease the life span?
    c. For example, in the case of project cost analysis, are there any special adaptions concerning investment, depreciation, and financing that we should be aware of?
3. *Project life span, investment, funding, and depreciation.* The expected life span of assessed infrastructure is closely related to the analysis period chosen in economic appraisal guidelines.

   a. How is the analysis period set in project cost analysis?
   b. In Norway, 'economic figures are not discounted in project cost analysis, as they are in the cost-benefit analysis' How is this in Sweden?
   c. When presenting results for a decision maker, would the cost be presented as one cost estimate or cost flow?
4. *Employment and population development.* In Norway, population growth is forecasted in line with Statistics Norway's population forecasts, mainly on a national basis.
   a. Is a similar methodology applied in Sweden?
   b. What estimates should be applied?
   c. We notice that Statistics Sweden publishes similar forecasts for Sweden. Are there openings for peculiar development for certain groups of employed persons or population groups more generally?
5. *Inflation and cost components.* In Norwegian economic appraisal analysis, there is an opening for adjusting for price development higher or lower than the general inflation, both backward based on historical prices and forward based on a forecast of the price development. This is, for instance, relevant for construction and energy prices.
   a. What is common practice in Sweden?
6. *Real wage growth.* In Norwegian economic appraisal analysis, real wage growth is forecasted in line with the Ministry of Finance's productivity and income growth forecasts. Analogously, some Swedish white papers predict developments in labor productivity and related covariates.
   a. How is real wage growth handled in the Swedish economic appraisal analysis?
   b. How does the cost analysis handle a project that depends on a considerable labor force or specific skills?
7. *Uncertainty in cost estimates and black swans:*
   a. How and to what extent does the conventional Swedish methodology for uncertainty analysis for model parameters differ from the Norwegian and other countries' methodologies?
   b. How and to what extent does the conventional Swedish methodology for uncertainty analysis for handling black swans differ from Norwegian and other countries' methodologies?
8. *Uncertainty in project implementation and project timeline:*
   a. How and to what extent does the conventional Swedish methodology for uncertainty analysis related to project implementation and project timeline differ from Norwegian and other countries' methodologies?

How does the conventional Swedish methodology for uncertainty analysis for handling black swans differ from Norwegian and other countries methodologies?

A.1.1.2 Interview Guide for Emergency Network Users

Project NOVA is a Swedish project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV) with the aim to produce Rakel G2, the second generation of Swedish Public Protection and Disaster Relief (PPDR) network. The Institute of Transport Economics (Norwegian Centre for Transport Research), Dovre Group and Analysys Mason have together formed a quality assurance team which undertakes a quality assurance of project NOVA.

As a part of the quality assurance process, we are interested in interviewing experts with knowledge of using, building and/or operating a PPDR network. In particular, insights from the users of PPDR networks are of great value to us because these users have the knowledge to help us answer some of our questions related to the user side of project NOVA and Rakel G2.

1. *Transition to new PPDR network:*
   a. Which general challenges and problems are most important related to the transition from Rakel G1 (TETRA) to Rakel G2 (3rd Generation Partnership Project (3GPP)/5G networks)?
   b. What are the main requirements that must be met before your users can move from Rakel G1 to Rakel G2?
2. *Price sensitivity:*
   a. What (if any) is your tolerance for increases in price when transitioning from Rakel G1 to Rakel G2 and the new 3GPP network?
   b. Can you say anything about your price sensitivity?
   c. What price do you expect to pay per subscription for using Rakel G2?
3. *Demand:*
   a. Do you expect that the new functionality available in Rakel G2 will lead to an increase in the number of users from your organization?
   b. What do you expect the demand for Rakel G2 and a PPDR 5G network to be like in Sweden?
   c. Are there any realistic alternatives to Rakel G2 for your users? Would you consider other options if the use of Rakel G2 is not mandatory?
4. *Functionality upgrades:*
   a. Project NOVA costs are based on no functionality upgrades throughout its lifespan. How important is it for you to have functionality upgrades of the PPDR network throughout its lifespan?

A.1.1.3 Interview Guide for Construction Companies

Project NOVA is a Swedish project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV) with the aim to produce Rakel G2, the second generation of Swedish Public Protection & Disaster Relief (PPDR) network. The Institute of Transport Economics (Norwegian Centre for Transport Research), Dovre Group and Analysys Mason have together formed a quality assurance team which undertakes a quality assurance of project NOVA.

As a part of the quality assurance process, we are interested in interviewing experts with knowledge of building and/or operating a PPDR network. In particular, insights from construction companies responsible for building the PPDR network are of great value to us because these construction companies have the knowledge to help us answer some of our questions related to project NOVA and the building of Rakel G2.

1. *Personnel requirements:*
   a. How much will your costs increase if you are required to only use workers with Swedish citizenship and security clearance?
2. *Timespan:*
   a. How many years would you estimate the rollout of a 5G network with approx. 7,500 sites to take from start to finish?
3. *Costs:*
   a. Do these prices for installation of the different sites match with your prices/calculations?
      i. Installation, acquiring of antenna system and base station of SEK 100,000

ii. Installation of radio link of SEK 50,000
iii. Installation of technical hut of SEK 150,000

b. Does the price for the base station gNodeB (gNB) of SEK 290,000 and antenna system of SEK 60,000 match your prices/calculations?
c. Does the price of SEK 30,000 for a radio link seem reasonable?
d. Does the price of SEK 600,000 seem reasonable for a technical hut? (E.g. own technical house with two rooms, teleroom and 7-day diesel room, Uninterrupted Power Supply, Supply A+B, robust and redundancy))

4. *Increase in costs throughout the construction period:*
   a. Do you expect the price level in the construction sector to be higher than the general inflation level in Sweden in the coming 5-, 10- or 20-year period?
5. *Construction strategy:*
   a. What would be the best strategy for deploying a 5G network in Sweden?
      i. Deploy all sites in one specific area (e.g., Bohuslän) and then move on to the next
      ii. Take all sites with a certain site type (e.g., owned sites by MSB/Trafikverket) and then move on to rented sites
   b. How will the selected rollout strategy influence time and cost?
      i. What will be the impact on total cost if rollout is delayed due to lack of financing?

A.1.1.4 Interview Guide for Infrastructure Providers

Project NOVA is a Swedish project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV) with the aim to produce Rakel G2, the second generation of Swedish Public Protection & Disaster Relief (PPDR) network. The Institute of Transport Economics (Norwegian Centre for Transport Research), Dovre Group and Analysys Mason have together formed a quality assurance team which undertakes a quality assurance of project NOVA.

As a part of the quality assurance process, we are interested in experts with knowledge of building and/or operating a PPDR network. In particular, insights from infrastructure providers are of great value to us because these tower companies have the knowledge to help us answer some of our questions related to project NOVA and especially related to antenna space leasing.

1. *Tenancy capacity of towers:*
   a. For Sweden, Telenor has reported a tenancy ratio (average no. of tenants per site) of 2.3 which is much higher than their numbers for Norway (1.6) and Finland (1.4). If the Telenor tenancy ratio for Sweden is indicative for the whole Swedish market, this means it is likely that a significant share of commercial sites is at max capacity. Do you have any insight into this? Do you see the fact that NOVA has estimated around 50 percent (around 3,500) of their sites to be rented space on commercial towers as a potential problem?
2. *Tower lease prices:*
   a. We are aware that most Nordic tower owners (e.g., Telia, Telenor and Elisa) are in the process of carving out or “commercializing” their site ownership and operations. We also know that Nordic site lease prices today are in general lower than continental prices. What is your take on future lease pricing in Sweden?
   b. With a such large number of tower leases, is it a possibility for Rakel G2 to get some sort of quantity discount from the tower companies?

3. *Site coverage:*
    a. Do you see 6,800 sites (7,350 sites including special objects) as a reasonable number of sites to create a PPDR network in Sweden?
4. *Personnel:*
    a. What was your split between permanent staff and consultants when establishing your 4G/5G networks, both in the project phase and in the business-as-usual phase?
    b. To what extent would a requirement to only use workers with security clearance and/or Swedish citizenship affect your costs?

A.1.1.5 Interview Guide for Telecommunication Operators

Project NOVA is a Swedish project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV) with the aim to produce Rakel G2, the second generation of Swedish Public Protection & Disaster Relief (PPDR) network. The Institute of Transport Economics (Norwegian Centre for Transport Research), Dovre Group and Analysys Mason have together formed a quality assurance team which undertakes a quality assurance of project NOVA.

As a part of the quality assurance process, we are interested in interviewing experts with knowledge of building and/or operating a cellular network. In particular, insights from telecommunication companies are of great value to us because these companies have knowledge about building and operating cellular networks which can help us answer some of our questions related to project NOVA.

1. *Technical complexity:*
    a. Which potential challenges do you see related to using a combination of commercial and dedicated mobile coverage? The PPDR network in Sweden will use multi-operator core networks (MOCN) functionality to exploit capacity in commercial networks in areas where the dedicated capacity is not sufficient.
2. *Site coverage:*
    a. Do you see 6,800 sites (7,350 sites including special objects) as a reasonable number of sites to create a PPDR network in Sweden?
3. *Reinvestments:*
    a. What level of reinvestments in the 3rd Generation Partnership Project (3GPP)/5G network would you need to only do maintenance work and no functionality upgrades?
4. *Tower lease prices:*
    a. We are aware that most Nordic tower owners (e.g., Telia, Telenor, Elisa) are in the process of carving out or “commercializing” their site ownership and operations. We also know that Nordic site lease prices today are in general lower than continental prices. What is your take on future lease pricing in Sweden?

A.1.1.6 Interview Guide for Governmental Telecommunication Operators

Project NOVA is a Swedish project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV) with the aim to produce Rakel G2, the second generation of Swedish Public Protection and Disaster Relief (PPDR) network. The Institute of Transport Economics (Norwegian Centre for Transport Research), Dovre Group and Analysys Mason have together formed a quality assurance team which undertakes a quality assurance of project NOVA.

As a part of the quality assurance process, we are interested in interviewing experts with knowledge of building and/or operating a PPDR network. In particular, insights from PPDR network agencies in other countries are of great value to us because these agencies have the knowledge to help us answer some of our questions related to project NOVA.

1. *Transition to new PPDR network:*
    a. Which general challenges and problems are most important related to the transition from TETRA to 3rd Generation Partnership Project (3GPP)/5G networks?
    b. Are there significant uncertainties related to the transfer of customers from 1st generation PPDR network to 2nd generation?
    c. Do you expect an increase in user fees when transitioning from TETRA to 3GPP?
2. *Site coverage:*
    a. Do you see 6,800 sites (7,350 sites including special objects) as a reasonable number of sites to create a PPDR network in Sweden?
3. *Technical complexity:*
    a. Which potential challenges do you see related to using a combination of commercial and dedicated mobile coverage? The PPDR network in Sweden will use Multi-Operator Core Networks (MOCN) functionality to exploit capacity in commercial networks in areas where the dedicated capacity is not sufficient.
4. *Financing:*
    a. How, in your experience, will delays or reductions in public funding impact the timeline, quality or costs of a PPDR network?
5. *Sites and site types:*
    a. For your 3GPP-based PPDR network, what is your split of rented sites vs owned towers?
6. *Reinvestments:*
    a. What is the level of reinvestments in your 3GPP network? Is this based on functionality upgrades within the lifespan of the network?
7. *Timespan:*
    a. What is the expected lifetime of your 3GPP network?
    b. How many years do you expect the rollout of the network to take from start to finish? What drives this timeline?
8. *Personnel:*
    a. What was your split between permanent staff and consultants when building 3GPP network, both in the project phase and in the business-as-usual phase?
    b. Have you seen a requirement to only use workers with security clearance and Swedish citizenship when building the network?

A.1.2 Interview Guides for the Analyses of Impacts External to the Infrastructure Project

A.1.2.1 Interview Guides for Economic Expertise

Interview Guide for Users of Rakel G2 – Network and Service Strategy

Project NOVA is a Swedish project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV) with the aim to deploy Rakel G2, the second generation of the Swedish Public Protection & Disaster Relief (PPDR) network. The Institute of Transport Economics, Dovre Group and Analysys Mason have together formed a quality assurance team that undertakes a quality assurance of project NOVA.

As a part of the quality assurance process, we are interested in interviewing PPDR network users. Your insights and priorities can help the NOVA team with the RakelG2 network and service strategy.

The purpose of this interview is to gather information on direct benefits from and other aspects related to usage of Rakel G2. When answering the questions below, please consider the relative benefits of Rakel G2 compared to a reference scenario where the Swedish government does not invest in a modernized PPDR network, but where users are instead left to buy whatever services are offered by commercial mobile operators.

1. *Mobile data (capacity and speed):*
    a. How do your Rakel users use mobile broadband from commercial providers today?
    b. What are the limitations of today's use – what added value would an offer from Rakel G2 provide?
    c. How important is general internet access versus access to internal/approved applications?
2. *Functionality:*
    a. How important is Direct Mode Operation for your users?
    b. How important is it to be able to call users outside Rakel from a Rakel terminal?
3. *Coverage:*
    a. What are your priorities in terms of coverage? Better surface coverage vs better indoor coverage?
4. *Interaction with other Rakel user groups:*
    a. How important is interaction with other agencies through Rakel?
    b. Which other agencies are most important for your users to interact with through Rakel?
    c. Beyond joint group calls, what role does Rakel play in better interaction with other agencies?
5. *Robustness:*
    a. Have your users experienced downtime with Rakel? Under what conditions has downtime occurred?
    b. What are your expectations for Rakel G2 regarding downtime, both under normal conditions and extraordinary events such as armed conflict?
6. *Security:*
    a. In your users' experience, is the integrity of information communicated via Rakel protected from unauthorized access? Why, or why not?
7. *General thoughts on the new emergency and preparedness network:*
    a. What are your biggest expectations for Rakel G2?
    b. What do you want from Rakel G2 that is not offered by Rakel G1 + commercial operators?
8. *Importance of network features:*
    a. On a scale from 1 (least important) to 6 (most important), how important are the following features to PPDR users in your organization with regard to a) voice and SMS, b) data and c) IoT?

        i. *Coverage:* Radio network coverage including indoor coverage and coverage in remote areas
        ii. *Robustness and accessibility:* The ability to maintain a functional service in the face of external stress, failures or unforeseen events
        iii. *Security:* The ability to maintain the integrity and confidentiality of system information, user data and metadata
        iv. *Capacity and speed:* Total network capacity available for end users
        v. *Interoperability:* The ability to seamlessly communicate and collaborate with Rakel users in other organisations, as well as with the general public
        vi. *Functionality:* Broadband data and special functions required by PPDR users, including Mission-critical push-to-talk and Direct Mode Operation
        vii. *User experience:* Sound quality, terminals and ease of use

9. *Equipment and expertise:*
    a. Rakel G2 will entail the need for new equipment and expertise related to use.
        i. What expectations do (your) agency/agencies have related to financing this?
        ii. Given that such equipment and expertise were to be financed from the current budget, what trade-offs will the agencies meet (i.e., necessary trade-offs regarding purchasing new equipment and other expenses)?
10. *Distributional impacts:*
    a. What distributional impacts does the introduction of Rakel G2 have through your service provision (e.g., on different industries and population groups, both in terms of type and spatial location)?

A.1.2.2 Interview Guide for Experts on Indirect Impacts – Network and Service Strategy

Project NOVA is a project run by the Swedish Civil Contingencies Agency (MSB) and the Swedish Transport Administration (TrV) with the aim to deploy Rakel G2, the second generation of the Swedish Public Protection & Disaster Relief (PPDR) network. The Institute of Transport Economics, Dovre Group and Analysys Mason have together formed a quality assurance team that undertakes a quality assurance of project NOVA.

As a part of the quality assurance process, we are interested in interviewing stakeholders with knowledge about the indirect impacts of the new PPDR network. Your insights and priorities can help the NOVA team with the RakelG2 network and service strategy.

The purpose of this interview is to gather opinions and inputs on priorities, expectations, and benefits from Rakel G2. When answering the questions below, please consider the relative benefits of Rakel G2 compared to a reference scenario where the Swedish government does not invest in a modernized PPDR network, but where users are instead left to buy whatever services are offered by commercial mobile operators.

1. *Mobile coverage:*
    a. How do you expect that investments in Rakel G2 infrastructure will affect the mobile coverage of commercial telecommunication operators?
2. *Realized security impacts:*
    a. How will Rakel G2 improve the public’s access to emergency services when faced with an emergency?
    b. Will the effect of Rakel G2 on the services provided depend on the type of emergency (i.e., smaller and more common incidents versus larger and more rare incidents)?

    c. Do you expect that RakelG2 will provide improved protection of information (conversation, data and IoT) conveyed through the network against intelligence gathering and hacking by malicious actors?
    d. National security: What benefit would Sweden have of Rakel G2 in a larger crisis such as an armed conflict?
3. *Perceived security impacts:*
    a. How do you think that the population's safety and security perception will be affected by the deployment of Rakel G2? Will different population groups react differently to the deployment of RakelG2 (i.e., people living in different areas)?
    b. Large public investments often generate negative media attention when faced with budget overruns and other obstacles. Can such media attention decrease the population's safety and security perception?
    c. How is the reputation of TrV, MSB and the public emergency and preparedness in Sweden likely to be affected by Rakel G2?
4. *Learning impacts:*
    a. What are the training costs and learning outcomes for the users expected to follow from use of Rakel G2, as a new and different kind of electronic communication?
    b. How does introduction of Rakel G2 affect the ability to adopt new technologies in the concerned user entities and their value chain?
    c. What learning outcomes on integration between PPDR networks and commercial networks follow from realization of Rakel G2?
5. *Cooperation impacts:*
    a. How do you think Rakel G2 may influence interagency communication skills and culture, and how may such inter-agency skills and culture influence cooperation in real life?
    b. Could Rakel G2 improve cross-country cooperation with Norway, Finland and Denmark, and, if yes, how?
6. *Economic impacts:*
    a. *Industry development:*
        i. How will Rakel G2 impact the Swedish telecom industry – in the short and long term?
        ii. How essential are major domestic deliveries of equipment and infrastructure (e.g., from Ericsson) to Rakel G2 for the development within technological manufacturing in Sweden?
        iii. The importance of Rakel G2 for employment in the telecom industry
        iv. The potential for Swedish export of similar PPDR networks in a case of a successful development of Rakel G2 dominated by the Swedish telecom industry
    b. *Distortion of competition and markets:*
        i. What are the trade-offs between a major role for the Swedish telecom industry in Rakel G2 vs high competition to keep costs low?
        ii. To what extent is national security an obstacle for allowing high competition within technological manufacturing?
        iii. To what extent may prioritization of local infrastructure and equipment providers from the Swedish government's side be hampered by EU competitive law?

iv. How does construction of Rakel G2 affect the competition in the markets for technological manufacturing?
v. Note that Telia is likely to be responsible for Rakel G2's use of commercial infrastructure for electronic communication, when dedicated base stations are unavailable (the so called "MOCN solution"). What potential impact will a successful development of Rakel G2 have on the commercial Swedish market and operators?
vi. How may Rakel G2 impact the profitability of different operators and overall competition and pricing?

7. *Environmental impacts:*
    a. What are the local environmental impacts near the sites from construction of Rakel G2, and how does this depend on location (e.g., urban areas and national parks etc.)?
    b. What impacts do you believe operation and construction of Rakel G2 has on global emissions of climate gases?
8. *Distributional impacts from cost and benefits of Rakel G2:*
    a. How do you think Rakel G2 impacts different stakeholders differently (i.e., agencies)? Will it benefit some agencies more than others?
    b. From a societal perspective, would you say there is a redistribution perspective of Rakel G2 that affects weaker groups more?
    c. Would you say Rakel G2 affects agencies (users) and/or residents differently depending on (residential) location?
    d. Is there any generational dimension regarding the benefit or who bears the cost of Rakel G2?
    e. Considering that future (work) generation will pay for Rakel G2 as well as getting some of the benefits?

A.2 Subappendix: Informants

In the following, we account for the informants in our quality assurance project. The informants have been anonymized due to confidentiality concerns.

A.2.1 Informants through Presentations for the Principal Organizations

In our project to the principal organizations, informants from the Swedish Transport Administration and the Swedish Civil Contingencies Agency gave valuable feedback regarding the project work. These informants include the project principals and other personnel working with the Nova project. In addition, the Nova Council provided their feedback in two separate meetings.

During the project, informants from the Swedish Transport Administration and the Swedish Civil Contingencies Agency gave lectures with project information and information about previous investigations associated with Rakel G2.

A.2.2 Reference Group Members

During the project, four reference group meetings were held. In addition to the consultant team and the project principals, four reference group members attended these meetings. Their affiliations are listed in Table A.1.

Table A.1: Anonymized list of reference group members

Type of informant	Organization
Economic expertise	Concept Research Programme at Norwegian University of Science and Technology (Forskningsprogrammet Concept ved Norges teknisk-naturvitenskapelige universitet, Norway)
Governmental telecommunication operator	Norwegian Critical Communication Network at Norwegian Directorate for Civil Protection (Nød- og beredskapskommunikasjon Direktoratet for samfunnssikkerhet og beredskap, Norway)
Governmental agency	Norwegian Communications Authority (Nasjonal kommunikasjonsmyndighet, Norway)
Governmental agency	Transport Analysis (Trafikanalys)

A.2.3 Interviewees for the Project Cost Analysis and the Uncertainty Analysis

In Table A.2, we have listed the type of interviewees that provided information relevant for the project cost analysis and the uncertainty analysis.

Table A.2: Anonymized interview list for the project cost analysis and the uncertainty analysis

Type of informant	Organization
Economic expertise	Swedish Transport Administration (Trafikverket)
Emergency network user	Swedish Police Authority (Polismyndigheten)
Emergency network user	Swedish Association of Local Authorities and Regions (Sveriges Kommuner och Regioner)
Governmental telecommunication operator	Astrid (Belgium)
Telecommunication construction company	Transtema
Telecommunication infrastructure company	Cellnex

A.2.4 Interviewees for the Analysis on Impacts External to the Infrastructure Project

In Table A.3, we have listed the type of interviewees that provided information relevant for the analysis on impacts external to the infrastructure project.

Table A.3: Anonymized interview list for the project cost analysis and the uncertainty analysis

Type of informant	Organization
Direct Impacts	Swedish Coast Guard (Kustbevakningen)
Direct Impacts	SOS Alarm
Direct Impacts	Swedish Sea Rescue Society (Sjöräddningssällskapet)
Direct Impacts	Swedish Association of Local Authorities and Regions (Sveriges Kommuner och Regioner)
Direct Impacts	Swedish Police Authority (Polismyndigheten)
Indirect Impacts	Norwegian Defence Materiel Agency (Forsvarsmateriell, Norway)
Indirect Impacts	Swedish Post and Telecom Authority (Post- och telestyrelsen)
Indirect Impacts	Swedish Defence University (Försvarshögskolan)
Indirect Impacts	Chalmers University of Technology and SCF Associates Ltd (United Kingdom)

B. Appendix: Supplementary Material on the Uncertainty Analysis

B.1 Elaboration on Analysis

In this appendix, uncertainty elements (uncertainty drivers and estimate accuracy uncertainties) utilized in the analyses are detailed. The appendix also documents which cost elements are included in the analysis, and how the cost elements are affected by uncertainty elements. The detailed descriptions of each uncertainty element describe risks and opportunities covered under each element, as well as scenarios used as basis for the quantifications.

B.1.1 Listing of Cost Elements, Uncertainty Drivers and Estimate Accuracy Uncertainties

Table B.1 details the cost elements used in PBEs as foundation for the uncertainty analysis.

Table B.1: Cost elements used in the uncertainty analysis on costs

Cost element
INV1 – Investment: BTS – TrV & MSB
INV2 – Investment: BTS – Commercial sites
INV3 – Investment: BTS – New greenfield sites
INV4 – Investment: transmission MSB and TrV
INV5 – Investment: accessnet/radioslingor
INV6 – Investment: Core
INV7 – Investment: Organization – project
INV8 – Investment: MOCN/roaming
REC1 – Recurring: BTS – TrV & MSB
REC2 – Recurring: BTS – Commercial sites
REC3 – Recurring: BTS – New greenfield sites
REC4 – Recurring: transmission MSB and TrV
REC5 – Recurring: transmission – commercial
REC6 – Recurring: transmission – accessnet/radioslingor
REC7 – Recurring: Core
REC8 – Recurring: Organization – project
REC9 – Recurring: Organization – permanent
REC10 – Recurring: MOCN/roaming
REI1 – Reinvestments: BTS – TrV & MSB
REI2 – Reinvestments: BTS – commercial sites
REI3 – Reinvestments: BTS – New greenfield sites
REI4 – Reinvestments: Core
REI5 – Reinvestments: Organization – project

Table B.2 shows the uncertainty drivers used in the uncertainty analysis, as well as which subanalysis a given uncertainty driver is relevant for.

Table B.2: Uncertainty driver overview

Uncertainty driver	Included in analysis		
	INV	REC	REI
Market uncertainty	X	X	X
Design development, maturity and system integration	X		
Project/operating organization and management	X	X	X
Project owners' governance and management	X		X
Authorities (legislation, rules, standards, regulations)	X	X	X
User influence and demand	X	X	X
Interfaces and stakeholders	X	X	X
Suppliers' capability	X		X
Site and transmission conditions	X		X

Table B.3 shows the estimate accuracy uncertainties used in the uncertainty analysis, as well as which subanalysis a given estimate accuracy uncertainty is relevant for.

Table B.3: Estimate accuracy uncertainties overview

Estimate accuracy uncertainties	Included in analysis		
	INV	REC	REI
Number of sites – TrV & MSB	X	X	X
Number of sites – commercial sites	X	X	X
Number of sites – new greenfield sites	X	X	X
Unit costs	X	X	
Personnel costs	X	X	X
Personnel quantity	X	X	X
Reinvestment needs			X
Inflation adjustments	X	X	X

B.1.2 Uncertainty Drivers

Table B.4 details scenarios, mappings (cause and effect) and quantifications for the "Market uncertainty" uncertainty driver.

Table B.4: Market uncertainty – description, scenarios and quantification

Market uncertainty

This uncertainty driver comprises uncertainty in the market for contractors for upgrading and establishment of sites. The uncertainty driver covers both general market development and specific market uncertainty through variation between market means. The uncertainty driver covers opportunities for the project to utilize TrV's existing frame agreements. The driver also covers uncertainty in market for suppliers of telecom systems, uncertainty regarding the market for hire of space in commercial towers. Further, the driver covers uncertainty regarding TrV's attractiveness as a client, and the attractiveness of the project and its contract to the contractor and supplier market is also included.

General market development covers:

- Price development for input factors
- Business cycles
- Changes in market profit margins
- Changes in market productivity
- Structure changes in the market

Market mean represents an average of assumed offers. Historical offers from reference projects will vary around market mean. The following affects variations around market mean values:

- Project attractivity
- Timing and competition
- Contract structures, execution strategy, incentive mechanism
- Schedule and intensity

Qualifications are based on empirical research on market mean development and variations around market mean values, as conducted by the NTNU Concept program, ref. Concept report 1. General market development uncertainty is quantified as ± 6 percent per year between analysis cost level and contract prices, while specific market uncertainty is quantified at ± 9 percent. For investments, a duration of 1.5 years between cost level (2024) and contract timing is assumed. Empirics indicate an annual standard deviation of ± 12 percent – giving market uncertainty at an 80 percent confidence level of ± 15 percent.

Recurring costs are quantified at ± 10 percent, as a high portion of rates are already regulated in MSB and TrV contracts. Reinvestments are quantified at ± 20 percent.

Minimum (P10)	Better market situation than estimated. Low market activity, the project is assessed as highly attractive in the market. Reductions in power prices in opex phase (affecting approximately 20 percent of site costs)
Most likely	Market situation as estimated
Maximum (P90)	Market situation worse than estimated. High activity and heated market, leading to lowered attractivity for the project. Increases in power prices in opex phase (affecting approximately 20 percent of site costs)

Affects	P(x)	P10	ML	P90
INV1–INV6, INV8	1,0	-15%	0%	15%
REC1–REC3 REC4–REC7, REC10	1,0	-10% -2.5%	0%	10% 2.5%
REI1-REI4	1,0	-20%	0%	20%

Table B.5 details scenarios, mappings (cause and effect) and quantifications for the "Design development, maturity and system integration" uncertainty driver.

Table B.5: Design development, maturity and system integration – description, scenarios and quantification

Design development, maturity and system integration					
This uncertainty driver comprises uncertainty regarding the concept and technical basis for the project, uncertainty regarding the maturity of the project and uncertainty regarding the integration of all main elements in the system and the MOCN solution. The uncertainty driver covers the following uncertainties: • General development in scope and design • Material choices and locations • Technical solutions and optimizations • Need for flexibility					
Minimum (P10)	Further detailing of the project leads to cost decreases. The project to date is more detailed than assumed, leading to lower need for estimate allowances.				
Most likely	Design development as estimated.				
Maximum (P90)	Further detailing of the project leads to cost increases and more expensive solutions. The project to date is less detailed than assumed, leading to higher need for estimate allowances. System integration is more challenging and time consuming than estimated, with substantial need for use of supplier personnel.				
Affects		P(x)	P10	ML	P90
INV6–INV8		1,0	-10%	0%	100%

Table B.6 details scenarios, mappings (cause and effect) and quantifications for the "Project/operating organization and management" uncertainty driver.

Table B.6: Project/operating organization and management – description, scenarios and quantification

Project/operating organization and management				
This uncertainty driver comprises uncertainty related to the project organization's competence, capacity and continuity, its stakeholder management capability, interface coordination, procurement strategies, management and coordination between MSB and TrV, change management, risk management, project control activities. The following uncertainties are included: • Capacity and competence in planning and executing projects within the project organization • Continuity • Access to resources with needed competence • Project control systems • Cooperation between the organization and suppliers, telecom system suppliers, other parts of MSB and TrV, and ministries • Procurement strategies and procurement basis • Coordination of decisions and personnel • Interface and change management • Lack of project strategies • Quality of current plans and strategies				
Minimum (P10)	A complete organization, with high competence and continuity. High control over contracts, changes, interfaces. Good coordination and cooperation with users, stakeholders and other actors. High focus on cost reductions. Good communication with suppliers, leading to positive working climate. Good level of cooperation within the organization, effective decision processes. High quality of planning and definition of the project gives high execution efficiency.			
Most likely	Management quality as estimated.			
Maximum (P90)	Lack of competence and continuity in the organization. The project control systems are not adapted to the project. Deficient project strategies. Poor coordination and cooperation with users, stakeholders and other actors. Low focus on cost reductions. Poor communication with suppliers, leading to negative working climate. Complaints directed at several contract allocations due to mistakes in procurement processes. Poor level of cooperation within the organization, ineffective decision processes. Low quality of planning and definition of the project gives low execution efficiency.			
Affects	P(x)	P10	ML	P90
INV1–INV5 INV6-INV8	1,0	-5% -10%	0%	10% 20%
REC1–REC7, REC10 REC8–REC9	1,0	-5% -25%	0%	5% 25%
REI1-REI4 REI5	1,0	-5% -10%	0%	10% 20%

Table B.7 details scenarios, mappings (cause and effect) and quantifications for the "Project owners' governance and management" uncertainty driver.

Table B.7: Project owners' governance and management – description, scenarios and quantification

Project owners' governance and management				
This uncertainty driver comprises uncertainty related to management and governance of the project, both within relevant ministries and government functions, as well as at higher levels in MSB and TrV. Further, the uncertainty driver comprises uncertainty related to changes and additional demands from project owners and delays in political decisions. The following uncertainties are included: • Project owner's competence and capacity • Cooperation between relevant ministries • Uncertainty in MSB and TrV's top management ability to lead and follow the project • Changes and additions from project owners • New political requirements • Changes in assumptions and requirement from project owners • Uncertainty related to the project being run by different agencies under different ministries • National security interests and effect on decisions • Sufficient and timely cost allocations				
Minimum (P10)	Timely decisions and grants. Project owner provides project organization with sufficient financial limits. High focus on cost reducing measures. High focus on national security interests leads to quick decisions. Lowered ambitions for reinvestments.			
Most likely	Governance and management as estimated.			
Maximum (P90)	Delays in decisions and budget allocations lead to project delays and higher execution costs. New requirements from project owners.			
Affects	P(x)	P10	ML	P90
INV1–INV6, INV8 INV7	1,0	-5% -10%	0%	5% 10%
REI1-REI4 REI5	1,0	-5% -10%	0%	5% 10%

Table B.8 details scenarios, mappings (cause and effect) and quantifications for the "Authorities (legislation, rules, standards, regulations)" uncertainty driver.

Table B.8: Authorities (legislation, rules, standards, regulations) – description, scenarios and quantification

Authorities (legislation, rules, standards, regulations)					
This uncertainty driver comprises uncertainty related to changes in project requirements due to changes in relevant laws, regulations, rules, and standards, as well as changes in how these are practiced. The following uncertainties are included: • Changes in security requirements • Limits on supplier use of foreign workforce • Uncertainty related to zoning processes • New requirements from supervisory authorities • Changes in laws and regulations • Changes in standards					
Minimum (P10)	Leniency in requirements and regulations leading to minor cost reductions.				
Most likely	Requirements and regulations as estimated.				
Maximum (P90)	Negative changes in security requirements, leading to higher costs for suppliers. Need for security clearances for a high proportion of the workforce. Delays in zoning processes leading to project delays. Other changes in regulations, legislation et cetera.				
Affects		P(x)	P10	ML	P90
INV1–INV8		1,0	-1%	0%	10%
REC1-REC10		1,0	-2.5%	0%	5%
REI1-REI5		1,0	-1%	0%	10%

Table B.9 details scenarios, mappings (cause and effect) and quantifications for the "User influence and demand" uncertainty driver.

Table B.9: User influence and demand – description, scenarios and quantification

<table>
<tr><th colspan="5">User influence and demand</th></tr>
<tr><td colspan="5">This uncertainty driver comprises uncertainty related to user-initiated changes to project solutions, project requirements and operational requirements, as well as uncertainty related to number of subscribers and types of subscriptions. The following uncertainties are included:
• Future technical innovation leading to changes in user expectations
• Users do not accept technical solution and block migration
• Changes in requirements from users
• Uncertainty as to what is required to migrate users from Rakel G1 to Rakel G2
• Changes in number of users, e.g., number of user organizations, users per organization, new users
• Uncertainty related to user organizations
• Limits on supplier use of foreign workforce</td></tr>
<tr><td>Minimum (P10)</td><td colspan="4">Lower number of users of the system than estimated leads to lower opex costs than estimated (but also reduced revenue). Minor cost optimalizations due to positive changes initiated by users.</td></tr>
<tr><td>Most likely</td><td colspan="4">User influence and demand as estimated.</td></tr>
<tr><td>Maximum (P90)</td><td colspan="4">Resistance from users in migrating to the new system. New requirements from users. Delays in necessary processes with users in Sweden and neighboring countries lead to delay in system migration. Higher use of the system than estimated leads to higher opex costs than estimated (but also increased revenue).</td></tr>
<tr><td>Affects</td><td>P(x)</td><td>P10</td><td>ML</td><td>P90</td></tr>
<tr><td>INV1–INV8</td><td>1,0</td><td>-1%</td><td>0%</td><td>5%</td></tr>
<tr><td>REC9
REC10</td><td>1,0</td><td>-2.5%
-10%</td><td>0%</td><td>5%
10%</td></tr>
<tr><td>REI1-REI5</td><td>1,0</td><td>-1%</td><td>0%</td><td>5%</td></tr>
</table>

Table B.10 details scenarios, mappings (cause and effect) and quantifications for the "Interfaces and other stakeholders" uncertainty driver.

Table B.10: Interfaces and other stakeholders – description, scenarios and quantification

Interfaces and other stakeholders					
This uncertainty driver comprises uncertainty related to interfaces with commercial network operators. The following uncertainties are included: • Opportunity to rent space on new masts in rural areas to commercial operators • Opportunity to reduce transmission costs (OPEX) through increased use of commercial networks. • Functioning MOCN solution based on commercial solution leading to reduced need for new sites in the later stage of investment period.					
Minimum (P10)	Reduced need for radio link investments due to increased use of commercial solutions leading to reduced investment costs (but also lower robustness). Opex costs reduced both due to revenue from rent by commercial operators for space on new masts in rural areas, and due to increased use of commercial transmission networks.				
Most likely	As estimated				
Maximum (P90)	Requirements and demands from other stakeholders leading to minor cost increases.				
Affects		P(x)	P10	ML	P90
INV2, INV4		1,0	-5%	0%	2.5%
REC4–REC6		1,0	-2%	0%	1%
REI1-REI5		1,0	-5%	0%	2.5%

Table B.11 details scenarios, mappings (cause and effect) and quantifications for the “suppliers' capability” uncertainty driver.

Table B.11: Suppliers' capability – description, scenarios and quantification

Suppliers' capability					
This uncertainty driver comprises uncertainty related to suppliers' capacity, competence and overall capability for successful project execution, e.g., their ability to handle and cooperate with interfaces, supplier prioritization, continuity of key supplier personnel, experience with similar projects and abilities for follow-up of subsuppliers. The following uncertainties are included: • Capabilities within project execution • Suppliers' ability to handle interfaces and cooperate with interfacing actors and contracts • Suppliers' prioritization of the project • Suppliers' understanding of scope and method • Suppliers' continuity • HSE work • Subsupplier follow-up • Site logistics • Experience with similar projects (construction projects with many repetitive operations and subprojects)					
Minimum (P10)	Competent suppliers with relevant competence due to overall low demand in the market. Supplier contributes with relevant experience to detail beneficial technical solutions. Suppliers prioritize the project, and succeed in key aspects of the project, including HSE, interfaces, planning etc. Leads to lower need for follow-up.				
Most likely	Suppliers' capability as expected.				
Maximum (P90)	Lack of correct competence at suppliers, e.g. due to market changes. Suppliers' attitudes and actions result in poor cooperation with MSB and TrV and with an opportunistic approach to contract variations. Suppliers are unsuccessful in coordinating detail design, procurement activities, construction and implementation, especially due to the fact that the project covers multiple sites. High need for follow-up of suppliers.				
Affects		P(x)	P10	ML	P90
INV1–INV5, INV7 **INV6, INV8**		1,0	-5% -10%	0%	5% 10%
REI1–REI3, REI5 REI4		1,0	-5% -10%	0%	5% 10%

Table B.12 details scenarios, mappings (cause and effect) and quantifications for the “Site and transmission conditions” uncertainty driver.

Table B.12: Site and transmission conditions – description, scenarios and quantification

Site and transmission conditions					
This uncertainty driver comprises uncertainty related to local conditions at the sites, including conditions of existing constructions and equipment, ground conditions, site access conditions, weather conditions and restrictions in the project execution phase. The following uncertainties are included: • Below ground conditions • Actual condition of existing infrastructure, buildings and masts • Weather conditions in the execution phase • Urban area project execution • Seasonal work • Efficiency related to logistics, rigging and operation • Site access • Distances to access points fiber optics and electricity • Double transmission (redundancy) and need for unobstructed view between radio links • Space on commercial towers • Site suitability					
Minimum (P10)	Logistics and handling of local conditions less complex than anticipated. Easier local conditions, both above and below ground, and better actual condition of existing infrastructure than estimated.				
Most likely	Local conditions as estimated.				
Maximum (P90)	Complex site execution leads to need for mitigating actions. Need for acquisition of additional areas, incl. need for zoning processes. Above and below ground conditions more challenging than expected. Findings of unforeseen infrastructure below ground. Lack of space on commercial towers leads to increased need for own sites (800 sites instead of 400). Local conditions make access network more expensive than expected due to obstructions between radio links.				
Affects		P(x)	P10	ML	P90
INV1–INV5, INV7		1,0	-10%	0%	20%
REI1–REI3, REI5		1,0	-10%	0%	10%

B.1.3 Estimate Accuracy Uncertainties

Estimate accuracy uncertainties covers uncertainty related to the accuracy of the current base estimate, assuming constraints and premises behind the estimate are kept constant. The estimate accuracy covers uncertainty in available reference data, which in turn leads to uncertainty in quantities, unit costs, percentages etc.

Table B.13 details scenarios, mappings (cause and effect) and quantifications for the "Number of sites" estimate accuracy uncertainty.

Table B.13: Estimate accuracy uncertainty – number of sites – description, scenarios and quantification

Number of sites				
Uncertainty related to the accuracy of the current base estimate in terms of number of sites, assuming that all other constraints and premises behind the estimate are kept constant.				
Minimum (P10) Number of sites overestimated.				
Most likely Number of sites as estimated.				
Maximum (P90) Number of sites underestimated.				
Affects	P(x)	P10	ML	P90
Number of TrV & MSB sites (INV1, INV4, REC1, REC4, REI1)	1,0	-5%	0%	5%
Number of commercial sites (INV2, REC2, REC4, REI2)	1,0	-10%	0%	5%
Number of greenfield sites (INV3, REC3, REI3)	1,0	-5%	0%	5%

Table B.14 details scenarios, mappings (cause and effect) and quantifications for the "Unit costs" estimate accuracy uncertainty.

Table B.14: Estimate accuracy uncertainty on unit costs – description, scenarios and quantification

Unit costs				
Uncertainty related to the accuracy of the current base estimate in terms of unit costs, assuming that all other constraints and premises behind the estimate are kept constant.				
Minimum (P10) Unit costs overestimated.				
Most likely Unit costs as estimated.				
Maximum (P90) Unit costs underestimated.				
Affects	P(x)	P10	ML	P90
Unit costs - investments (INV1-INV6, INV8)	1,0	-10%	0%	10%
Unit costs – recurring costs (REC1–REC7, REC10)	1,0	-10%	0%	10%

Table B.15 details scenarios, mappings (cause and effect) and quantifications for the "Personnel costs" estimate accuracy uncertainty.

Table B.15: Estimate accuracy uncertainty – personnel costs – description, scenarios and quantification

Personnel costs				
Uncertainty related to the accuracy of the current base estimate in terms of costs per FTE, assuming that all other constraints and premises behind the estimate are kept constant. Compared with costs related to the operation phase and reinvestments, a lower share of permanent employees is expected for the investment phase, increasing the uncertainty span.				
Minimum (P10)	Costs per FTE overestimated.			
Most likely	Costs per FTE as estimated.			
Maximum (P90)	Costs per FTE underestimated. Higher need for consultants than expected in the investment phase.			
Affects	P(x)	P10	ML	P90
Personnel costs – investments (INV6–INV7)	1,0	-10%	0%	25%
Personnel costs – recurring costs (REC8–REC9)	1,0	-10%	0%	10%
Personnel costs – reinvestments (REI5)	1,0	-5%	0%	5%

Table B.16 details scenarios, mappings (cause and effect) and quantifications for the "Personnel quantities" estimate accuracy uncertainty.

Table B.16: Estimate accuracy uncertainty – personnel quantities

Personnel quantities				
Uncertainty related to the accuracy of the current base estimate in terms of number of FTEs needed to undertake the project.				
Minimum (P10)	FTEs underestimated.			
Most likely	FTEs as estimated.			
Maximum (P90)	FTEs overestimated.			
Affects	P(x)	P10	ML	P90
Personnel quantities – investments (INV7)	1,0	-10%	0%	25%
Personnel quantities – recurring costs (REC8–REC9)	1,0	-30%	0%	30%
Personnel quantities – reinvestments (REI5)	1,0	-15%	0%	15%

Table B.17 details scenarios, mappings (cause and effect) and quantifications for the "Reinvestment needs" estimate accuracy uncertainty.

Table B.17: Estimate accuracy uncertainty – reinvestment needs

Reinvestment needs				
Uncertainty related to the accuracy of estimating of reinvestment needs, assuming that all other constraints and premises behind the estimate are kept constant.				
Minimum (P10)	Annual reinvestments approximately 1% of investments.			
Most likely	As estimated. Annual reinvestments approximately 2.5% of investments.			
Maximum (P90)	Annual reinvestments near 4% of investments.			
Affects	P(x)	P10	ML	P90
Reinvestment needs (REI1–REI4)	1,0	-50 percent	0%	50 percent

Table B.18 details scenarios, mappings (cause and effect) and quantifications for the "Inflation adjustments" estimate accuracy uncertainty.

Table B.18: Estimate accuracy uncertainty – inflation adjustments

Inflation adjustments				
Uncertainty related to the accuracy of the inflation adjustment in the base estimate.				
Minimum (P10)	Actual inflation is approximately 1% from 2023 to 2024			
Most likely	Inflation as estimated, approximately 1.8% from 2023 to 2024			
Maximum (P90)	Actual inflation is approximately 3.5% from 2023 to 2024			
Affects	P(x)	P10	ML	P90
INV1–INV8, REC1–REC10, REI1–REI5	1,0	-1%	0%	2%

B.2 Appendix: Uncertainty Cost Analysis Methodology

In our uncertainty analysis, we have utilized Dovre Group's work process and method for uncertainty cost analysis.

Dovre Group's work process and method for uncertainty analysis are based on the Successive principle (Norwegian University of Science and Technology / Steen Lichtenberg), supplemented with best practices from more complex and specialized analyses where necessary. The method may be summarized in the following six process steps.

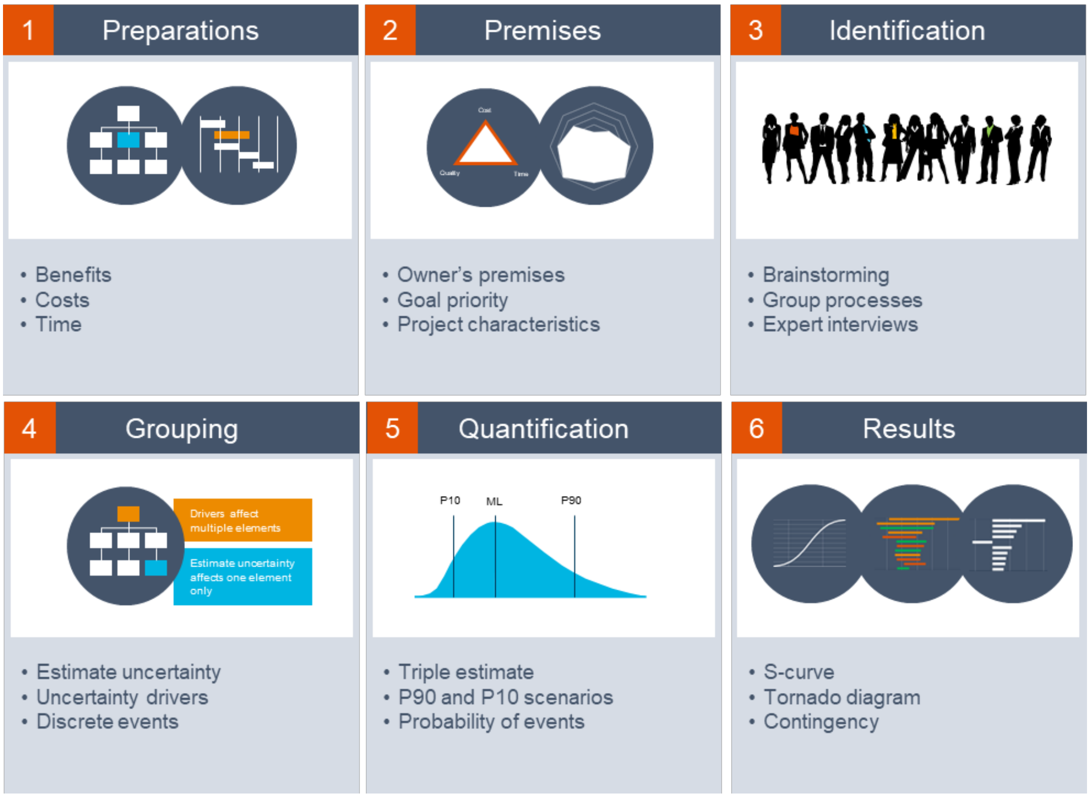

Figure B.1: Dovre Group's process and method for uncertainty analysis

Each of the steps is described in more detail below. The analysis will provide a basis for the identification and preparation of appropriate measures, as described at the end of this document.

B.2.1 Preparations

Review of relevant project documentation. Verification of basis for the analysis (scope of work, cost estimates, schedules, profitability calculations), and assessment of the estimating process and methods, estimate structure and benchmarking of key figures. Establish preliminary analysis model and plan further analysis process.

B.2.2 Premises

B.2.3.1 Owner's Premises

The decision-makers normally define only a few key premises for the project, but in many cases, the project management adds a relatively large number of detailed explicit and implicit assumptions for the cost estimate and schedules. These may however not be premises for the project from an owner's perspective, and if that is the case the uncertainty regarding these assumptions must be included in the uncertainty analysis. As illustrated in the figure below, this difference in perspective can be significant.

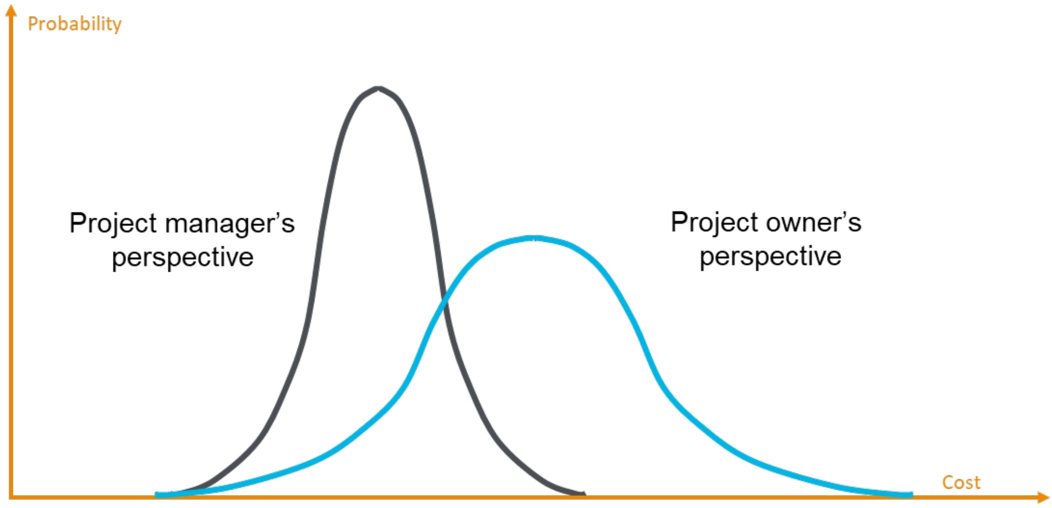

Figure B.2: Project owner's and project manager's perspectives

To establish a realistic quantification of the size of the project uncertainty, it is therefore necessary to clarify what the valid assumptions for the analysis are.

B.2.3.2 Goal Priority

Clarification of the priority between the objectives for cost, schedule and quality (performance, content) is critical for a realistic assessment of the size of the project uncertainty.

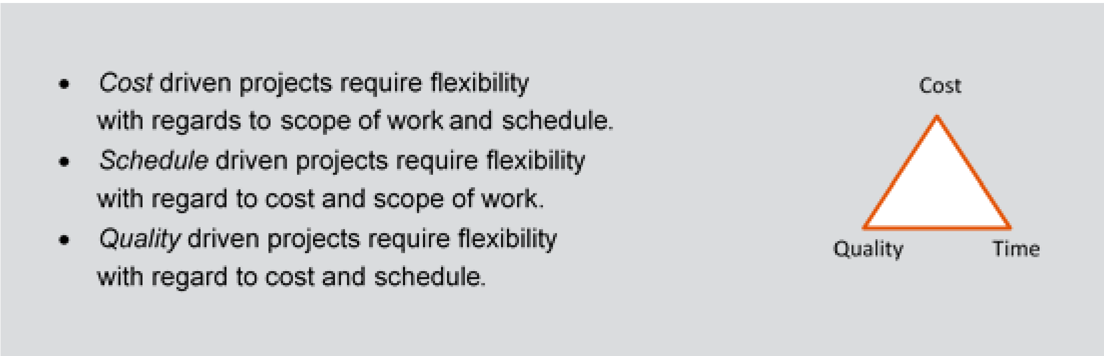

Figure B.3: Dovre Group's model for the prioritization of project objectives

B.2.3.3 Project Characteristics

The project characteristics indicate the level of uncertainty for eight fixed parameters and provide an overview of the challenges related to the project. A scale of 1 to 6 is used, where 1 is negligible and 6 is very high.

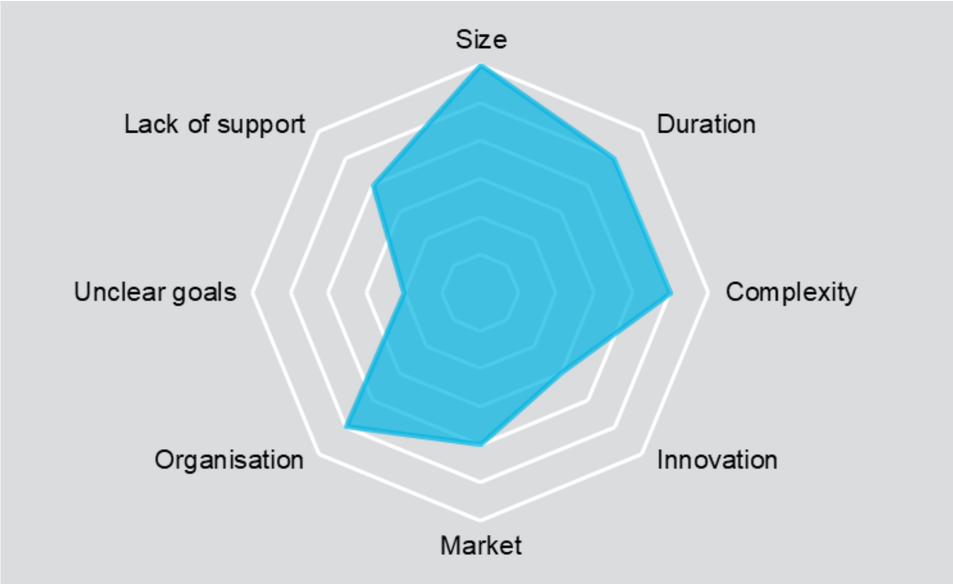

Figure B.4: Dovre Group's methods for assessment of challenges (project characteristics)

B.2.3 Identification

The process of identifying relevant risks and uncertainties should be carried out with participation of key representatives from project management, project owners and users. Normally, group processes are used, based on recognized creative methods such as Brainstorming and Six thinking hats (DeBono), expert interviews and assessment of experiences from other similar types of projects.

The identification process usually results in the identification of a large number of uncertainties. It is however important to ensure that the quantified uncertainty elements in the analysis do not overlap with each other and that they collectively cover all relevant uncertainty in the project. Due to this, the list may contain elements of uncertainty that should be grouped together, but it may also lack some elements.

Structuring the identified uncertainties as shown in the matrix below provides an overview where the balance concerning ownership (project, company, external) and type of uncertainty (technical, organizational, economical) can be assessed.

Table B.19: Structuring according to ownership and type of uncertainty (example)

	Technical	Organizational	Economical
External	Technological development Site conditions Environmental regulations Infrastructure Regulatory authorities	Public authorities Competing enterprises Competing projects Stakeholders Laws and regulations	Price level development Exchange rates Economic development Market conditions Weather conditions
Company	Functional requirements Operational requirements Standardization Quality requirements Technical standards	Project portfolio Project governance Resources Competence Communication	Marketing Market research Strategic plans Financing General contracting strategies
Project	Product characteristics Scope of work / quantities Level of innovation Specific technical issues Specifications	Organisational structure Project management Leadership Internal cooperation Authority	Execution strategy Project contract strategy Profitability analysis Cost estimates Schedules

B.2.4 Grouping

Based on the identified uncertainties, an appropriate number of uncertainty elements will be defined, that are linked to the cost items (or activities/benefits) they affect and quantified separately. The uncertainty elements can be divided into the following main groups.

B.2.5.1 Estimate Uncertainty

Uncertainty related to quantities and unit prices for each of the cost items, within defined assumptions regarding technical solutions, work methods, schedules etc. Quantified by triple-estimates for each cost item. The successive principle demands that uncertainty which affects more than one cost item is not included in the assessment of estimate uncertainty but is defined as an uncertainty driver instead. If this principle is not respected, a modelling error is introduced that may lead to analysis results with an unrealistically narrow variability.

B.2.5.2 Uncertainty Drivers

Internal and external factors, categorized by cause, which affect the whole or parts of the project beyond the assumptions for the estimates. The effect of the uncertainty drivers is quantified in the form of triple estimates in percent of one or more cost items. Examples of such drivers include further development of the scope of work and solutions, influence from users and stakeholders, interfaces with other projects, corporate governance, project strategies, availability of resources, market, site conditions and currency-related issues.

B.2.5.3 Discrete Events

Uncertainty related to binary events (i.e., events that do or do not occur), with significant potential consequences for the project. Event uncertainty is defined as the probability for an event to occur multiplied by its impact if it occurs. The effect of event uncertainties is quantified with probability and impact in the form of triple estimates in percent of one or more cost items.

Events with very low probability and very large impact are usually not included in the quantitative analysis (as this does not significantly affect the results) but are instead highlighted and described qualitatively.

B.2.5 Quantification

The successive principle requires the cost estimate to be divided into an appropriate number of cost items according to uncertainty exposure or other relevant reasons, and that the estimate uncertainty for each is estimated by triple estimates. In addition, the effects of uncertainty drivers and event uncertainties are quantified by triple estimates and probabilities.

By establishing cause-and-effect relationships between the uncertainty elements and the cost items, the correlation between the cost elements is taken care of directly, as illustrated below.

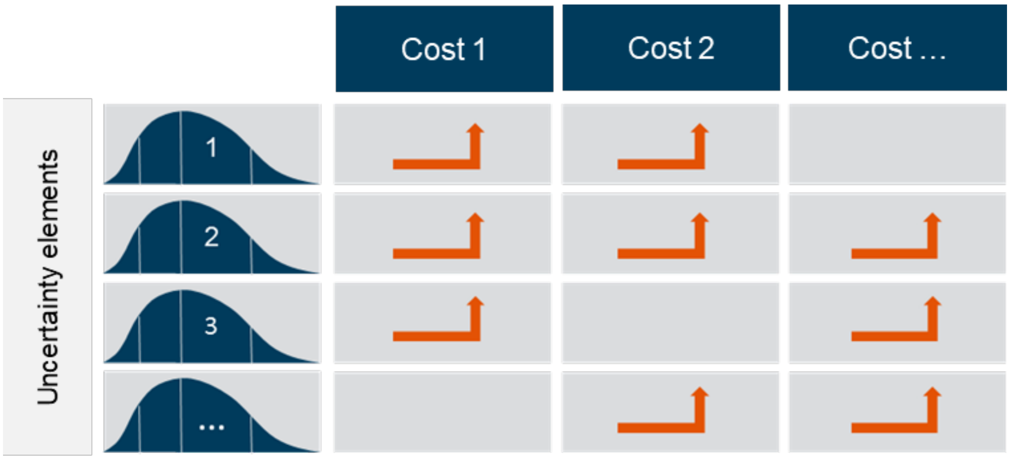

Figure B.5: Cause-and-effect relationship between uncertainty elements and cost elements

B.2.6.1 Triple Estimates

The quantification is based on the Erlang distribution with triple estimates for optimistic, most probable, and pessimistic values, based on scenarios where optimistic and pessimistic represent the 10 and 90 percentiles (P10 and P90) respectively.

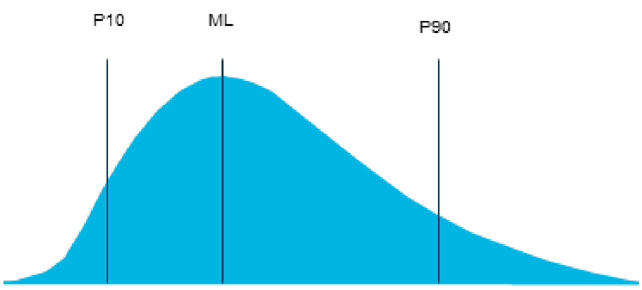

Figure B.6: Triple estimates

The definition of P10 and P90 as input values is easy to communicate and understand (one in ten projects goes below P10 and one in 10 projects goes above P90) and makes it possible to achieve realistic uncertainty ranges. An additional effect of using P10 and P90 as input values is that the choice of distribution function has practically no effect on the final result. For these two reasons, this choice of input values is established as best practice.[4]

B.2.6.2 Probability

For event uncertainty, triple estimates are used to quantify the impact. In addition, the probability of the event occurring must be quantified.

B.2.6.3 Documentation

For all uncertainty elements, the assessments are documented with a description of what the uncertainty element includes, which items it affects, scenarios for the optimistic, the most probable and the pessimistic outcome, as well as the quantification itself.

B.2.6.4 Analysis Tools

Dovre Group's work process and method for uncertainty analysis is, as mentioned earlier, based on the successive principle, but we also have very good knowledge of most other processes and tools that are used internationally, from relatively simple models to very complex ones. We also have solid experience with the use of tools for Monte Carlo simulations, such as @Risk and Crystal Ball, as well as specialized tools for network analyses such as Safran Risk and several other software tools.

Our key resources have authored or reviewed multiple research reports on methods and tools for estimation and uncertainty analyses, including Concept reports no. 1, 10, 11, 12, 13, 14, 15, 51 and 59, and a report on improved cost estimation for road and rail projects. We are familiar with the strengths and weaknesses of the different methods and tools and know how we can make practical adjustments in the analyses to avoid modelling errors.

In recent years, we have usually used our in-house analysis model, AnRisk ©, which has received much praise from our clients because it is easy to understand and delivers realistic results. AnRisk © simply makes it a bit easier to get things right, for everyone who is involved in the process.

The model handles both continuous distributions (estimate uncertainty and uncertainty drivers), discrete distributions (event uncertainty) and covariation (correlation) where necessary. We do however also use other tools if required by the analysis or in case the client wishes us to use a specific tool.

B.2.6 Results

In addition to a discussion of the results in the actual model, we normally use the following types of graphics.

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[4] Let a be optimistic value corresponding to p10, m be most likely value, b be pessimistic value corresponding to p90, E be expected value, SD be the standard deviation, Var be the variance, $Covar$ is the covariance and $Corr$ is the correlation coefficient. The formula for uncertainty per uncertainty elements are given by $E = p(a + 0.42m + b)/2.42$ and $SD^2 = p(1-p)[(a + 0{,}42m + b)/2{,}42]2 + p[(b-a)/2{,}53]^2$. Formula for general uncertainty are given by $E(tot) = \sum E$ and $SD(tot) = \sqrt{(\sum(Var + Kovar))} = \sqrt{(\sum SD^2)}$, $Var = SD^2$, $Covar(ab) = 2SD(a)SD(b)Corr(ab)$ and $Corr = [-1{,}1]$. As uncertainty for a single element relates to the expected value, the variance for each element is adjusted by the contribution that the other elements have to the expected value. The calculations have been verified by Norwegian University of Science and Technology.

B.2.7.1 Cumulative probability distribution (S-curve)

The s-curve in dark blue shows different cost levels with the associated probability of getting below this cost. The cumulative probability is shown on the Y-axis and the cost is shown on the X-axis. The figure also shows the base estimate in light blue, the expected cost in green and the pessimistic cost (P85) in orange.

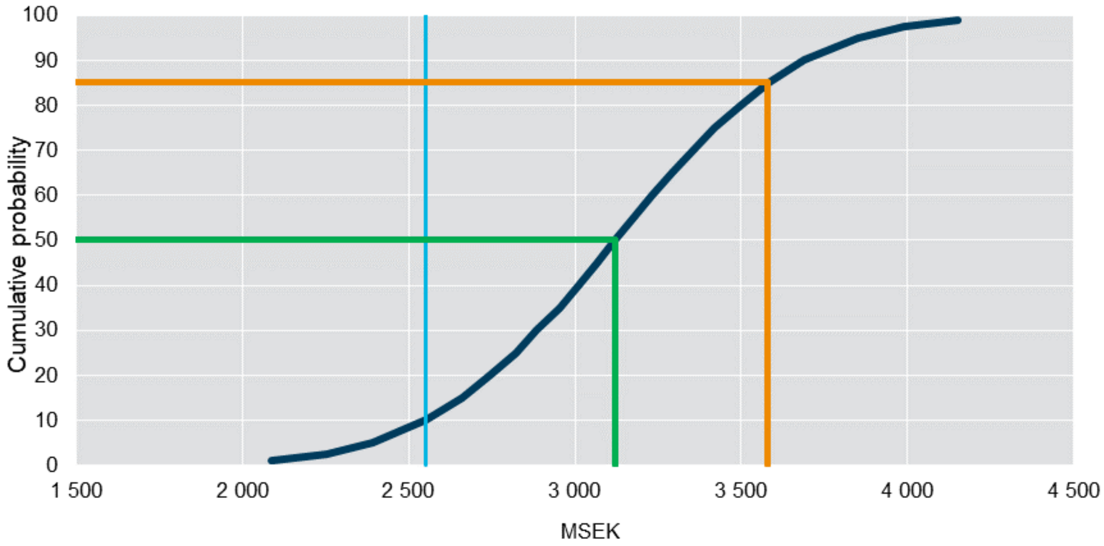

Figure B.7: Cumulative probability distribution (s-curve)

B.2.7.2 Tornado Diagram

The tornado diagram shows which uncertainty elements, in descending order, contribute the most to the total uncertainty in the form of dispersion (standard deviation). The colors indicate the degree of manageability for these elements, where green is the most and red is the least controllable.

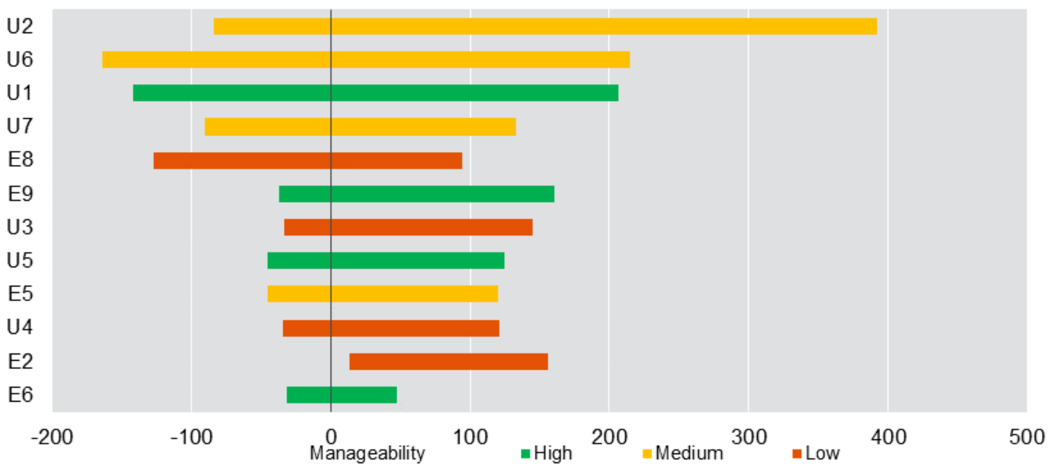

Figure B.8: Tornado diagram

However, the priority list must be based on an assessment that also includes manageability, time criticality and non-quantified elements.

B.2.7.3 Contingency Contribution Diagram

The contingency contribution diagram shows which uncertainty elements, in descending order, contribute the most to the total contingency (the difference between the expected cost and the base estimate).

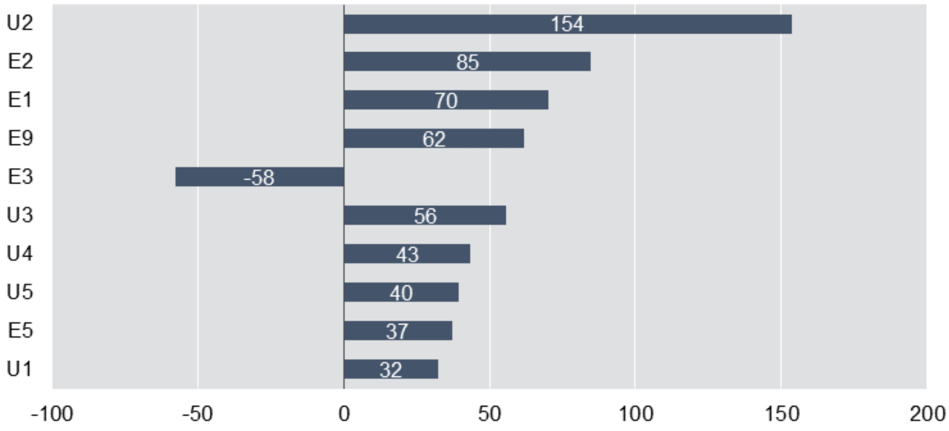

Figure B.9: Contingency contribution diagram

B.2.7.4 Waterfall Diagram

The waterfall diagram provides an overview of the base estimate, contingency, expected cost, provision for uncertainty, and potential scope reductions, as well as a recommended budget for the responsible agency and a recommended parliament budget for the project. According to the governmental project model, the budget for the responsible agency is usually set to P50 and the parliament budget is normally set to P85. For other clients, the diagram is adapted in accordance with their project model.

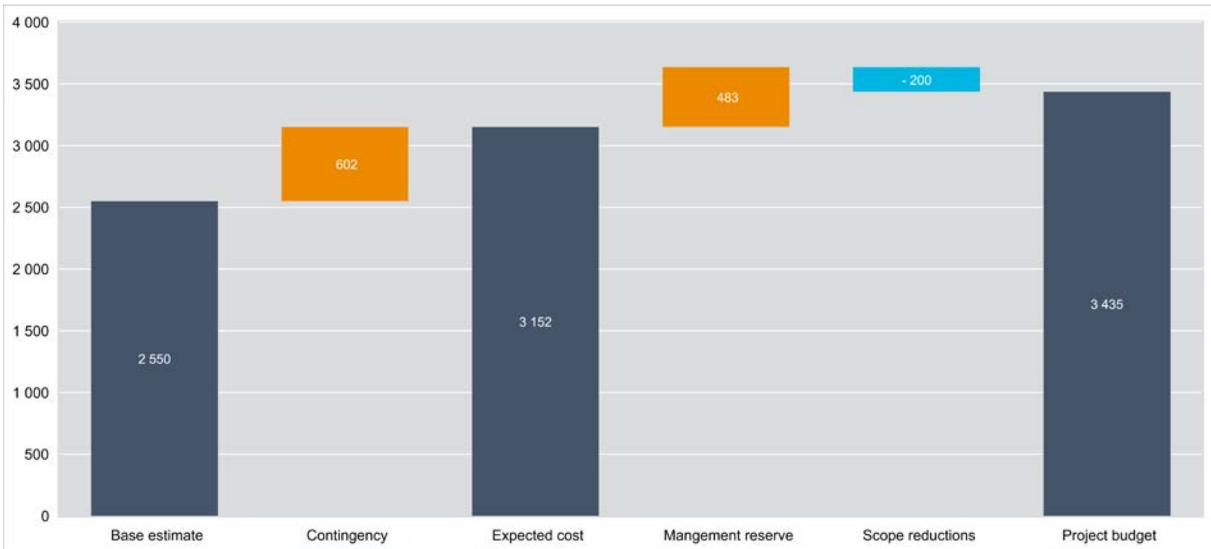

Figure B.10: Waterfall diagram

B.2.7.5 Assessment of results

Self-assessment of the results, in textual form, based on professional judgment and experiences from comparable projects.

It is important for us that the analysis results reflect the real uncertainty in a project as closely as possible. Compared to the variability that can be seen in experience data from completed projects, the variability in many uncertainty analyses is significantly lower than it should be. However, to our satisfaction, Concept report no. 59 shows that the variability in our analyses reflects the situation very well (79 percent of the projects fall within the 80 percent interval from our analyses).

B.2.7 Risk Management Actions

The results from the analysis will provide the basis for further identification and development of possible risk management actions. The measures will generally be targeted at both the probability of an outcome occurring and the impact in case of an outcome. In our experience, especially the latter is often given too little attention: For example, weather conditions are often seen as a risk that is not controllable, and indeed we cannot reasonably influence the weather, but we can adapt the project in such a way that it is less affected by the weather conditions. We divide the measures into four main categories:

- *Transfer*: Transfer the uncertainty to the party that is best capable of managing it. Typical examples may be taking out insurance, appropriate division of work and contractual risk-sharing.
- *Reduce*: We can reduce uncertainty by obtaining more information, selecting proven technical solutions, using standard contracts and more. Such measures may however also reduce the upside potential of the project.
- *Exploit*: Measures to exploit the opportunities in the project. One example of this may be to choose flexible technical solutions which often are more expensive but may result in considerable benefits if the upside potential comes through.
- *Accept*: Build in buffers in the form of slack in the plans and contingency reserves.

Follow-up of the measures should be incorporated as an integrated and natural part of the further management of the project, in accordance with Dovre Group's *Project Risk Analysis and Management (PRAM)* guidelines or the client's processes for uncertainty management.

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